Effect of the elevated temperature on *Grevillea robusta* A Cunn ex R Br: physiological and growth approach to understand heat stress response

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 Received: 20.04.2024/Accepted: 30.05.2024

ABSTRACT

Silver oak *(Grevillea robusta* A Cunn ex R Br), an evergreen tree belonging to family Proteaceae is native to Australia – New South Wales and Queensland. An experiment was conducted to observe the likely impact of elevated temperature on growth behavior, biomass accumulation and physiological response of seedlings of silver oak grown in pot under open top chamber conditions. The present study examined the early growth of silver oak and other related parameters under elevated temperature for two months as compared to ambient air. Results showed more growth in plant along with increased leaf area, height and number of leaves per plant. Various other parameters like leaf area index, moisture content of leaves and shoot and root were determined. The physiological traits like photosynthesis, transpiration, stomatal conductance and water use efficiency were also examined.

Keywords: *Grevillea robusta*; elevated temperature; physiological response; photosynthesis

INTRODUCTION

Temperature is a primary factor affecting the rate of growth and development of a plant. It can affect photosynthesis by the modulation of the rates of activity of photosynthetic enzymes and the electron transport chain. Besides growth and development, extreme temperature also has potential impact on pollination which is one of the most sensitive phenological stages across all tree as well as crop species. Responses to temperature differ among crop species throughout their life cycle and are primarily the phenological responses ie stages of plant development. For each species, a defined range of maximum and minimum temperatures form the boundaries of observable growth. Vegetative development (node and leaf appearance rate) increases as temperatures rises to the species optimum level. For most plant species, vegetative development usually has a higher optimum temperature than for reproductive development. Temperature effects are elevated by water deficits and excess soil water demonstrating that understanding the interaction of temperature and water will be needed to develop more effective adaptation strategies to offset the impacts of greater temperature extreme events associated with changing climate. Ongoing climate change is mainly evident as increase in average temperature. It is expected to have a significant impact on world's biomes, with forest ecosystems especially vulnerable to these changes. The effect of climate change on forests is both indirect, through its impact on various tree species of different ecological requirements and direct, through its impact on all living components of the forest ecosystem.

At global level, several studies have been carried out on the effect of elevated temperature on physiological characteristics and growth dynamics of different plant species (Boisvenue and Running 2006, Lindner et al 2010, Gonzalez et al 2010, Paulsen and Körner 2014, Eckstein and Krause 1989, Bednarz and Ptak 1990, Bigler et al 2006, Pretzsch et al 2013, Maracchi et al 2005, van der Sleen et al 2015, Linares and Camarero l 2012, Seneviratne et al 2012, Buriro et al 2011, Essemine et al 2010, Iloh et al 2014, Walther et al 2002, Jump et al 2006, Ashraf and Harris 2013, Matala et al 2005, Fries et al 1998, Loehle 2000, Moore et al 2006).

Grevillea robusta, commonly known as silver oak, is a medium to large tree commonly planted as ornamental in many warm-temperate and semi-tropical climates. It has been established as a forest tree in some countries and shows promise as a fast-growing timber tree in subtropical and dry rainforest environments receiving more than 1,000 mm per year of average rainfall. Silver oak grows in full sunlight but can tolerate some shade. At younger age, it can tolerate drought, but may die back at maturity (15-20 years of age) from prolonged drought stress (more than 4 months). It is adapted to wide variety of soil types but prefers slightly acidic to neutral soils. Roots run shallow without drought stress. Temperature is a primary factor that affects the rate of plant development. Increase in the global surface temperature with climate change and precipitation regime can significantly impact plant development processes and its productivity. Under an increasing climate change scenario, there is a greater likelihood of air temperatures exceeding the optimum range for many plant species.

The present study was carried out to know the impact of increase in temperature in present scenario of climate change that has positive as well as negative impacts on growth and physiological characters of silver oak plant. The study is important to understand adaptive behavior of silver oak plant in future changing climate. Hence, it will also identify adaptive traits of plants to cope up and survive in future climate change. Baseline data have been generated to predict future climate change impacts on silver oak. The present study was proposed to focus on the effect of elevated temperature on growth response of plants, biomass production and to observe physiological behavior of silver oak against elevated temperature.

