Atmospheric Stressors: Challenges and Coping Strategies

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Abstract

The basic principle of agriculture lies with how crop/livestock interacts with atmosphere and soil as a growing medium. Thus any deviation of external optimal atmospheric conditions affects the pathway through changes in atmospheric and edaphic/feed factors for crop/animal growth, development and/or productivity. Besides these, change and variability in atmospheric conditions have increased due to human activities to induce greenhouse gas emissions. In the continuation of current trend in carbon emissions, temperatures will rise by about 1 °C and 2 °C by the year 2030 and 2100, respectively. With warmer climate, frequency and severity of extreme weather events would increase as indicated by incidences of heat waves, extreme rains, hailstorm, etc. during recent years. Besides these, events like cloudburst, cyclone, sand/dust storm, frost and cold wave and deteriorated air quality are becoming regular events. However, the type and intensity of stress events will probably have varying impacts in different ecoregions. These events cause huge impact both in terms of mechanical and physiological on commodities across crop, livestock, poultry and fisheries. The quantum of impact on crops mainly depends on the type of stress and crop/animal/fish, its stage/age and mode of action of the stress. Management strategies for mitigation of these stresses require both application of current multidisciplinary knowledge, development of a range of technological innovations and timely interventions. It's high time to update our knowledge regarding existing

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P.S. Minhas et al. (eds.), *Abiotic Stress Management for Resilient Agriculture*,
DOI 10.1007/978-981-10-5744-1_2

technologies and side by side explores new avenues for managing atmospheric stresses in agriculture. The first step for the scientific community will be to screen and identify species for tolerance to atmospheric stresses followed by complete insight of the biological processes behind the atmospheric stress response combined with emerging technologies in breeding, production, protection and postharvest which is likely to improve productivity and reduce losses. The type and level of stresses must be properly quantified through proper scientific planning for present as well as future references for finding mitigation and adaptation solutions. Keeping above in view, this chapter has been prepared which includes aspects covering atmospheric stresses, their challenges and coping strategies in various agricultural enterprises including crops, livestock, poultry and fisheries. This chapter will ignite the minds of all stakeholders including students and researchers to explore more in finding proper adaptation, and mitigation measures. This will pave the way for developing food and livelihood systems that will have greater economic and environmental resilience to risk.

2.1 Introduction

Agriculture is critical to development since the majority of the world's poorest and hungry people depend on it for their livelihoods. However, agriculture in turn depends on basic natural resources: biodiversity, soil and water and environmental factors. In spite large-scale development of soil-, water- and crop-based technologies to optimize and sustain crop productivity in the recent past, the latter continues to be affected significantly by number of climate variability factors. These factors like temperature, relative humidity, light, availability of water, mineral nutrients, CO_2, wind, ionizing radiation or pollutants determine plant growth and development (20). Effect of each atmospheric factor on the plant depends on their intensity and duration of act. For optimal growth, the plant requires a certain quantity of each of the environmental factors, and any deviation from such optimal conditions adversely affects its productivity through plant growth and development. These stress factors include extreme temperatures, too high or too low irradiation, extreme of water that induce drought or waterlogging, etc. (Fig. 2.1). Some of these are induced as a result of recurring features of climate variability, e.g. cold/heat waves, floods/heavy rain, cyclones/tidal waves, hail/thunder storms, etc., and these critical environmental threats are often referred as extreme weather events.

As climate change has become a reality, the implications of global warming for changes in extreme weather and climate events are of major concern for agrarian as well as civic society. However, since extreme events are typically rare events, therefore only limited observational data are available for their impacts (Lenton et al. 2008; Loarie et al. 2009; Sherwood and Huber 2010). Over the last couple of years, we experienced typical events, i.e. Kuwait reporting snow; the USA devastated by Hurricane Katrina and Paris sweltering in 40 °C heat; Mumbai sunk under 940 mm of heavy rainfall in a single day; Delhi froze with below 0 °C; Rajasthan had floods

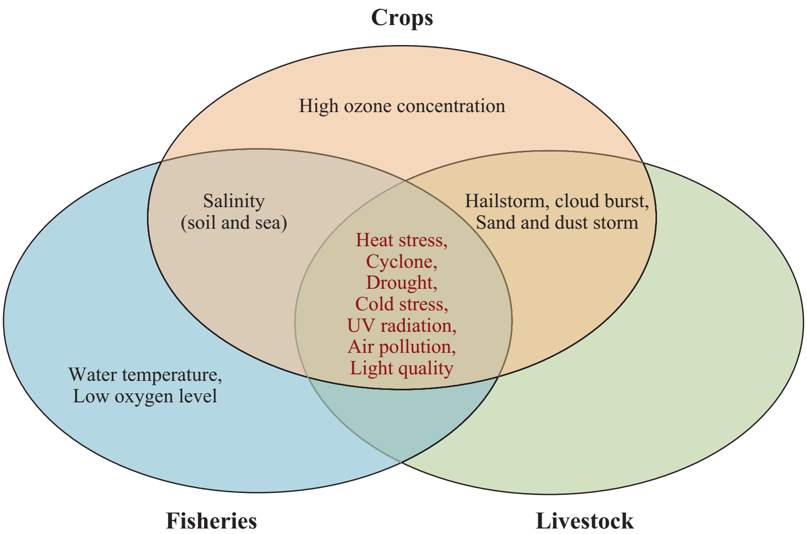

Fig. 2.1 Impact of atmospheric stresses across various agricultural commodities

twice in a year; across pan India there were unprecedented hailstorm events; and many more (Bal and Minhas 2016). The year 2016 will stand out in the historical record of the global climate in many ways. The average global temperature across land and ocean surface areas for 2016 was 0.90 °C above the twentieth century average ((NOAA 2015). This marks the fifth time in the twenty-first century a new record high annual temperature has been set and also marks the 40th consecutive year (since 1977) that the annual temperature has been above the twentieth century average (NOAA 2015). Heat waves were extremely intense in various part of the world including India and Pakistan leading to thousands of deaths. Similarly, extreme precipitation led to flooding that affected areas across Asia, South America, West Africa and Europe and dry conditions in southern Africa and Brazil which exacerbated multi-year droughts (WMO 2016). These events have signalled and forced us to accept the unusual change in the behaviour within our atmospheric. The Fifth Assessment Report of the IPCC has also reiterated that climate change is real and its impact is being felt across countries in the world, e.g. in many parts of India, and the number of rainy days and rain intensity have decreased and increased, respectively, which is counterproductive to the recharge of groundwater because of runoff of rainwater (IMD 2015). Warmer summer and droughts have also made agriculture nonsupportive. Global food production is gradually increasing, but the relative rate of increase especially for major cereal crops is declining (Easterling and Apps 2005; Fischer and Edmeades 2010). In these circumstances, what makes climate smart agriculture more important is ever-increasing demand for food, issues with climatic variability which makes farming more vulnerable to vagaries of nature. In this chapter, an attempt has been made to assess various atmospheric stressors: their current and expected future behaviour and damage potential in Indian agriculture along with possible management options.

2.2 Atmospheric Composition: Past, Present and Future

Since the industrial revolution, atmospheric concentrations of various greenhouse gases have been rising due to anthropogenic activities (Fig. 2.2). In 2011, the concentrations of three key greenhouse gases, viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), were 391 ppm, 1803 ppb and 324 ppb and exceeded the pre-industrial levels by about 40%, 150% and 20%, respectively (Hartmann et al. 2013). Atmospheric concentrations of carbon dioxide (CO_2) have been rising steadily, from approximately 315 ppm (parts per million) in 1959 to 392.6 ppm in 2014 (IPCC 2014) at a rate more than 2 ppm per year and crossed the 400 ppm mark in Mauna Loa Observatory in 2015 (NOAA 2015) and ready to touch 410 ppm mark (NOAA 2017). If fossil fuel burning and other human interventions continue at a business as usual, CO_2 will rise to levels of 1500 ppm (NOAA 2015). Out of all GHGs, CO_2 is the most important GHG as more than 64% of total emission is CO_2, and other gases such as methane, nitrous oxide and fluorinated gases contribute 18, 6 and 12%, respectively.

Out of all anthropogenic sources of climate compounds, fossil fuel and biomass burning are the main ones. Atmosphere serves as a conduit for the transport of toxic material added sometimes inadvertently by the output of agricultural and industrial systems. When fossil fuels are burnt, carbon-based petrochemical products are broken up in combustion to form carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NOx), sulphur oxides (SOx) and very fine particulates. However, chlorofluorocarbons (CFCs) a group of compounds

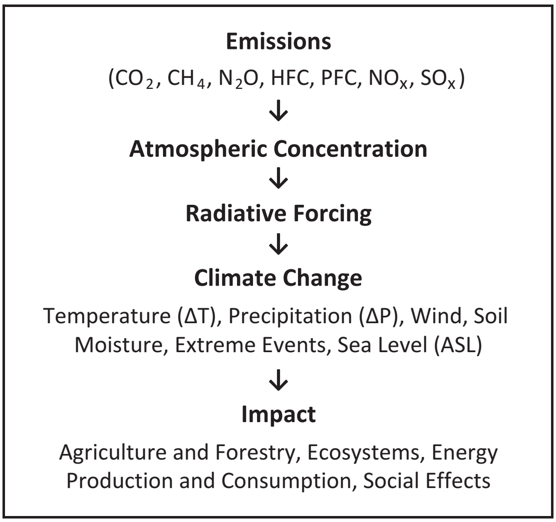

Fig. 2.2 Possible chain of events of the potential effect on climate and society on anthropogenic emissions (Source: Fuglestvedt et al. 2003)

which contain the elements chlorine, fluorine and carbon are unlikely to have any direct impact on the environment in the immediate vicinity of their release whereas at global level have serious environmental consequences. Their long life in the atmosphere means that some end up in the higher atmosphere (stratosphere) where they can destroy the ozone (O_3) layer, thus reducing the protection it offers the Earth from the sun's harmful UV rays (SEPA 2016) besides contributing to global warming through the greenhouse effect. With the possible exception of CO_2 and black carbon, all compounds are likely to be affected by future climate change (Ramanathan and Carmichael 2008). In the atmosphere, when a sufficient concentration of sulphur and nitrogen oxides and hydrocarbons builds up and bombarded by sunlight, a complex series of chemical reactions takes place that creates more chemicals, including nitrogen dioxide (NO_2) and O_3 (Huthwelker et al. 2006). Methane (CH_4) is of particular importance since its climatic impact is strongly enhanced through atmospheric chemical interaction involving tropospheric O_3 and stratospheric H_2O. However, secondary aerosols like O_3 and sulphate are distinctly different from long-lived climate gases CO_2, CH_4, N_2O and halocarbons (Isaksen et al. 2014).

