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EFFECT OF ELEVATED CO_2 AND TEMPERATURE ON PHYSIOLOGICAL AND BIOCHEMICAL CHANGES IN FORAGE CROPS – A REVIEW

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SUMMARY

As global population continues to increase, crop yields and forage crop yield must increase proportionally to meet the future demand for food and fodder. Forage and livestock sector has increased at a very rapid rate throughout the country and worldwide in recent years due to their important roles in sustainable forage yield and crop productivity. Atmospheric carbon dioxide concentration [CO_2] is increasing rapidly and is expected to surpass 550 ppm within this century. Mean annual temperature significantly increased 0.4ºC over the last 100 years. Atmospheric CO_2 and temperature may significantly modify plant, production and productivity. Changes in leaf anatomy and ultra-structure are associated with physiological performance in the context of plant adaptations to climate change. Elevated CO_2 enhance root exudation, root growth and increased plant biomass. Grasslands occupy in excess of 25% of the Earth's land area, but forage crops and grassland species have received limited attention from re- searchers studying climate change. In this review we discussed about the effect of elevated CO_2 and temperature on physiological and biochemical changes of forage crops and development of future climate-resilient varieties for sustainable crop production and livestock production.

Key words : Elevated CO_2, temperature, climate change and forage crops

Global climate change will pose a serious challenge to crop production across the world. One of the important components of global climate change is increase in the Earth's near-surface temperatures. The mean global surface temperature exhibited an increase over the past decade particularly with sharp increase since the 1970's (Gadgil, 1996). Mean annual temperature derived from 73 stations of India showed a significant warming of 0.4ºC over the last 100 years, which is comparable to global mean trend of 0.3ºC increase per hundred years (Hingane et al., 1985). This increase in temperature is often associated with increase in concentrations of atmospheric carbon dioxide (CO_2) and other heat-trapping greenhouse gases such as methane, nitrous oxide, ozone and water vapour. Since 1750, concentration of atmospheric CO_2 has increased from 278 ppm (Pearson and Palmer, 2000) to currently 400 ppm (IPCC, 2014). CO_2 level may increase up to 550 ppm by 2050 (Solomon *et al*., 2007; IPCC, 2014) and 605-755 ppm by 2070 (IPCC, 2014) depending on the scenario of future development. Such global climatic changes will have affect through their direct and indirect effect on crops, soil, livestock and pests. Food, fodder and nutritional security depend on the quality of seed and many experiments conducted worldwide suggested that climate, has a marked effect on fodder and fodder seed productivity and quality. Currently, India is facing a net deficit of 61.1% green fodder, 21.9% dry crop residues and acute shortage in availability of seeds (64%) of many forage crops. At present seed availability of forage crops is only 15-20%. As global population continues to increase, crop yields and forage crop yield must increase proportionally to meet the future demand for food and fodder (Myers *et al.,* 2017). There is high demand for forage yield and fodder seed production at present and future as well. A major challenge ahead for those involved in the seed industry, therefore, is to provide cultivars that can maximize future crop production in a changing climate (Ainsworth et al. 2008b; Bruins 2009; Ceccarelli *et al.,* 2010). Climate resilient crops such as forages pulses, grasses and millets, such as sorghum, pearl millet, millets, have proven to be climate smart [Singh et al., (2010), Singh *et al.,* (2020), Dheeravathu *et al.,* (2021c), Dheeravathu *et al.,* (2021b) Dheeravathu *et al.,* (2021a), Dheeravathu *et al.,* (2018), Dheeravathu *et al.,* (2017a), Dheeravathu *et al.,* (2017b)]. Considering the effect of elevated CO_2 and temperature on forage growth, yield and productivity and identification of physiological and biochemical changes mechanism in forage crop varieties/genotypes/lines could play a major role in sustaining livestock production and will be helpful in future breeding programs.