MATERIAL and METHODS

Study area

The open-top chamber (OTC) facility with automated controlled conditions of CO_2, temperature and relative humidity was established at central nursery of Forest Research Institute, Dehradun, Uttarakhand. Two chambers OTC 1 and OTC 2 were used in the study. Five seedlings of silver oak of same height were put in OTC 1 chamber and five seedlings in OTC 2 in polybags of size 25 cm × 13 cm × 10 cm. Equal water treatment was provided in both the chambers. Readings were taken at an interval of 30 days and total period of study was two months. Growth parameters like number of leaves per plant, leaf length, leaf area, plant height, collar diameter and leaf shoot and root moisture content were measured along with various physiological parameters like photosynthesis, transpiration, stomatal conductance and water use efficiency.

Construction of OTC facility

OTCs were built with high quality multi-layered polycarbonate sheets (3-4 millimeter thickness and 80-85% light transmission level) of 3 m × m × 4 m dimensions with galvanized iron structure with proper foundation and grouting. A suitable door of 6 feet × 3 feet size was provided in each chamber. Flat and angle aluminum with rust-free screws were used for mounting of polycarbonate sheet. Square pipes (stainless steel) were used for chamber supporting structure. Welding at four corners and inclination of 30^o at top was provided to protect against high wind and moderate vibrations. Sealing of chamber was done at the top, corners and center along with gaskets. Door was sealed using U-type gaskets with overlapping of sheets to prevent loss of CO_2 through doors. These chambers were used to carry out the experiment under controlled conditions of CO_2, temperature and relative humidity.

Controlling of CO_2, temperature and relative humidity

The sensors for measuring CO_2, temperature and relative humidity were placed inside the chamber with the support of iron rod. The portable sensors of temperature, humidity and CO_2 were placed in each chamber as monitor device to obtain data of CO_2, temperature and relative humidity. These sensors were protected from natural hazards (like rain, sun radiation, snowfall, small animals, birds etc) by enclosing with rust-free powder coated MS box. The sensor box was movable and had flexibility to adjust it on any height in chamber according to plant canopy/plant height. Hundred per cent CO_2 gas of commercial grade was supplied to the chambers through CO_2 gas cylinder and maintained at set level (800 ppm) using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler, pump, CO_2 analyzer, PC-linked programme logic control (PLC) and supervisory control and data acquisition (SCADA). The uniformity of CO_2 was maintained by mixing CO_2 gas diluted with air by 120 liter capacity of air compressor. The NDIR (non-dispersive infrared) principal-based CO_2 sensors manufactured by Topac, USA were used to monitor CO_2 level in each chamber.

The IR-based ceramic heaters (size 910 mm × 120 mm × 90 mm with 2 KVA power requirements), made by Max Detect, USA, were put in chamber to maintain the required temperature (+2.0°C ambient). As per canopy height of the plant, the height of the heater was adjusted from ground to the top of chamber by using rope system and rotating pulley clockwise and anti-clockwise. The resistance temperature detectors (RTDs) sensors were used to measure temperature by correlating the resistance of the RTD element with temperature. Humidity sensors made by Max Detect, USA were mounted in each chamber to monitor RH (relative humidity). The dehumidifiers made by Whitewashing House, USA were put in the chamber to maintain the level of humidity (5.0-10.0% decreased level in ambient RH).

Chambers' specifications

The OTC was used with specification of OTC 1 (control chamber without any treatment), OTC 2 (elevated CO_2^- 800 ppm), OTC 3 (elevated temperature ±2.0°C ambient), OTC 4 (elevated CO_2^+ elevated temperature), OTC 5 (elevated temperature + SH-simulated humidity) and OTC 6 (elevated CO_2 + elevated temperature + simulated humidity). One set of the plants (clones) was kept outside of the chambers in natural conditions and designated as AMB (ambient).

Statistical analysis

Data obtained from the present study were statistically analyzed and results were obtained on physiological and growth parameters of silver oak with the effect of elevated temperature in controlled conditions.