Intensification in agriculture has put tremendous pressure on the land and ecosystems. Approximately 508 million tons of on-field crop residues are generated per year in India, out of which 43 and 23% were rice and wheat, respectively (Koopmans and Koppejan, 1997). About 116 million tons out of these residues are burnt by farmers (Streets et al. 2003; Venkataraman et al. 2006). The primary carbon-containing gases emitted from biomass burning in order of abundance are CO_2, CO, and CH_4, which include two major greenhouse gases (Stockwell et al. 2014). In all, open burning of crop residue accounted for about 25% of black carbon, organic matter and carbon monoxide emissions, 9–13% of fine particulate matter (PM 2.5) and carbon dioxide emissions and about 1% of sulphur dioxide emissions.

2.2.1 Changes in Atmospheric Composition and its Effect on Climate

It is evident from scientific reports that global warming is most probably due to the man-made increases in greenhouse gas emissions, which ratifies the discernible human influence on the global climate. Emissions from fossil fuels, industry, land use and land-use change have increased greenhouse gas concentrations and led to almost 1 °C rise in global mean temperature on pre-industrial levels and also influenced the patterns and amounts of precipitation; reduced ice and snow cover, as well as permafrost; raised sea level; increased acidity of the oceans; increased the frequency, intensity and/or duration of extreme events; and shifted ecosystem characteristics (IPCC 2007a; IPCC 2013). The overall state of the global climate is determined by the balance between energy the Earth receives from the Sun and the energy which the Earth releases back to space, called the global energy balance, and how this energy balance is regulated depends upon the flows of energy within the global climate system. This process also causes the climate change to happen (Morshed 2013).

Earth's lowest part of the atmosphere has warmed up on an average by about 0.6 °C in the last 100 years or so (IPCC 2013). Global warming, in turn, has also triggered changes in the behaviour of many climatic parameters and occurrence of extreme events, more prominently in the last few decades. It is estimated that agriculture contributes around 10–15% of total anthropogenic emissions globally (IPCC 2007b). The greenhouse gases (GHG) trap heat radiated from the Earth and increase global mean temperature. The mean global temperature may increase by 0.3 °C per decade (Jones et al. 1999) with an uncertainty of 0.2–0.5% (Houghton et al. 1990) and would reach to approximately 1 °C and 2 °C above the present value by years 2030 and 2100, respectively, which would lead to global warming (IPCC 2013). Land-use and land-cover pattern over time in response to evolving economic, social and biophysical conditions has a serious impact on the atmospheric processes in addition to emission of heat-trapping greenhouse gases from energy, industrial, agricultural and other sources. Cities are warmer than surroundings because of greater extent of concrete area altering the surface albedo and affecting the exchange of water and energy between land and atmosphere (Lynn et al. 2009).

2.2.2 Climate Change and Extreme Events

While natural variability continues to play a key role in extreme weather, climate change has shifted the odds and changed the natural limits, making certain types of extreme weather especially cold wave, frost, hailstorm, thunderstorm, dust storm, heat wave, cyclone and flood more frequent and more intense. However, year-to-year deviations in the weather and occurrence of climatic anomalies/extremes have become a matter of concern. As the climate has warmed, some of the extreme weather events have become more frequent and severe in recent decades (IPCC 2014) and especially in warmer climate, the frequency of extremes such as heat waves increases (IPCC 2007b). Some of these events since 1990 are listed in Table 2.1, while the most prone areas in India are given in Table 2.2. During the period 1991–1999 (twentieth century), the Indian states – Jammu and Kashmir, Rajasthan and Uttar Pradesh – experienced 211, 195 and 127 number of cold waves, and Bihar, West Bengal and Maharashtra experienced 134, 113 and 99 heat waves, respectively (De et al. 2005). In addition, there is evidence (Holland and Webster 2007) that changes in distribution (e.g. tropical cyclone development occurring more equatorward or poleward of present day) have historically been associated with large changes in the proportion of major hurricanes. Earth is witnessing increases in extreme heat, severe storms, intense precipitation, drought and hailstorm (Allan 2011). The global temperature has increased by 0.74 °C during the past 100 years and could be increased by 2.6–4.8 °C by the end of this century (IPCC 2013). Heat waves are longer and hotter, and likely that has more than doubled the probability of occurrence of heat waves in some locations.

Heavy rains and flooding are more frequent. Patterns of precipitation and storm events, including both rain and snowfall, are also likely to change. However, some of these changes are less certain than the changes associated with temperature.

Table 2.1 Major atmospheric stress-related events in agriculture in India since 1990

Year	Type	Affected area	Loss of crops/livestock
Cyclone			
1994	Cyclone	Andhra Pradesh and Tamil Nadu	0.44 Mha
1996	Cyclone	Andhra Pradesh	0.10 Mha
1999	Super cyclone	Odisha	1.80 Mha
2006	Cyclone (Ogni)	Andhra Pradesh	Rice crop
2013	Cyclone (Phailin)	Odisha	0.50 Mha
30 Oct, 2014	Cyclone (Nilofar)	Gujarat	3 Mha cotton
			1.23 Mha groundnut
2014	Cyclone(Hudhud)	Andhra Pradesh	0.33 Mha
Cold wave/frost			
1994	Hailstorm	North West India, Andhra Pradesh, Maharashtra	0.46 Mha
2003	Frost	Punjab	Potato
2006, 2008	Frost	NW India especially in Punjab	
2011	Frost	Madhya Pradesh	0.007 Mha pigeon pea
2012	Cold wave	Madhya Pradesh and north Maharashtra	
2014	Hailstorm	Maharashtra	1.8 Mha
2015	Hailstorm and unseasonal rain	Northern and Central India	6.3 Mha
Heat wave			
1998	Heat wave	Odisha	>2000 human lives lost
2002	Heat wave	Southern India	>2002 human lives lost
2003	Heat wave	Andhra Pradesh	20 lakhs birds died
2015	Heat wave	Andhra Pradesh, West Bengal and Odisha	>2500 human lives lost
Extreme rain/cloudburst			
26 Jul. 2005	Extreme rain	Mumbai, India	57.0″ of rain in 10 hours
2008	Kosi floods	North Bihar	527 deaths, 19,323 livestock perished
5 Aug. 2010	Cloudbursts	Leh, Ladakh	9.8″ in 1 hour
29 Sep. 2010	Extreme rain	NDA, Pune, India	5.7″ of rain in 1 hour
4 Oct. 2010	Cloudbursts	Pashan, Pune	7.2″ in 1.5 hours
1 Jul. 2016	Cloudbursts	Pithoragarh	54.0″ in 24 hours

Source: http://www.mospi.gov.in

Table 2.2 Most probable areas of India affected by diverse atmospheric stressors

Type of natural disaster (season)	Affected regions in India
Cloudburst-induced landslides	North East Himalaya (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura), including Darjeeling and Sikkim Himalaya
	North West Himalaya (Uttarakhand, Himachal Pradesh and Jammu and Kashmir)
	Western Ghats and Konkan hills (Tamil Nadu, Kerala, Karnataka, Goa and Maharashtra)
	Eastern Ghats of Araku area in Andhra Pradesh
Cyclones April to December, with peak activity between May and November	Eastern coast (Bay of Bengal): Calcutta, Andhra Pradesh, Orissa, Tamil Nad and West Bengal.
	Western coast (Arabian Sea): mainly strike Gujarat and less frequently, Kerala
Heat waves March to July with peak temperatures in April, May, late October	South Indian: Khammam and Ramagundam (Telangana), Kalburgi and Bangalore (Karnataka)
	Eastern states: Bankura and Kolkata (West Bengal) and Bhubaneswar, Titlagarh and Jharsuguda (Odisha)
	North India: Punjab, Allahabad and Lucknow (UP), Gaya (Bihar), Delhi
	West India: Vidarbha and Marathwada (Maharashtra), Churu (Rajasthan), Ahmadabad (Gujarat)
	Central India: Jashpur (Chattisgarh), Harda (Madhya Pradesh)
Cold waves from December to March	Northern states: Punjab, Haryana, New Delhi, Jammu and Kashmir, Himachal Pradesh
	Eastern states: Bihar and Tripura
	Western states: Rajasthan
	Northern and central MP, Maharashtra
Frost (Dec, Jan, Feb)	Punjab, Himachal Pradesh, Haryana, Uttarakhand
Hailstorm (Mar, Apr, May)	Himachal Pradesh, Maharashtra, Madhya Pradesh, Karnataka, Punjab, West Bengal
Sand and dust storm (May, June)	North-western states of Rajasthan, Delhi
Smog due to crop-residue burning	Punjab, Haryana, Uttarakhand, Western Uttar Pradesh (Oct–Nov)
	Maharashtra, Uttar Pradesh, Tamil Nadu (Dec–March)

Projections are that future precipitation and storm changes will vary by season and region. Some regions may have less precipitation, some may have more precipitation, and some may have little or no change. The amount of rain falling in heavy precipitation events is likely to increase in most regions, while storm tracks are projected to shift poleward (IPCC 2013). Besides these hailstorm has widened its horizon. In recent years, weather events especially deadly heat waves and devastating floods have necessitated in understanding the role of global warming in driving these extreme events. These events are part of a new pattern of more extreme weather across the globe shaped in part by human-induced climate change (IPCC 2013, 2014). All weather events are now influenced by climate change because all weather now develops in a different environment than before.