Effect of elevated CO_2 and temperature on physiological and biochemical traits

Under elevated CO_2 most plant species show higher rates of photosynthesis, increased growth, increased water use efficiency (drought), and lowered tissue concentrations of nitrogen and protein, while under elevated temperature lower rates of photosynthesis, decreased growth, and higher tissue concentrations of nitrogen and protein (Table 1). Increasing level of CO_2 concentration has effect through modification of stomata behavior on photosynthesis, water use efficiency and crop yield, etc. Stomata movements may change in response to elevated CO_2. A doubling CO_2 concentration reduces the conductance at the leaf level by 30-40 per cent, although large differences among species exist. Elevated CO_2 concentrations found to be linked to changes in herbage growth patterns, decreased fodder quality, pasture variety, nutrient availability, and resource use efficiency, all of which have been linked to reduced reproductive efficiency and the escalation of different health concerns (Rojas-Downing *et al.*, 2017). Two responses of crops to elevated CO_2 are an increase in the rate of photosynthesis and a decrease in stomatal conductance. The increase in net photosynthesis in C_3 species has been reported as high as 50-100 per cent when CO_2 concentration doubles compared to 10 per cent in C_4 species (Vanaja et al., 2006). Increasing level of CO_2 concentration has positive effect on plant height, leaf area, internodal length and total dry matter production. Global climate changes have led to increased temperatures and increased frequency of droughts in some parts of the world and floods in some other parts of the world. It has been estimated that 2°C increase in temperature above 30°C reduces the maize yields by 13 per cent as compared to 20 per cent intra seasonal variation in the rainfall, which reduces the maize yields by 4.5 per cent. Further, every degree increase in day temperature above 30°C would decrease yield by 1 per cent in optimum conditions and 1.7 per cent in drought conditions. Oat requires optimum growing temperature, around 16°C-20°C from germination till grain filling for maximum yield. Sorrells and Simons (1992) reported an optimum temperature of 13°C - 19°C for high grain and straw yields. High temperature stress during post juvenile growth and development severely reduces grain yield and quality of oat. CO_2 enrichment is likely to allow yield increase of 13% in most C_3 crops (Jaggard *et al*., 2010 and Taylor *et al*., 2018) but it is often associated with increasing temperature which may negate yield increase, particularly if it occurs during reproductive growth (Allen and Boote 2000; Wheeler *et al.,* 2000). Ahmed *et al.,* (1993) reported that cowpea heat-tolerant line accumulated substantial shoot biomass, exhibited less accumulation of starch in leaves, and possibly had less down-regulation of photosynthesis in response to CO_2 enrichment and heat stress than the heat-sensitive lines. Madan Pal *et al*., (2004) reported that elevated CO_2 results in increased leaf size, plant height, fresh and dry mass, leaf carbon and phosphorus content in berseem but poor in leaf nitrogen, soluble proteins, calcium and iron. Berseem cultivated under elevated CO_2 (900 μl^{-1}) conditions showed increase in total chlorophyll and starch accumulation in leaf reported by Bhatt *et al.,* 2007 (Table 2). Dry biomass production showed an increase of 20% in *Stylosanthes seabrana*, 46% in *S. viscosa* and 70% in *S. scabra* in open top chamber with elevated CO_2 over the open field grown crops (Moorti and Bhat, 2007) (Table 2). Oat, cultivated under elevated CO_2 (600+50 ppm) conditions showed increase in plant height, leaf area and dry mass production but poor accumulation of soluble protein and nitrogen in leaves (Swami *et al.,* 2007). Carvalho *et al*., (2020) reported that under elevated CO_2 and warming climate, maximum productivity and the N, Ca and S increased in guinea grass (Table 2). Plant survival under rapid climate change occurs mainly due to phenotypic plasticity, with complex adjustments in plant physiology and the structure of leaf tissues (Matesanz *et al*., 2010). Plant

TABLE 1
Effects of elevated CO_2 and temperature on physiological and biochemical responses

Weather Parameters	Physiological/ Biochemical activities	Responses
Elevated CO_2	Ribulose 1,5bisphosphate Corboxylase Oxygenase (Rubisco)	Increases
	Photosynthesis	Increases
	Leaf area	Increases
	Stomatal conductance	Increases
	Stomatal closure	Increases
	Photo respiration	Decreases
	Leaf water status	Increases
	Water use efficiency	Increases
	Tissue nitrogen content	Decreases
	Protein content	Decreases
	Biomass/ yield	Increases
Elevated temperature	Ribulose 1,5bisphosphate Corboxylase Oxygenase (Rubisco)	Decreases
	Reactive oxygen species (ROS)	Increases
	Antioxidant enzymes	Decreases
	Pollen viability	Decreases
	Pollen germination percentage	Decreases
	Pollen tube growth	Decreases
	Biomass/ yield	Decreases
	Protein content	Increases

TABLE 2
Effects of elevated CO_2 and temperature on physiological and biochemical traits in forage crops