RESULTS and DISCUSSION

Photosynthetic rate of plants grown under ambient atmosphere in watered conditions was high as compared to the drought conditions. In case of elevated temperature atmosphere, photosynthetic rate of plants grown under watered conditions was found 58 per cent higher as compared to the plants grown under drought conditions. After leaving the plants to grow under drought conditions inside OTC (elevated temperature) as well as under ambient conditions, when readings were taken with the help of portable photosynthesis analyzer at an interval of 15 days, it was found that under watered conditions, rate of photosynthesis was higher inside OTC as well as under ambient conditions as compared to the drought conditions (Fig 1).

The rate of transpiration was found very high under water sufficient conditions as compared to the drought conditions. When reading was taken at an interval of 15 days after allowing the plant to grow under water scarce conditions, inside OTC (+5°C elevated temperature) the transpiration rate was found 2.5 m mol $m^{-2}s^{-1}$ in watered conditions as compared to 0.3 m mol $m^{-2}s^{-1}$ under drought conditions and similarly under ambient conditions, the transpiration rate was found 2.2 m mol $m^{-2}s^{-1}$ under watered conditions as compared to the drought conditions of 0.5 m mol $m^{-2}s^{-1}$ (Fig 2).

After the interval of 15 days, the stomatal conductance under OTC was 643 per cent higher in watered conditions as compared to drought conditions. Under ambient conditions, stomatal conductance was 0.038 (375% high) in watered conditions as compared to the 0.008 m mol $m^{-2}s^{-1}$ stomatal conductance of plants grown in drought conditions. So, in both the atmospheres (ambient and elevated temperature) under watered conditions, stomatal conductance was higher than the drought conditions. It shows that plant reduces water loss by closing stomatal performance (ie by reducing stomatal conductance) under drought situations (Fig 3).

Water use efficiency was found 18 per cent higher in plants grown under drought conditions under the OTC as compared to the watered conditions. After the intervals of 15 days, inside OTC and under ambient conditions, the water use efficiency of plants grown under ambient (normal atmospheric conditions) conditions was higher than the plants grown under elevated temperature (Fig 4).

After the interval of 15 days, water use efficiency was higher under drought conditions in ambient atmosphere as compared to the watered conditions. In case of elevated temperature atmosphere, the efficiency of plant under watered conditions was greater than the drought conditions. Under ambient atmosphere with drought conditions, P_n/E was 717 per cent more than water available conditions, whereas, under watered conditions inside OTC, it was 6 per cent efficient than water stress conditions (Fig 5).

Carboxylation efficiency of plants grown inside OTC under watered conditions was 130 per cent higher than that under drought conditions. Under drought conditions in ambient atmosphere, it was 29 per cent higher as compared to the watered conditions (Fig 6).

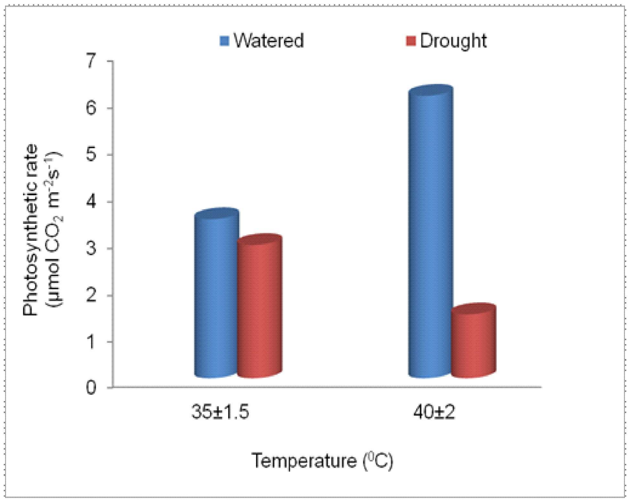

Fig 1. Impact of drought conditions on photosynthetic rate of plants grown in elevated temperature and ambient conditions