2.3 Impact of Atmospheric Stresses on Agriculture

The agricultural commodities include field crops, horticultural crops, livestock, poultry and fisheries. The basic principle of agriculture lies with how crop/livestock interacts with atmosphere and soil/food as a growing medium. The system acts as pathway which regulates the intake of water/feed, nutrients and gas exchanges. Thus any change in the quality and quantity of atmospheric variables will certainly affect the pathway through changes in atmospheric and edaphic/feed factors. Besides these, climate change is also adding salt to the wound by aggravating the extreme weather events. Agriculture production is sensitive to temperature, increasing carbon dioxide concentration as well as change in precipitation. Impacts of all these forces together imply that agriculture production will respond non-linearly to future climate change. The impacts are complex to understand. However, there is high level of agreement across studies that the impact in all probability is going to be negative for most crop categories. The volume of loss of agricultural produce due to extreme weather events will be more as compared to global warming effects (IPCC 2012). According to global assessment report, India's average annual economic loss due to natural disasters is estimated to be 10 billion dollar in which cyclone and flood accounts for 0.5 and 7.5%, respectively (UNISDR 2015). In a similar manner, other atmospheric stresses like hailstorm, heat wave, cold wave, frost, etc. cause huge losses to Indian agriculture. Since agriculture makes up roughly 14% of India's GDP, a 4.5–9% negative impact on production implies a cost of climate change to be roughly up to 1.5% of GDP per year (Venkateswarlu et al. 2013). Similarly a temperature increase of 3–4 °C can cause crop yields to fall by 15–35% and 25–35% in Afro-Asia and Middle East, respectively (Ortiz et al. 2008).

In quantitative and qualitative terms, effect of aberrant changes in atmospheric variables on agriculture can be conjectured, and most of them are estimated to be negative. The impact may be of direct (mechanical) or indirect (physiological) depending on the type of stress, type of crop, stage of crop and mode of action of the stress on the commodity. Thus the likely effect of climate change on crop production adds to the already complex problem as yield in some of the most productive regions of the world is approaching a plateau or even declining (Pathak et al. 2003).

2.4 Mechanical Damage

2.4.1 Hailstorm

Though hurricanes, tornadoes and lightning command more dramatic attention, but worldwide, hail ranks as one of the most dangerous and destructive of all severe weather phenomenons (Rogers 1996) causing a severe damage to standing crops in a very short span of time (Berlato et al. 2005). Hails can damage the field as well as fruit crops which depend on stage of the crop, size and texture of hailstones and speed and force of hail as it hits the ground. A high-velocity impact early in the season can also cause substantial damage, the impact of which may not be recovered with time (Rogers 1996). Damages in mature produce quickly become focal points for diseases like brown/grey rot smut, while the disease may initially be limited to damaged tissues but can quickly spread to intact plant parts in warm, humid conditions (Awasthi 2015). Hailstorm causes primary injuries due to direct impact of hails which causes heavy defoliation, shredding of leaf blades, breaking of branches and tender stems, lodging of plants, peeling of bark, stem lesions, cracking of fruits, heavy flower and fruit drop, etc. This is followed by secondary injuries which are nothing but the manifestations of primary injuries like dieback or wilting of damaged plant parts, loss of plant height, staining, bruises, discoloration of damaged parts like leaves and fruits affecting their quality and rotting of damaged fruits and/or tender stems and branches due to fungal and bacterial infections (Bal et al. 2014).

2.4.2 Extreme Rain/Cloudburst

A cloudburst is an extreme amount of precipitation, sometimes accompanied by hail and thunder that normally lasts no longer than a few minutes but is capable of creating flood conditions. Cloudbursts effect landslides which are resultant of shear failure along the boundary of moving soil or rock mass. The prolonged and intensive rainfall during cloudburst results in pore-water pressure variations, and seepage forces trigger for landslides (Surya 2012). The process leading to landslide is accelerated by anthropogenic disturbances such as deforestation and cultivation of crops lacking capability to add to root cohesion in steep slopes (Kuriakose et al. 2009). In hilly regions orchards are mainly established on the slopes of the mountains. Extreme rain can wash away the top productive soil layer and in extreme cases can wash away the whole orchard along with the landslide (Duran-Zuazo and Rodriguez-Pleguezuelo, 2008). High intensity of rains can damage the seedling planted on the ridges and also damages to ridges and furrow system.

2.4.3 Cyclone

The Indian Ocean is one of the six major cyclone-prone regions of the world. In India, cyclones from Indian Ocean usually occur between April and May and also between October and December. The frequency of tropical cyclones in the north Indian Ocean covering the Bay of Bengal and the Arabian Sea is the least in the world (7% of the global total); their impact on the east coast of India as well as the Bangladesh coast is relatively more devastating (Suma and Balaram 2014). Cyclones in coastal areas severely affect agriculture sector through direct damage by high-speed wind, rain and extensive flooding. High tides also bring in saline water and sand mass making the fields unsuitable for agriculture (Kumar et al. 2014). Fruit can also be stripped from the trees by the force of wind. Severe wind can cause lodging and damage to especially perennial orchard crops. Storm damage in crops is especially determined by storm severity and crop maturity. A severe storm close to harvest is more serious than a less severe storm earlier in the season (Iizumi and Ramankutty 2015).

During cyclone, feed and fodder become scarce and consequently many animals starve to death; veterinary dispensaries and livestock aid centres become dilapidated; and productivity of animals decreases. The indirect effects include infection and disease of farm animals, fish and crop plants. In addition, agricultural marketing is adversely affected due to lean season of animal, fish and crop production (Kumar et al. 2014).

In fisheries, sea grasses and mangroves which provide nurseries to many coastal fish species are vulnerable to increased rates of damage if storms and cyclones become more intense (Waycott et al. 2011). If storms become more intense, greater levels of damage to shrimp ponds is expected as waves will penetrate further inlands due to rise in sea level. Floods caused by cyclones and more extreme rainfall events are expected to be a threat to ponds constructed in low-lying areas or close to rivers. Flooding can cause damage to ponds and other infrastructure and the escape of fish through overtopping of pond dykes by rising waters.

2.4.4 Sand/Dust Storms

Sandstorm/dust storm adversely impacts the agricultural activities. There is a direct loss of plant tissue as a result of sandblasting by the sand and soil particles (Stefanski and Sivakumar 2009). With this loss of plant leaves, there is reduced photosynthetic activity and therefore reduced energy for the plant to utilize for growth, reproduction and development of grain, fibre or fruit. If the timing of the sand and dust storms is early enough in the agricultural season, the plant might be able to regrow the lost leaves, and the loss in the final crop yield could be relatively minor. However, even in this instance, any regrowth of leaves will still probably result in yield losses (Sivakumar and Stefanski 2007). Additionally these storms delay plant development, increase end-of-season drought risk, cause injury and reduced productivity of livestock, increase soil erosion and accelerate the process of land degradation and decertification, fill up irrigation canals with sediments and affect air quality. Additionally, the loss of energy for plant growth delays plant development, and in regions with short growing seasons, the plant damage reduces yield during grain development, and if it occurs at maturity but before harvest, there will be a direct harvest loss (Alavi and Sharifi 2015; Stefanski and Sivakumar 2009). If there is a large enough deposit of sand or soil material early in the season, the young plant would be buried and killed due to lack of sunlight for photosynthesis. The loss of topsoil increases soil erosion and accelerates the process of land degradation and decertification by removing the layer of soil that is inherently rich in nutrients and organic matter. Livestock not sheltered from the storm could be directly harmed, and any stress from the physical environment to livestock can reduce their productivity and growth (Stefanski and Sivakumar 2009; Starr 1980).

2.5 Physiological Damage

2.5.1 High Temperature Stress

2.5.1.1 Crops

Physiological processes in the plants are essentially affected by the alteration of surrounded environmental temperature. However, high temperatures beyond certain optimum level reduce plant growth by affecting the shoot net assimilation rates, and thus the total dry weight of the plant is collectively termed as heat stress (Wahid et al. 2007), which is one of the most important factors limiting crop production (Bita and Gerats 2013). In higher plants, heat stress significantly alters cell division and cell elongation rates which affect both leaf size and leaf weight (Prasad et al. 2008). Heat stress induces changes in rate of respiration and photosynthesis and leads to a shortened life cycle and reduced plant productivity (Barnabas et al. 2008). Exposure of plants to severe heat stress decreases the plant growth especially stem resulting in decreased plant height (Prasad et al. 2006).

As heat stress becomes more severe, a series of processes occurs in plants which affect rates of important metabolic processes, including photosynthetic CO_2 assimilation, dark respiration and photorespiration (Sicher 2015). As stress increases, closure of stomata slows down or stops CO_2 diffusion, consequent increase in photorespiration and ultimately inhibits growth processes of the plant. High heat-associated water uptake issue aggravates heat stress problem. There is a major slowdown in transpiration leading to reduced plant cooling and internal temperature increase. It also leads to inhibition of photosynthesis due to stomal closure (Lafta and Lorenzen 1995). At the cellular level, as stress becomes more severe, there is loss of membrane integrity, cell membrane leakage and protein breakdown, and finally, if stress is severe enough, there can be plant starvation and death of the plant (Bita and Gerats 2013). The heat stress also varies with the duration of exposure to high temperature, degree of heat and crop genotypes (Kim and Lee 2011). The most important effect of heat stress on plants is the reduction in the growth rate; however, coupled effect of heat stress along with drought stress had more detrimental effect on growth and productivity of crops as compared to the effect of the individual stress (Prasad et al. 2008). The most affected stage is the reproductive growth, and the affected process is pollen grain development (Bita and Gerats 2013). Sexual reproduction and flowering have been extremely sensitive to heat stress, which often results in reduced crop plant productivity (Hedhly et al. 2009; Thakur et al. 2010).