Common name	Botanical name	Elevate CO_2 and temperature	Effect on traits	References
White clover	*Trifolium repens* L.	475 ppm	Increased germination	Edwards *et al.,* (2001)
Blue grass	*Poa pratensis* L.		Increased germination	
Rye grass	*Lolium perenne* L.		Increased germination	
Alfalfa	*Medicago sativa* L.	$700 \pm 50\ \mu l^{-1}$	Increased germination	Ziska and Bunce (1993)
Berseem	*Trifolium alexandrinum* L.	elevated CO_2 ($900\ \mu l^{-1}$)	Increased total chlorophyll and starch accumulation in leaf	Bhatt *et al.,* 2007
		Elevated ($600\ \mu l^{-1}$) CO_2	Increased leaf size, plant height, fresh and dry mass, leaf carbon and phosphorus content, Poor in leaf nitrogen, soluble proteins, calcium and iron	Madan Pal *et al*., (2004)
Oat	*Avena sativa* L.	600+50 ppm	Increase plant height, leaf area and dry mass production	Swami *et al*., 2007
Stylosanthes	*Stylosanthes seabrana* B.L. Maas & t Mannetje *Stylosanthes viscosa* (L.) Sw. *Stylosanthes scabra* Vogel		Increases dry biomass production	Moorti and Bhatt (2007)
	Stylosanthes hamata (L.) Taub		Increases plant height and leaf area index	Tiwari *et al.,* 2007
Cenchrus	*Cenchrus ciliaris* L			
			Increases plant height, tiller number, leaf length, leaf width, fresh weight, dry weight and leaf area index	Bhatt *et al.,* 2007
Guinea grass	*Megathyrsus maximum* (Jacq.) B.K.Simon & S.W.L. Jacobs	>2°C Ambient	Increases biomass and N, Ca and S nutrient contents.	Carvalho *et al.,* (2020)
Oat	*Avena sativa* L.		Decreases plant height and shortened the days to 50% flowering	Dheeravathu *et al.,* (2022)

physiology, productivity and leaf anatomy are closely linked because mesophyll characteristics affect carbon assimilation rates and leaf function (Yuan *et al*., 2012). Furthermore, the leaf tissue thickness is important in many processes, such as leaf thermal regulation, light interception, and CO_2 and water vapor diffusion (Terashima *et al*., 2011). For forage species, the proportion of leaf tissues is essential in the digestibility and nutritional value for animals (Grabber *et al.,* 1992). Many studies have shown that increased CO_2 concentration can alleviate the inhibition of abiotic stress on plant growth and physiological function (Shanmugam *et al*., 2013; Medina *et al*., 2016; Li *et al.,* 2017; Wei *et al.,* 2018). This increase causes a rise of intercellular CO_2 concentration (Ci), which could compensate for the CO_2 restriction caused by the decrease of stomatal conductance under stress (Morison and Gifford 1983). It also reduces transpiration by reducing the stomatal conductance (Gs), thus improving the WUE of plant leaves under stress (Fleisher *et al*., 2008; Pazzaglia *et al*., 2016; Varga *et al*., 2017). A limited water supply inhibits the photosynthesis in forage crops and affect on its growth rate and yield. The optimization of water use for crops and forage crops by improvement of WUE is a challenge for securing agricultural sustainability in arid and semi-arid areas. Oat requires optimum growing temperature, around 16°C-20°C from germination till grain filling for maximum yield. Sorrells and Simons (1992) reported an optimum temperature of 13°C-19°C for high grain and straw yields. High temperature stress during post juvenile growth and development severely reduces grain yield and quality of oat. Elevated temperature decreased plant height and days to 50% flowering was shortened under elevated temperature compared to ambient condition in oat (Dheeravathu *et al.,* 2022) (Table 2).

CONCLUSION

Climate change has a significant impact on agriculture owing to temperature fluctuation and the effects of elevated CO_2, which is negatively influencing agricultural productivity and production systems for food, feed, and fodder, as well as animal health throughout the world. Climate change is having the most severe effects on crops and livestock. These effects differ depending on the degree of warming and the resulting changes in rainfall patterns, as well as from one region to the next. Perennial forage crops have a deep root system, higher nitrogen, phosphorus, light, and water use efficiency, drought resistance and increased biomass production under adverse climatic conditions, regeneration capability and acceptable nutritional quality. This indicates that these crops might be used as feed crops in the future. Hence, a comprehensive study involving identification of physiological and biochemical CO_2 responsive/ temperature stress tolerance mechanisms in forage crops is needed to address the changing climate scenario. Resource-smart approaches such as crop modeling, computer simulation in plant breeding, cost-effective techniques such as crop diversification to develop resilience in agrarian systems, policy interventions and improved forage crop varieties are recommended.

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