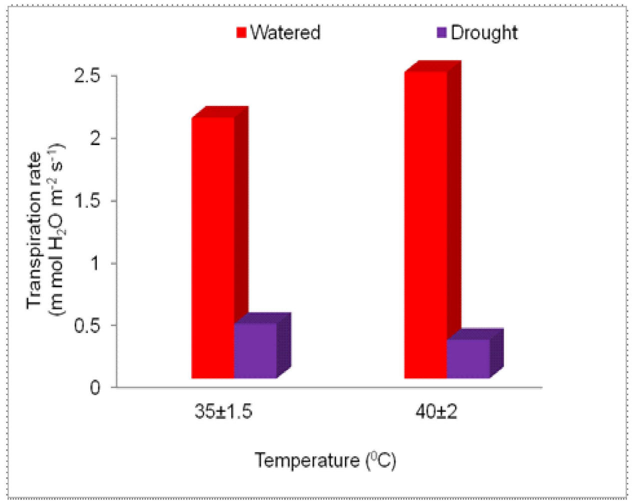

Fig 2. Impact of drought conditions on transpiration rate of plants grown under elevated temperature and in ambient atmospheric conditions

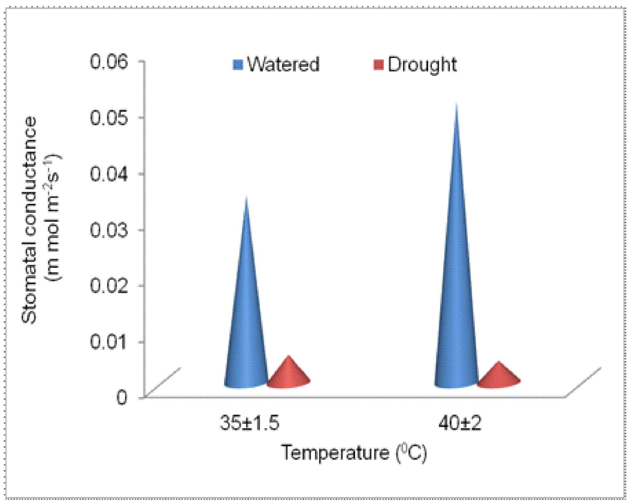

Fig 3. High stomatal conductance under watered conditions inside OTC and ambient conditions (outside OTC)

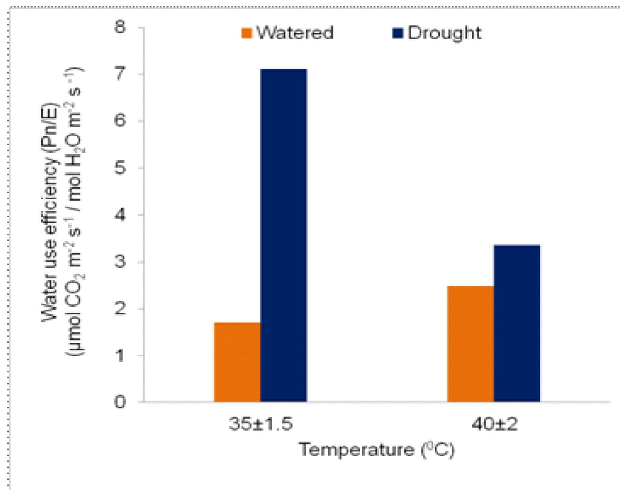

Fig 4. Water use efficiency (Pn/E) under drought conditions in ambient atmosphere and elevated temperature atmosphere

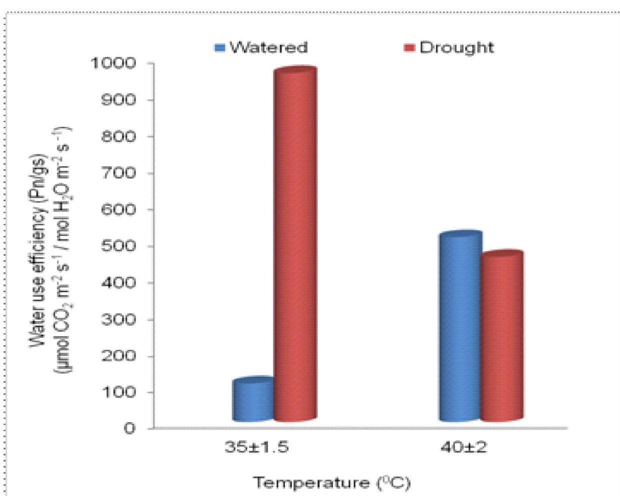

Fig 5. Water use efficiency (Pn/gs) under drought conditions in ambient atmosphere and elevated temperature atmosphere