In general, higher temperatures are associated with longer and intense radiation and higher water use. C_3 plants generally have a greater ability for temperature acclimation of photosynthesis across a broad temperature range, CAM plants acclimate day and night photosynthetic process differentially to temperature, and C_4 plants are adapted to warm environments (Yamori et al. 2014). CAM plants can also strengthen the CO_2 fertilization effect and the CO_2 anti-transpiring effect of C_3 and C_4 plants to a considerable extent. However, higher night temperature may increase dark respiration of plants and diminishing net biomass production. The reduction in crop yield in response to high temperature is due to disturbance of relationship of source and sink for assimilation of photosynthates (Morita et al. 2005; Johkan et al. 2011).

The negative impact on yield of wheat and paddy in most part of India is due to increase in temperature, water stress and reduction in number of rainy days. For every 1 °C increase in temperature, yield of wheat, soybean, mustard, groundnut and potato are expected to decline by 3–7% (Agarwal 2009). In the year March 2004, temperatures were higher in the Indo-Gangetic plains by 3–6 °C, and as a result, the wheat crop matured earlier by 10–20 days. Presently, the Indian lowlands are the source of approximately 15% of global wheat production, but it is anticipated that climate changes will transform these into a heat-stressed, short-season production environment (Bita and Gerats 2013). In sorghum, heat stress reduces the accumulation of carbohydrate in pollen grains and ATP synthesis in the stigmatic tissue (Jain et al. 2007). In the IPCC scenario with the slowest warming trend, maize and soybean yields were predicted to decrease by 30–46% before the end of the century (Schlenker and Roberts 2009). In the year 2003, Europe experienced a heat wave in July, where temperatures rose by 6 °C above average and annual precipitation 50% below average and resulted in record crop yield reduction (Ciais et al. 2005). Many legumes and cereals show a high sensitivity to heat stress during flowering and severe reductions in fruit set, most probably as result of reduced water and nutrient assimilate transport during reproductive development (Young et al. 2004).

In horticultural crops, temperature is the most important factor. In onion and tomato, bulb initiation and formation, its bulb and fruit size and qualities are affected by sudden rise in temperature. In most fruit crops, generally higher temperature decreased the day interval required for flowering and cooler temperature though required more days for flowering, but the number of flowers produced increased proportionally at this temperature (Srinivasarao et al. 2016). Optimum temperature range in citrus is 22–27 °C, and temperatures greater than 30 °C increased fruit drop (Cole and McCloud, 1985). During fruit development when the temperatures exceed the optimum range of 13–27 °C with temperatures over 33 °C, there is a reduction in sugar content, acid content and fruit size in citrus (Hutton and Landsberg 2000). These effects can lead to change in choice of orchid crop and geographical shift in cultivation of particular crop.

2.5.1.2 Livestock

Under heat stress, a number of physiological and behavioural responses of livestock vary in intensity and duration in relation to the animal genetic makeup and environmental factors (Freeman, 1987). Heat stress is one of the most important stressors especially in hot regions of the world. In humid tropics along with extended periods of high ambient temperature and humidity, the primary non-evaporative means of cooling (viz. conduction, convection and radiation) becomes less effective with rising ambient temperature, and hence under such conditions, an animal becomes increasingly reliant upon evaporative cooling in the form of sweating and panting to alleviate heat stress (Kimothi and Ghosh 2005).

In north Indian condition, livestock begins to suffer from mild heat stress when thermal heat index (THI) reaches higher than 72, moderate heat stress occurs at 80 and severe stress is observed after it reaches 90 (Upadhyay et al. 2009). In Queensland, the first-service pregnancy rate decreased in dairy cattle, and number of services per pregnancy increased with THI above 72 which corresponds to temperature 25 °C and RH 50% (McGowan et al. 1996). Thermal stress lowers feed intake and reduces animal productivity in terms of milk yield, body weight and reproductive performance. Heat stress reduces libido, fertility and embryonic survival in animals. Enhanced heat dissipation during heat stress may also lead to electrolyte losses (Coppock et al. 1982). The poor reproductive performance in buffaloes especially during summer months is due to inefficiency in maintaining the thermoregulation under high environmental temperature and relative humidity (RH) as those have dark skin and sparse coat of body hair which absorb more heat along with poor heat dissipation mechanism due to less number of sweat glands (Marai and Haeeb 2010).

Weak symptoms of oestrous are exhibited in buffaloes during summer (Parmar and Mehta 1994) which results in reduction of luteinizing hormone secretion and oestradiol production in anoestrus buffaloes (Palta et al. 1997) leading to ovarian inactivity, and also the survival of embryo in the uterus is impaired due to the deficiency of progesterone in the hot season (Bahga and Gangwar 1988). This endocrine pattern may be partially responsible for the low sexual activities and low fertility in summer season in the buffaloes. The poor nutrition and high environmental temperature are the two major factors responsible for long anoestrous and poor reproductive performance in Murrah buffaloes (Kaur and Arora 1984). Similarly heat stress in lactating dairy cows causes significant loss of serum Na^+ and K^+ (West 1999) and also reduces birth weights of Holstein calves (Collier et al. 1982). High ambient temperature can adversely affect the structure and physiology of cells as well as functional and metabolic alterations in cells and tissues including cells of immune system (Iwagami 1996). Heat stress in lactating animals results in dramatic reduction in roughage intake, gut motility and rumination which alters dietary protein utilization and body protein metabolism (Ames et al. 1980). Temperature extremes can influence disease resistance in dairy calves (Stott et al. 1976; Olsen et al. 1980).

2.5.1.3 Poultry

Heat stress interferes with the broilers comfort and suppresses productive efficiency, growth rate, feed conversion and live weight gain (Etches et al. 1995; Yalcin et al. 1997) due to changes in behavioural, physiological and immunological responses. With rise in ambient temperature, the poultry bird has to maintain a balance between heat production and heat loss. This forces the bird to reduce its feed consumption by 5% to reduce heat from metabolism to a tune for every 1 °C rise in temperature between 32–38 °C (Sohail et al. 2012). In addition, heat stress leads to reduced dietary digestibility and decreased plasma protein and calcium levels (Bonnet et al. 1997; Zhou et al. 1998). Heat stress limits the productivity of laying hens, as reflected by egg production and egg quality, as the bird diverts feed metabolic energy to maintain its body temperature and also lower egg production and egg quality (Hsu et al. 1998; Tinoco 2001). The resulting hyperventilation decreases CO_2 blood levels, which may decrease eggshell thickness (Campos 2000). Plasma triiodothyronine and thyroxine, which are important growth promoters in animals, adversely affect heat-stressed broiler chickens (Sahin et al. 2001).

There are direct effects on organ and muscle metabolism during heat exposure which can persist after slaughter (Gregory, 2010); however, chronic heat exposure negatively affects fat deposition and meat quality in broilers (Imik et al. 2012). In addition, heat stress is associated with depression of meat chemical composition and quality in broilers (Dai et al. 2012). Chronic heat stress decreased the proportion of breast muscle, while increasing the proportion of thigh muscle in broilers (Lara and Rostagno, 2013) and protein content lower and fat deposition higher in birds subjected to hot climate (Zhang et al. 2012). Heat stress causes decrease in production performance, as well as reduced eggshell thickness and increased egg breakage (Lin et al. 2004). Additionally, heat stress has been shown to cause a significant reduction of egg weight, eggshell weight, eggshell per cent (Lara and Rostagno 2013) and all phases of semen production in breeder cocks (Banks et al. 2005). In hotter climate, immune-suppressing effect of heat stress is more on broilers and laying hens (Ghazi et al. 2012) and will alter global disease distribution (Guis et al. 2012) through changes in climate. This may also increase the insect vectors, prolong transmission cycles or increase the importation of animal reservoirs. Climate change would almost certainly alter bird migration and directly influence the virus survival outside the host (Gilbert et al. 2008).

2.5.1.4 Fisheries

Climate change will affect fisheries and aquaculture via acidification, changes in sea temperatures and circulation patterns, frequency and severity of extreme events and sea level rise and associated ecological changes (Nicholls et al. 2007). However, inland aquaculture will be affected by changing temperatures, water scarcity and salinization of coastal waters (Shelton 2014). Increased temperature may affect the distribution pattern of some fish species where some of them may be migrate to the higher latitude for cooler place (Barange and Perry 2009). Changes in temperature will have direct effects on swimming ability (Van-der-Kraak and Pankhurst 1997). Sea level rise due to glacier melting will destroy the mangrove forest as well as destroy the marine fish nursery ground. With rising temperature, the physiological activity of the fishes also increases with increase in oxygen demand, whereas the solubility of the oxygen in water is inversely related to temperature and salinity (Chowdhury et al. 2010). Thus, in pond culture system, critically low oxygen concentrations occur overnight when all aquatic organisms use the dissolved oxygen for respiration, and the decrease in dissolved oxygen-induced hypoxic condition results in reduction of growth and reproduction success of fishes (Weiss 1970). Temperature rise also increases the evaporation rate which will ultimately reduce the surface and volume of water in the fish ponds (Bhatnagar and Garg 2000).

With global warming, tropical and subtropical areas will experience more reduction in ecosystem productivity than temperate and polar ecosystems (Shelton 2014).

Marine fisheries sector is already overexploited due to overfishing (Hilborn et al. 2003) and inland fisheries already affected due to pollution, habitat alteration and introduction of alien species/culture fish (Allan et al. 2005). The effects of increasing temperature on freshwater and marine ecosystems where temperature change has been rapid are becoming evident, with rapid poleward shifts in distributions of fish and plankton (Brander 2007). High temperature can cause stratification leading to algae blooms and reduced levels of dissolved oxygen. Tilapia can tolerate dissolved oxygen concentration as low as 0.1–0.5 mg L^{-1} but only for a limited period (Bell et al. 2011). Though tilapia and carp are considered hardy fish, repeated or prolonged exposure to extreme temperature and low dissolved oxygen, especially at higher stocking densities, increase the stress and the susceptibility of the fish to other physiological complications and diseases. Reproduction of fish is highly sensitive to fluctuation in temperature. For example, the fish spp. tilapia can tolerate temperature up to 42 °C, whereas exposure to high temperature results in more deformities in early larval stage and sex ration skewed towards male. In river Ganga, an increase in annual mean minimum water temperature by 1.5 °C has been recorded in the upper cold-water stretch of the river and by 0.2–1.6 °C in the aquaculture farms in the lower stretches in the Gangetic plains (Vass et al. 2009). This change in temperature has resulted in a perceptible biogeographically distribution of the Gangetic fish fauna (Menon 1954).

2.5.2 Extreme Rain and Cloudburst

2.5.2.1 Crops

Extreme rain or cloudburst causes severe waterlogging in poorly drained areas and can impact crop growth in both the short and long term through oxygen deprivation or anoxia through a number of biological and chemical processes. Germinating seeds and emerging seedlings are very sensitive to waterlogging as their level of metabolism is comparatively higher (Tuwilika 2016). The first symptom of flooding damage is stomata closure, which affects not only gas exchange but also decreases the passive absorption of water, which is also negatively influenced by anaerobic conditions in the rhizosphere (Kozlowski and Pallardy 1997). A decrease in transpiration leads to leaf wilting and early senescence and finally resulting in foliar abscission (Ashraf 2012).

There are large differences in plant tolerance to flooding and insufficient aeration of root media among herbaceous species (Das 2012). Waterlogged conditions reduce root growth and can predispose the plant to root rots. Therefore, plants having experienced waterlogging display nitrogen and phosphorus deficiencies due to restricted root development (Postma and Lynch 2011). In light-textured soils, waterlogging impacts growth in cereals by affecting the availability of nitrogen in the soil through excessive leaching of nitrate nitrogen beyond the rooting zone. In heavier soils, nitrate nitrogen can be lost through denitrification (Aulakh and Singh 1997). The amount of loss depends on the amount of nitrate in the, soil temperature and length of time that the soil is saturated (Tuwilika 2016).

2.5.3 Frost and Cold Wave

2.5.3.1 Crops

Cold or low temperature stress comprises of chilling (<20 °C) and freezing temperatures (<0 °C) those that hamper the plant growth and development. Generally, exposure to cold temperature affects developmental events in the shoot apex which directly determine the differentiation of the panicle and hence potential yield and spikelet fertility resulting in fewer grains. In addition, photosynthesis is impaired which reduces growth and results in indirect yield loss because there is less carbohydrate available for grain production (Takeoka et al. 1992).

In India frost mainly occurs in the translunar plans and elevated hilly areas. It is a phenomenon when gross minimum temperature drops to below 0 °C in a short time and plants suffer injury. In plants conversion of cellular water into ice is a major reason for cell rupture in cold stress (Mckersie and Bowley 1997; Olien and Smith 1997). In Punjab, potato crop suffered heavily during 2006 and 2008 when the timely planted crop (mid-Sept. to mid-Oct.) performed better than late-planted crop (late Oct. to mid-Nov.). In late-planted crop, yield reduced by 30–60% (Arora et al. 2010). The temperature at which frost damage occurs in a crop depends on the species and type of cultivar. In potato, frost damage is likely to occur when the temperature drops to −2 °C or lower, and it can cause partial or complete loss of leaf area leading to a reduction in photosynthesis and hence yield (Carrasco et al. 1997). According to Angadi et al. (2000), temperatures below 10 °C result in slower and reduced growth and premature stem elongation in rapeseed and mustard. At early stage of plant growth, various phenotypic symptoms occur in response to chilling stress; however, at flowering stage low temperature may cause delayed flowering, bud abscission and sterile or distorted flowers, while at grain filling the source-sink relation is altered, kernel filling rate is reduced, and ultimately small-sized, unfilled or aborted seeds are produced (Jiang et al. 2002; Thakur et al. 2010). Low temperatures affect not only normal heading but also panicle exertion and prevent the normal elongation of internodes of rice (Farrell et al. 2006). In case of fruit crop, damage to trees was relatively more in low-lying areas where cold air settles and remains for longer time on the ground. Frost during early flowering and ear emergence can result in partial or complete sterility of florets and spikelets and therefore reduced grain number and yield (Al-Issawi et al. 2012).

2.5.3.2 Livestock

Despite the absence of a challenge to homeothermy in cattle, there are marked seasonal fluctuations in the cattle's level and efficiency of production which probably arise from hormonal and adaptive changes occurring as a consequence of mild cold stress (Young 1981). In cold stress, cow's requirement for nutrient and energy intake increases due increased metabolism rate. Freezing of fodder crops results in changes their metabolism and composition that can be toxic to livestock (FAO 2016). Here, two problems need to be considered – prussic acid poisoning and bloat. Prussic acid is not normally present in plants, but under certain conditions, forage can accumulate large quantities of cyanogenic glycosides which can convert to prussic acid

(Robson 2007) a potent, rapidly acting poison, which enters the bloodstream of affected animals and is transported through the body. It inhibits oxygen utilization by the cells, and the animal dies from asphyxia. Prussic acid poisonings occurs in areas associated with light frost. Cold condition stimulates appetite of animals, which may be slightly beneficial for production but the same may reduce utilization efficiency of dietary energy (Young 1981). Cold environment increases the whole-body glucose turnover and glucose oxidation, thus resulting in less production of ketones and resulting increased metabolic rate (Ravussin et al. 2014).

2.5.3.3 Poultry

Cool temperatures are the primary triggers for the accumulation of fluid causing abdominal swelling (ascites) during commercial broiler production (Wideman, 2001) which accounts for losses of about US$ 1 billion annually worldwide (Maxwell and Robertson 1997). The incidences are higher in the colder environmental temperatures (Wideman 1988; Shlosberg et al. 1992; Yahav et al. 1997), because cold ambient temperatures increase the cardiac output, oxygen requirement and blood flow and result in increased pulmonary arterial pressure overload on the right ventricle (Julian et al. 1989). In white Leghorn hens, a reduction in environmental temperature from 20 to 2 °C almost doubles the oxygen requirement (Gleeson, 1986). During the development of ascites, birds exhibit classic haematological changes. Haematocrit, haemoglobin and red blood cell counts (RBC) all increase dramatically (Cueva et al. 1974; Maxwell et al. 1986, 1987; Yersin et al. 1992). Birds exposed to cold stress have severely injured liver and affects thyroid hormones which play a key role in energy expenditure and body temperature homeostasis (Nguyen et al. 2016). Moderate cold exposure during early post-hatching period causes long-term negative effect on growth performance of chicken (Baarendse et al. 2006).

2.5.3.4 Fisheries

Depth of water plays an important role in fish growth and development. When water depth in fish pond is less than 0.5 m, rapid lowering of temperature in a shallow depth reduces dissolved oxygen level, which is detrimental to the fish's survival (Changi and Ouyang 1988). Higher air temperatures and incoming solar radiation increase the surface water temperatures of lakes and oceans (Hader et al. 2015). Foggy and cloudiness and lack of solar radiation or photosynthesis by aquatic vegetation also raise carbon dioxide levels and deplete oxygen levels in water bodies. Under acute cold condition, when water temperature is around 10–12 °C in the month of December 2002 and January 2003, bacterial septicaemia and fungal infections were reported in some ponds (Declercq et al. 2003). Stray incidences of fish/prawn mortality (3–5%) take place of fishponds. This may probably due to emaciated growth because of low feed intake during extreme winter month.

2.5.4 Air Quality and Pollution

2.5.4.1 Crops

Among the major greenhouse gases are methane and tropospheric ozone, which are both of concern for air quality (West et al. 2007). Primary air pollutants, such as sulphur dioxide, nitrogen oxide and particulates, are emitted directly into the atmosphere. These are generally present in high concentrations in urban areas or close to large point sources, such as around thermal power stations have large effects on local farming communities. Secondary pollutants like tropospheric (ground level) ozone are formed by subsequent chemical reactions in the atmosphere and have increased historically at the surface in industrialized regions and in the global background troposphere (Vingarzan 2004). Ozone is considered to be the most powerful pollutant for its impacts on crops (Fuhrer et al. 1997). Ozone symptoms characteristically occur on the upper surface of affected leaves and appear as bleaching of the leaf tissues. Ozone exposure has a strong linear relationship to yield loss in wheat grown in field experiments (Fuhrer et al. 1997).

At lower atmosphere, chances of encountering radiation-absorbing aerosols or chemical substances such as ozone (O_3) and sulphur dioxide are more than it does at lower elevations. With regard to plants, UV-B (280–320 nm) impairs photosynthesis in many species; while rice is considered to be sensitive to elevated levels of UV-B (Teramura et al. 1991), cotton is known to be sensitive to O_3 (Temple 1990). India comes under region with high photochemical smog and the condition most likely to aggravate in the future (Krupa and Kickert 1993). UV-B radiation damages DNA, proteins, lipids and membranes and increases plant susceptibility to disease (Hidema and Kumagai 2006). Excess UV-B can directly affect plant physiology and cause massive amounts of mutations. However, it has not yet been ascertained whether an increase in greenhouse gases would decrease stratospheric ozone levels. When the concentration of sulphates and nitrates increases in the atmosphere, very fine acidic particles are formed, and when nitrogen oxides and reactive organic gases combine, especially on sunny, still days, a photochemical (ozone) smog is formed. NO_2 is the pollutant closely associated with ozone (Cho et al. 2011) because of the role that NO_2 plays as a precursor of O_3 in polluted air.