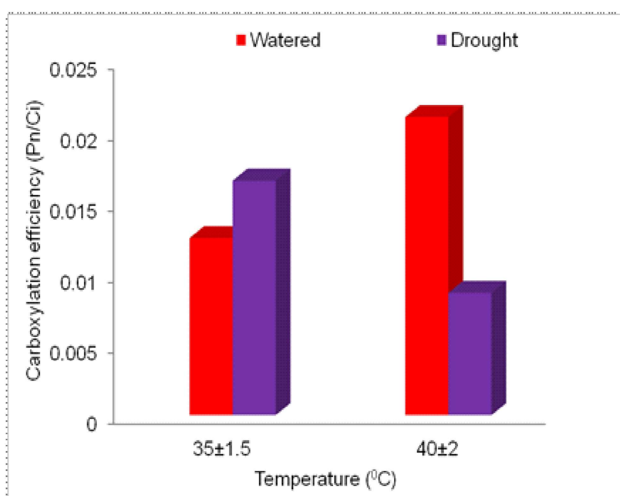

Fig 6. Carboxylation efficiency under ambient conditions and OTC (elevated temperature)

After the interval of 15 days, it was found that mesophyll efficiency was 500 per cent higher in plants grown in drought conditions under ambient atmosphere as compared to the plants grown under watered conditions. The mesophyll efficiency was 90 per cent higher under drought conditions inside OTC than watered conditions. Hence, it can be said that mesophyll performance was very good under ambient conditions (Fig 7).

Under ambient atmosphere, intercellular concentration of CO_2 was found 59 per cent higher in plants grown under watered conditions than those plants which were grown under drought conditions. And inside OTC, concentration under watered conditions was higher by 160 per cent than drought conditions (Fig 8).

After the interval of 80 days, the number of leaves and buds in the plants grown under the two different conditions was counted. Under ambient atmospheric conditions, number of leaves was 14 per cent more than those of elevated temperature conditions and number of buds was 17 per cent more in ambient conditions as compared to elevated temperature conditions (Fig 9).

The observations on plant height and stem collar diameter were made for the period of 80 days after planting them under two different conditions viz ambient and elevated temperature. Growth in height was 13 per cent more under ambient atmosphere than elevated temperature conditions and collar diameter was 11 per cent higher in ambient conditions than under elevated conditions. Mid-diameter and top diameter were also more in ambient conditions than in elevated temperature conditions (Fig 10).

Under ambient temperature conditions, primary root length was 36 per cent more than the elevated temperature conditions. In secondary root length, only slight difference was observed under OTC and in ambient atmosphere. There was 31 per cent more growth in leaf length under ambient atmosphere than under OTC. Leaf area was found 88 per cent more under ambient atmosphere as compared to elevated atmospheric conditions (Fig 11).

After the interval of 80 days, the fresh weight of different parts of plants grown under two conditions was measured. Leaf fresh weight was found 17 per cent more under ambient conditions than those grown under elevated temperature conditions. The fresh weight of stem, root and overall weight of plants grown under ambient atmospheric conditions was found more than the plants kept under the elevated conditions (Fig 12).

Physiological characters: Physiological characters were measured in terms of photosynthetic rate, transpiration rate, stomatal conductance, water use efficiency, carboxylation efficiency, mesophyll efficiency and intercellular CO_2 concentration. Under both the conditions (ambient and elevated temperature conditions), the photosynthetic rate, transpiration rate and stomatal conductance were observed to be higher in water sufficient conditions as compared to drought conditions. Whereas, the water use efficiency was found to be higher in drought conditions as compared to the watered conditions, under both the temperature conditions. After the interval of 15 days, there was slight variation in water use efficiency under both conditions. In ambient conditions, the water use efficiency was higher in drought conditions, whereas, it was lower in elevated conditions as compared to watered conditions. The same trend was followed by carboxylation efficiency. The mesophyll efficiency was lower in watered conditions in both the temperature conditions (ambient and elevated) as compared to drought conditions. Intercellular CO_2 concentration was found to be higher in watered conditions as compared to drought conditions in both atmospheric conditions.