Sulphur dioxide enters the leaves mainly through the stomata, and acute injury is caused when leaves absorb high concentrations of sulphur dioxide in a relatively short time. Newly expanded leaves usually are the most sensitive to acute sulphur dioxide injury. And different plant species and varieties of the same species may vary considerably in their sensitivity (McCormac and Varney 1971). The effects of SO_2 on crops are influenced by other biological and environmental factors such as plant type, age, sunlight levels, temperature and humidity. Thus, even though sulphur dioxide levels may be extremely high, the levels may not affect vegetation (Cohen et al. 1981). The burning of sulphur-containing fuels release SO_2, and when the atmosphere is sufficiently moist, the SO_2 transforms into tiny droplets of sulphuric acid and causes acid rain (Ahrens 2015). Acid rain damages the protective waxy coating of leaves and allows acids to diffuse into them, which interrupts the evaporation of water and gas exchange so that the plant can no longer breathe (Izuta

2017). Elevated CO_2 stimulates photosynthesis leading to increased carbon (C) uptake and assimilation, thereby increasing plant growth (Kant et al. 2012). However, as a result of differences in CO_2 use during photosynthesis, plants with a C_3 photosynthetic pathway often exhibit great growth response relative to those with a C_4 pathway (Poorter 1993; Rogers et al. 1997).

Particulate matter such as cement dust, magnesium-lime dust and carbon soot deposited on vegetation can inhibit the normal respiration and photosynthesis mechanisms within the leaf (Thara et al. 2015). Cement dust causes chlorosis and death of leaf tissue by the combination of a thick crust and alkaline toxicity in wet weather (Griffiths 2003), and dust coating affects the normal action of pesticides and other agricultural chemicals applied as sprays to foliage (Ravichandra 2013). In addition, accumulation of alkaline dusts in the soil can increase soil pH to levels adverse to crop growth (Thara et al. 2015). Air pollution injury to plants can be evident in several ways. There may be a reduction in growth of various portions of a plant, or plants may be killed outright. Acute symptoms of injury from various pollutants in different horticultural and agronomic groups are visible on the affected plant. Symptom expressions produced include chlorosis, necrosis, abscission of plant parts and effects on pigment systems (Taylor 1973).

2.5.4.2 Livestock

Air contains fine suspended particles, bacteria, pollens, which cause allergies and respiratory diseases in animals (Takizawa 2011). Pig and poultry are kept in indoor facilities for a variable part of their life. However, for dairy cattle, goat and sheep; the housing facilities are quite open and air quality is to a certain extent comparable with the outdoor air quality. Also in many piggeries, high levels of ammonia, airborne dust, endotoxin and microorganisms can be found (Wathes et al. 1998). Ammonia is considered as one of the most important inhaled toxicants in agriculture, and long-term low-level exposure causes mucosal damage, impaired ciliary activity and secondary infections in laboratory animals (Davis and Foster 2002).

Dust particles within a livestock farming environment consist of up to 90% organic matter (Aarnink et al. 1999; Heber et al. 1988), which provides opportunities for bacteria and odorous components to adhere themselves to these particles. The contaminated air is dissipated into the external environment via ventilation; however, the concentration of airborne contaminants can be still higher within livestock building (Arogo et al. 2006). Dust particles that can potentially harm livestock is grouped as inhalable dust particles-PM100 (less than100 microns in diameter), thoracic dust particles-PM10 (less than 10 microns in diameter) and repairable dust particles-PM 5 (less than 5 μ in diameter). PM5 can enter the smallest cavities of the lung, the alveolithus making them the most hazardous causing shortness of breath, chronic bronchitis, asthma and other lung diseases (Choiniere 1993; Banhazi 2009). CO_2 is considered to be a potential inhalation toxicant and of CO_2 in the blood caused acidosis in animal (Hernandez et al. 2014). Similarly fluoride-contaminated forage that is eaten by cattle or sheep may cause fluorosis.

2.5.4.3 Poultry

In poultry houses, birds and their wastes generate different forms of air pollution, namely, ammonia, carbon dioxide, methane, hydrogen sulphide and nitrous oxide gases, as well as the dust (Kocaman et al. 2005). Inadequate ventilation in the poultry shed accumulates gases such as carbon dioxide, ammonia and methane and reach toxic levels (David et al. 2015). Most ammonia originates from the decomposition of the nitrogen-containing excretion from the kidneys and the gut of the bird (Groot-Koerkamp and Bleijenberg 1998). Poor environments normally don't cause disease directly, but they do reduce the chickens' defence mechanism, making them more susceptible to existing viruses and pathogens (Quarles and Kling 1974). Aerial ammonia in poultry facilities is usually found to be the most abundant air contaminant. Ammonia concentration varies depending upon several factors including temperature, humidity, animal density and ventilation rate of the facility. Chickens exposed to ammonia shows reductions in feed consumption, feed efficiency, live weight gain, carcass condemnation and egg production (Reece and Lott 1980). The presence of dust in animal housing adversely affects health, growth and development of animals and increases disease transfer within flocks (Feddes et al. 1992).

2.5.4.4 Fisheries

Oceans absorb approximately 25% of anthropogenic CO_2 (Logan 2010), and these dissolved CO_2 reacts with seawater to form weak carbonic acid, causing pH to decline and reducing the availability of dissolved carbonate ions which is required by many marine calcifying organisms to build their shells or skeletons (Orr et al. 2005). Till date, average alkalinity of ocean has declined from 8.2 to 8.1 (IPCC 2007c), equivalent to a 30% increase in acidity. Havenhand et al. (2008) reported that expected near-future levels of ocean acidification reduce sperm motility and fertilization success of the sea urchin and suggest that other broadcast spawning marine species may be at similar risk. Similarly, impacts on oxygen transport and respiration systems of oceanic squid make them particularly at risk of reduced pH (Portner and Langenbuch 2005). Fish embryos and larvae are more sensitive to pH change than juvenile and adults (Brown and Sadler 1989). Extremely high or low pH values in water cause damage to fish tissues, especially the gills, and haemorrhages may occur in the gills and on the lower part of the body and cause secondary infection (Declercq et al. 2013). The toxicity of ammonia is affected by the amount of free CO_2 in the water as the diffusion of respiratory CO_2 at the gill surface reduces the pH of the water (Svobodova et al. 1993). Radiation plays an important role in aquatic ecosytem. UV-B radiation (280–320 nm) impairs growth and photosynthesis in many species, especially in phytoplankton.

2.6 Management Strategies to Cope Atmospheric Stress Events

Global climate change will have significant impacts on future agriculture, and therefore climate change mitigation for agriculture is a global challenge. In a country like India, one of the most vulnerable countries owing to its large agricultural sector, vast population, rich biodiversity, long coastline and high poverty levels will be severely affected by climate change if new strategies for amelioration are not devised (Nelson 2009; Fischer and Edmeades 2010). For this a thorough understanding is required for various physical, physiological, metabolic and biochemical processes that occurs in normal as well as stresses environments so as to form the basis for developing climate smart mitigation strategies. Nevertheless, plant and livestock responses to high temperatures clearly depend on genotypic parameters, as certain genotypes are more tolerant (Prasad et al. 2006; Challinor et al. 2007). Though plants adapt to various stresses by developing more appropriate morphological, physiological and biochemical characteristics, analysing plant phenology in response to heat stress often gives a better understanding of the plant response and facilitates further molecular characterization of the tolerance traits (Wahid et al. 2007). As far as atmospheric stresses are concerned, a complete insight of the biological processes behind the atmospheric stress response combined with classical and emerging technologies in production, breeding and protection engineering is likely to make a significant contribution to improved productivity and reduction in losses. The following section contains some of the adaptation and management options available to mitigate those atmospheric stresses.

2.6.1 High Temperature Stress

2.6.1.1 Crops

High temperature stress could be avoided by agronomic/crop management practices. The selection of type of tillage and planting methods play an important role in emergence and growth of a crop. The methods of planting may improve the plants tolerance against heat stress through the soil moisture. The presence of crop residues/mulch on the soil surface keeps soil temperature lower than ambient during the day and higher at night. Mulches also conserves soil moisture (Geiger et al. 1992), thereby making it available to crop for a longer period which augments transpiration, keeps the canopy cool and protects the crop from terminal heat and decline in yield. The selection of cultivar as per the agroecological conditions and probable temperature variability scenario during the crop growth period is important to get better yield under high temperature stress conditions. Although periods of elevated temperature may occur at any period during the growing season of the crop, earlier sowing, use of earlier maturing cultivars and adopting heat stress-tolerant cultivars are the best options (Krishnan et al. 2011). Selecting optimum planting time helps in avoiding high temperature stress during anthesis and grain filling so that crop escapes the hot and desiccating wind during grain-filling period which is one of the critical stages.

Water management is critical from the view point that damage potentiality due to high temperature stress is commonly associated with water stress, and plants can tolerate heat stress until crop keeps on transpiring. Continuous supply of water to heat-stressed crop helps to sustain grain-filling rate, duration and size of grain (Dupont et al. 2006). Water-stressed plants attempt to conserve water by closing their stomata; as a consequence evaporative cooling diminishes, leaf temperatures increase drastically, and at that point, the metabolic activity in plants stops. Proper irrigation scheduling as per soil type, crop type, stage of the crop as per the available water and weather may help in mitigating the effects of heat stress on crop.

Chemicals having potential to protect the plants against high temperature (Hasanuzzaman et al. 2012) is another option. Proline accumulates to high concentration in cell cytoplasm under stress conditions without interfering with cellular structure or metabolism. Exogenous proline guarantees the protection of vital enzymes of carbon and antioxidant metabolism and improved water and chlorophyll content as the basis of heat tolerance in chickpea plants (Kaushal et al. 2011). Activities of different antioxidant enzymes are temperature sensitive, and activation varies with different temperature ranges, tolerance or susceptibility of different crop varieties, their growth stages and growing season (Chakraborty and Pradhan 2011). In wheat, spray of indole acetic acid, gibberellic acid and abscisic acid significantly improves grain yield under high temperature stress (Cai et al. 2014).

Phytohormone/bioregulators like salicylic acid also play significant role in the regulation of plant growth and development. Salicylic acid improves the plant growth and yield of maize by enhancing photosynthetic efficiency (Khan et al. 2003). In mustard, the same with lower concentration as foliar application increased the H_2O_2 level and reduced the catalase which amplifies the potential of plants to withstand the heat stress (Dat et al. 1998). Abscisic acid (ABA) as a plant growth hormone regulates stomata opening, root hydraulic conductivity and application of α-tocopherol and SA decreased consumption of photosynthates and increased membrane stability which aided in transport of photosynthates, which thereby induce tolerance to different abiotic stresses such as drought, salinity and temperature stresses increased yield (Farooq et al. 2008).

Application of nitrogen, phosphorus and potassium improves plant growth under moderate heat stress (Dupont et al. 2006). Under high temperature stress, foliar application of thiourea promotes root growth by enhancing assimilate partitioning to root at seedling and pre-anthesis growth stages (Anjum et al. 2011). Potassium involves in several physiological processes, i.e. photosynthesis, translocation of photosynthates into sink organs, maintenance of turgidity and activation of enzymes are increased under stress conditions (Mengel and Kirkby, 2001), and the deficiency of potassium resulted in decrease in photosynthetic CO_2 fixation and impairment in partitioning and utilization of photosynthates. Application of KNO_3 and zinc can also improve heat tolerance in wheat (Graham and McDonald 2001). Calcium is found to control guard cell turgor and stomatal aperture (Webb et al. 1996). The foliar application of potassic fertilizer, urea and zinc may help in improving crop yield by alleviating the ill effects of high temperature.

Due to incomplete understanding of tolerance mechanisms and accurate phenotyping for stress responses, the conventional and molecular plant-breeding efforts have been limited (Bita and Gerats 2013). In addition, generating high-yielding and stress-tolerant crops requires not only a thorough understanding of the metabolic and developmental processes involved in stress responses but also in energy regulation (Hirayama and Shinozaki, 2010). High temperature stress is detrimental to cereal crop productivity, and the existence of genetic variability in heat stress tolerance is an indispensable factor for the development of more tolerant cultivars. If limited variability for tolerance to heat is available within a crop species, wild germplasm can also be used as tolerance source (Pradhan et al. 2012).

Agroforestry as an integral component of conservation agriculture can play a major role as trees can buffer climate extremes that affect crop performance. In particular, the shading effects of trees can buffer soil as well as canopy temperature. In addition it also sublimes atmospheric saturation deficit and reduces exposure to supra-optimal temperatures, of which physiological and developmental processes and yield become increasingly vulnerable (Challinor et al. 2005). Trees in farms bring favourable changes in field microclimate by influencing radiation flux (radiative and advective processes), air temperature, wind speed and saturation deficit of understory crops all of which will have a significant impact on modifying the rate and duration of photosynthesis, transpiration, etc. (Monteith et al. 1991).

2.6.1.2 Livestock

In animal husbandry, physical modifications of environment, genetic development of heat tolerant breeds and nutritional stress management are the three major key components to sustain production in hot environment (Beede and Collier, 1986). Scientifically designed sheds provide comfortable environment to animals. However, in hot and humid areas though shade reduces heat accumulation, it hardly reduces air temperature or relative humidity, and additional cooling is necessary for farm animals (St-Pierre et al. 2003). Genetic variation exists among animals for cooling capability and stress tolerance. Heat shock proteins (HSP) play important role in stress responses of animals. It was observed that genotype differences exist in HSP genes of indigenous breed and cross-bred dairy cattle indicating the relative heat stress tolerance phenotype of native indigenous cattle (Sajjanar et al. 2015). These results indicate that more heat-tolerant animals can be selected genetically or cross-breeding programme (Kimothi and Ghosh 2005). As adaptation to heat stress requires the physiological integration of many organs and systems, viz. endocrine, cardiorespiratory and immune system (Altan et al. 2003), the administration of antioxidants has proved useful for improvement of several immune functions (Victor et al. 1999).

Antioxidants, both enzymatic and non-enzymatic, provide necessary defence against oxidative stress as a result of thermal stress (Rahal et al. 2014). Both vitamin C and vitamin E have antioxidant properties. Vitamin C and E having antioxidant property along with electrolyte supplementation was found to ameliorate the heat stress in buffaloes (Sunil Kumar et al. 2010). Zinc and other trace elements like copper and chromium act as typical antioxidants as they work indirectly as normal copper levels are necessary to maintain the structural integrity of DNA during oxidative stress (Rahman 2007). Additional supplementation of electrolytes (Na, K and Cl) is one among the nutritional strategies which has beneficial effects in heat-stressed dairy cows in terms of milk yield, acid base balance and lower temperature (Sanchez et al. 1994). Lactating cows and buffaloes have higher body temperature of 1.5–2 °C than their normal temperature. Therefore to maintain thermal balance, they need more efficient cooling devices to reduce thermal load (Upadhyay et al. 2009). Provision of sprinklers and fans to mitigate heat stress facilitates the buffalo heifers to reduce the heat load and increased the time of lying down (Tulloch 1988).

2.6.1.3 Poultry

In hot and humid environment, poultry shades should be designed as an open style house with proper shading for adequate air movement, grass cover on the ground surface to reduce sunlight reflection and shiny surface roof for more reflection of solar radiation. During hot periods, lower-protein diets supplemented with limiting amino acids should be replaced with high-protein diet (Pawar et al. 2016). Glucose in drinking water helps in alleviating the influence of heat stress on whole-blood viscosity and plasma osmolarity (Zhou et al. 1998). Aviaries should be equipped with overhead sprinkler systems, which cool the air and reduce the chances of heat injuries. Addition of ammonium chloride and potassium chloride to drinking water is desired to maintain carbon dioxide and blood pH under control. Vitamin E supplementation is beneficial to the egg production of hens at high temperature and associated with an increase in feed intake (Kirunda et al. 2001).

2.6.1.4 Fisheries

Genetic variation also exists among fish species for thermal tolerance against increasing diurnal water temperature and induced hypoxia condition in which heat shock proteins (HSP) play important role in stress responses and determinant for critical thermal maxima and critical thermal minima of each fish species which is also dependent upon fish habitat and adaptation. Brahmane et al. (2017) identified that tilapia, *Oreochromis mossambicus* juveniles, responds to constant rearing temperatures with significantly higher growth achieved at 30 °C as compared to 25 °C. Besides genetic screening, few adaptive measures may be taken as restoration of mangrove forest can protect shorelines from erosion and provide breeding ground for fish while sequestering carbon (Daw et al. 2009). In addition, deepening of the stock area, raising bund height, adjusting crop calender and planting shade tress in and around the stock area would counter the higher temperature. (FAO 2012).

2.6.2 Extreme Rain and Cloudburst

2.6.2.1 Crops

Conservation agriculture provides alternatives that can address challenges posed by erosion due to intense rain events. Soil surface covered by plant residues not only increases water infiltration and cuts down soil erosion and runoff but also mitigates some of the challenges presented by climate change (FAO 2009). On the other hand, CA practices increase carbon accumulation (sequestration) through recycling of crop residues and increase the nutrient supply and turnover capacity of soils and resulted in significant changes in the physio-biological properties of the soils. Zero tilled fields covered with organic mulch result in enhanced erosion check, increased water-holding capacity of soils and ability to withstand longer dry spells during crop growing period (Bhattacharyya et al. 2015).

2.6.3 Frost and Cold Wave

2.6.3.1 Crops

Long-term counter measures for frost protection mainly include selection of favourable topography, breeding of frost-tolerant variety, non-use and overuse fertilizer and adjusting the sowing time (Arora et al. 2010). The fruit crops under frosty weather can be protected by creation of hot air or smoke, covering small fruit plant areas with straw, dry grass, etc. (Rathore et al. 2012). Sprinkler irrigation releases latent heat of fusion by releasing heat into the surrounding air and maintains soil moisture in the soil profile. Growth regulator and other growth-promoting chemicals also enhance resistance to cold stress (Colebrook et al. 2014). Windbreaks or shelter belts if raised around the plantations prevent the convective frost or cold wave damage (Rathore et al. 2012). In the places where frost is a recurrent phenomenon, new orchard growers should select low temperature-tolerant fruit species and varieties depending upon their leaf structure, succulency and concentration of solutes as these reutilize water formed after melting of crystals for initiating metabolic activities in the cells (Rathore et al. 2012).

2.6.3.2 Livestock

The problem of fodder poisoning can be prevented or at least minimized with proper management of the fodder field and feeding pattern (Vough 1978). Removing livestock from pastures for several days after a frost is the best preventative management strategy to reduce prussic acid poisoning in case of Sudan grass and sorghum-Sudan grass pastures (Lemengar and Johnson 1997). In periods of cold weather, provision of windbreak is to be made enabling the cows to take shelter in the leeward side of the cold wave and preferably reducing the walking area so that animals stand in a group to stay warm. Appropriate nutritional supplementation is the key to managing cold stress.

2.6.3.3 Poultry

Poultry house made up of low-heat-conducting materials like bamboo and wood helps to maintain optimum night temperature in the shelter. In addition, with the help of light bulbs and physical barriers, movement of chicks should be restricted nearer the heat source. The orientation of poultry house should be east-west alignment for proper ventilation and to gain maximum solar energy during winter. The surface of poultry house should be covered with a bedding material called litter; it maintains uniform temperature and also absorbs moisture and promotes drying (Banday and Untoo 2012). In winter season, energy-rich source like oil/fat should be added to the diet so that the requirement of other nutrients will be reduced.

2.6.3.4 Fisheries

Adoption of hardy fish species like tilapia and carp may be taken up. Though the optimum range for growth of common carp is similar to tilapia, i.e. 23–30 °C, carp is much more cold tolerant than tilapia (Bell et al. 2011). To escape the cold stress due to lowering of temperature, deep water ponds (100–200 cm) may be adopted compared to shallow water ponds (<50 cm). Though the optimal temperature range for growth of common carp is similar to tilapia, i.e. 23–36 °C, carp is much more cold tolerant than tilapia. Intermittent aeration of water would probably help to alleviate respiratory stress to fishes.

2.6.4 Hailstorm

2.6.4.1 Crops

Shelter belts and windbreaks around orchard are always recommended to avoid heavy damage to the main crop, which also lowers the water requirements and other related stresses. In areas with higher probability of hailstorm occurrence, shade nets can be a good option especially for high-value crops along with nylon nets used for protection against bird damage. Though little information is available on measures for faster recovery in hail-damaged plants, application of additional nitrogen encourages new growth (Patel and Rajput 2004; Badr and Abou El-Yazied 2007). In case of orchard crops, broken branches and twigs should be removed followed by spraying of recommended chemicals to avoid secondary fungal and bacterial infections. The fallen fruits should be removed to reduce the spread of disease and pest during their decay. Water-based paint should be applied on large wounds on trunks and branches to avoid desiccation and disease infection. Fruit thinning by removal of hail-damaged fruits improves yield and quality of remaining fruit. Bud-breaking chemicals and growth/bioregulators may be applied to induce the vegetative growth in orchard crop along with fertilizers (Bal et al. 2014; Boyhan and Kelley 2001). Proper drainage facilities are to be provided to avoid waterlogging and to avoid secondary infection of diseases. Near-maturity bulb crops like onion and garlic may be harvested to avoid rotting.

2.6.5 Cyclone

2.6.5.1 Crops

Pre-cyclone preventive measures must be taken care of as per the nature of urgency. Windbreak reduces the wind speed; hence promotion of several tiers of windbreak plants near the sea coast should be encouraged (Kumar et al. 2014). In case of damage in early-growth stage of the crop, replanting/transplanting of short-duration field crops is one of the strategies to reduce the loss. If the crop is in reproductive phase, by doing partial removal of the canopy although there will be yield reduction, partial yield can be harvested. If the cyclone forewarning is well before time, partial or complete removal of canopy is possible. Stakes made of bamboo often overcomes moderate wind speed. Banana plantations use of healthy suckers for replanting after cyclone damage is recommended, and survived banana plants having banana fingers in fruit-filling stage may be provided with additional nutrition through bunch tip (Kumar et al. 2014). However, quick harvest, threshing and drying the grains before the cyclonic system through early warning, is the best option. Availability of covered threshing floor cum drying yard and polythene sheets for covering the produce so that grains do not get moist are possible options to prevent grain damage.

2.6.5.2 Livestock

Animals should be shifted to a safer place as soon as warnings for impeding cyclones are received. Animal sheds should be constructed with lightweight timber, coconut and palm tree leaves that will not harm the animals even if they collapse during cyclonic winds. Preserving the fodder resource should be on higher priority for meeting the demand during the crisis period. Molasses can be used as an alternate fodder during cyclone periods and periods of non-availability of fodder to protect the animals from disaster impacts and also from scarcity of food/fodder. To provide clean and unpolluted water to the animals, it may be treated with chlorine or bleaching powder before giving it to the animals. Animals must be vaccinated against communicable diseases during emergency periods, and the carcasses of animals must be buried in a pit over which lime will be sprinkled. In addition, nutritional supplements must be provided to improve immunity in animals (NDMA 2008).

2.6.5.3 Poultry

Birds need special care after storm events. Restocking of birds and arrangement of feeds and medicines should be arranged for poultry revival (Kumar et al. 2014). There should be sufficient supply of quality water preferably chlorinated for prohibiting the growth of bacteria. In cooler areas, birds may be kept warm using heaters to reduce stress (Sen and Chander 2003). Moisture-infected feed is to be replaced with dry feed. Birds which die due to diseases must be treated separately and cremated or buried in a deep pit and lime sprinkled over it along with other anti-infectants (NDMA 2008).

2.6.5.4 Fisheries

Fish farmers should be provided with fish fingerlings and feed, boats and nets as per need (Kumar et al. 2014). There is need to improve on the awareness of the fishers knowledge to climate change by involving them in the disaster preparedness and planning process. Restocking of fish fingerlings should be done immediately. Physical protection of inlet and outlet of aquaculture farms and ponds must be ensured to reduce the migration of the fishes (Kumar et al. 2014).

2.6.6 Sand/Dust Storm

Though the environmental and health hazards of storms cannot be reduced permanently, its impact can be reduced by taking appropriate measures.

2.6.6.1 Crops

Surface crop residues help stabilize the soil, reduce erosive force of wind and reduce number of saltating particles. Appropriate control of dust raising factors such as increasing the vegetation cover must be taken to stabilize soil and sand dunes by acting as windbreaks (Speer 2013; Shivakumar 2005). Especially standing stems decrease the wind energy available for momentum transfer at soil surface (Hagan and Armbrust 1994) as geometry of crop alters the soil microclimate, impacts the degree of soil protection and also conserves soil moisture (Nielsen and Hinkle 1994). Specified tillage operation increases cohesion of soil particles by mechanical action but needs to be taken as per soil type and topography specifications. In arid and semiarid areas, summer tillage is discouraged and a limited tillage recommended after the first monsoon showers (Gupta et al. 1997).

2.6.6.2 Livestock

The main purpose for implementing control methods for airborne pollutants in the livestock building is to ensure that production efficiency gets maximized (Banhazi et al. 2009). To control the dust, we need to understand the livestock environment as in the confines of a building, the air quality depends directly on building management, feeding and manure handling, ventilation system and the overall cleanliness (Choiniere 1993). This can be achieved through improved configuration and management of livestock buildings, provision of adequate ventilation, decreased stocking density and management of the animals contained in these buildings (Banhazi et al. 2009).

2.7 Way Forward

Since unusual atmospheric events are becoming usual events, to make future agriculture remunerative, risk-free and sustainable, first the dynamic characteristics of atmospheric stressors have to be understood. The scientific community must respond to the need of credible, objective and innovative scientific alternatives to tackle the stress impacts. There are, however, ways by which the adverse impacts can be mitigated and agriculture can be adapted to changing scenarios. The first step is to form integrated interdisciplinary research partnerships as atmospheric stressors already pose and will continue to pose challenges for agriculture and managed ecosystems.

As every year is becoming warmer than the previous year and unprecedented heat or cold wave conditions have become a common phenomenon, adaptation and mitigation options have to be explored either using field management practices or by applying genetic improvement tools for developing tolerant varieties. The use of chemicals like plant bioregulators and growth hormones having minimal or no residual effects and rescheduling of sowing/planting periods need to be explored. Regular events like extreme rain and hailstorm have necessitated focusing on developing protective structures. Especially research on designing low-cost shade net or poly-structures for high-value horticultural crops is the need of the hour as horticultural production in India has already surpassed the food grain production. Stresses arising out of increased atmospheric aerosol and decrease in available light need extra attention as change in land-use pattern and crop residue burning has changed the way we have been dealing these aspects in the past. Lastly abrupt changes in the magnitude and periodicity of atmospheric variables will have impact on distribution of disease vectors and pest dynamics which needs extra attention.

With unprecedented increase in demand for animal proteins, our prime focus must be towards developing low-cost environment suitable animal shelter structures for improved animal production and wellness. Future research in livestock must be done keeping a balance between competition for natural resources and projected atmospheric anomalies as unlike crop production where there will be a vertical growth, however livestock production is expected to have a horizontal growth. A large agenda of work still remains concerning the robust prediction of animal growth, body composition, feed requirement and waste output in future climate. To cater the target for lowering the emission level, interdisciplinary research approach must be undertaken to lower the methane emission from animal sector. Lastly the use of biotechnology can't be ignored if we want to impart heat-tolerant traits in high meat and milk yielding breeds.

Though the country has achieved food grain security for entire population, we are yet to solve the problem of poor nutrition, especially protein- and mineral-associated health issues. As poultry meat is the cheapest source of proteins, this sector has potential to provide food and livelihood securities to major chunk of Indian population. With emergence of heat stress as one of the major problems in Indian poultry industry, our primary area of focus should be to explore innovative approaches, including genetic marker-assisted selection of poultry breeds for increased heat tolerance and disease resistance for better productivity. Application of modern molecular techniques in poultry breeding has great potential to improve poultry productivity in a sustainable manner. Simultaneously, the possibilities of heat stress mitigation must be explored in terms of designing of suitable poultry housing for hot regions. Nutrition being one of the major factors in mitigating heat stress, study of the nutrient supplementation and feeding practices should be given priority.

Future research on fisheries must be oriented to understand the implications of greenhouse gas emission-induced sea acidification on fisheries ecosystem productivity and habitat quality and quantity especially on habitat of phytoplankton. Secondly, biotechnological intervention in terms of identification of heat and hypoxia tolerance traits in fish, identifying the molecular pathways and marker-assisted selection of fast-growing and tolerant species.

Though a lot of scientific advances have been made related to understanding of physical and physiological aspect of various atmospheric stressors, much work remains to be done regarding quantifying its impacts and long-term implications on agriculture. Thus only option left before us is to fight it in our own way. Firstly before doing so, the types and level of stresses must be properly quantified for future references. Secondly researches on finding mitigation and adaptation measures need to be scientifically planned so as to make it economically viable. By doing so, these scientific measures can be successfully adopted by growers to make future agriculture economically sustainable and less risky against the atmospheric anomalies.

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