Physiological adjustment through the formation of heat shock proteins (HSPs) and cell dehydration as well as heat avoidance by reducing the heat load are some of the adaptations found in plants growing in hot environments (Gutschick and Wiegel 1988). Different functional types often differ in the strength of their response to environmental changes. For example, in response to elevated CO_2, woody plants show less acclimation of stomatal conductance than crops or grasses and light-saturated photosynthetic rates are stimulated more strongly in trees than in other functional groups (Ainsworth and Rogers 2007). Within trees, stomatal conductance in evergreen conifers is less responsive to elevated CO_2 than in broad-leaved trees (Medlyn et al 2001)

Growth characters: With reference to growth parameters, the total fresh and dry weight (g), plant height (cm) and collar diameter (mm) were observed to be higher in ambient atmospheric conditions. The maximum number of leaves, buds and leaf area index

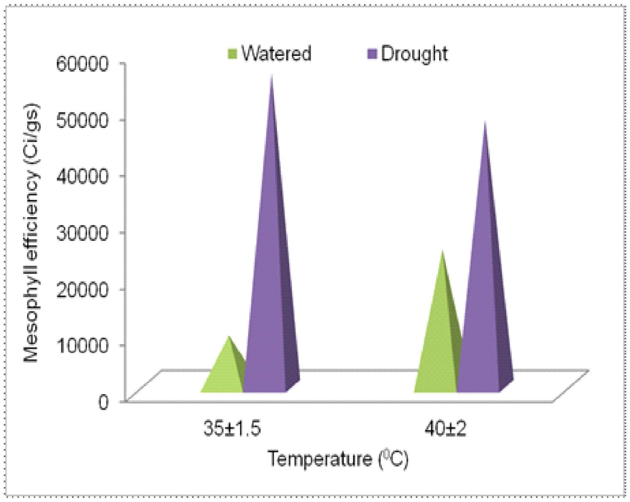

Fig 7. Mesophyll efficiency under OTC and ambient conditions

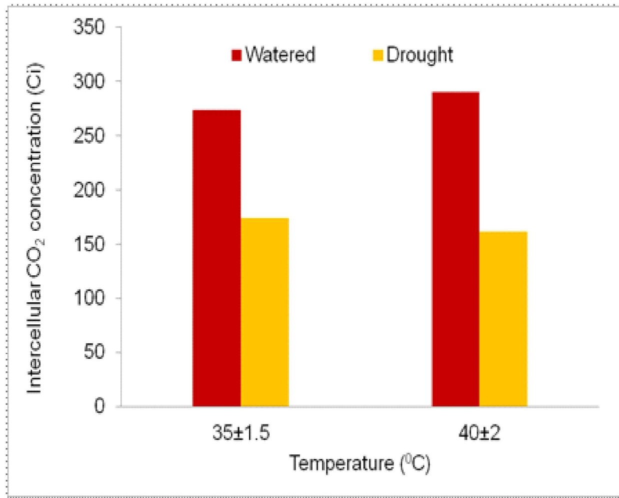

Fig 8. Intercellular CO_2 concentration under ambient and elevated atmospheric conditions

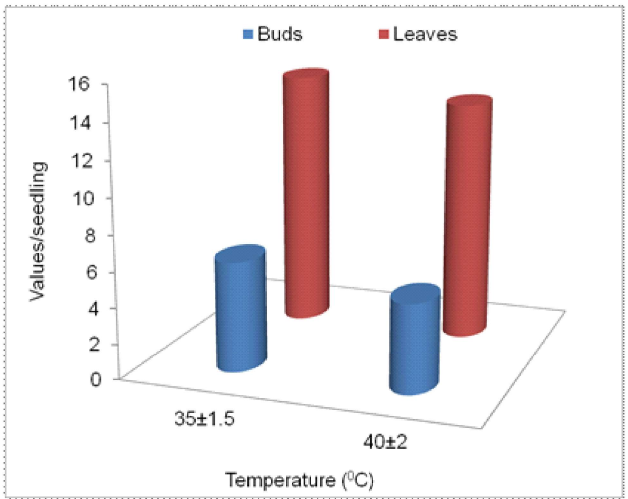

Fig 9. Impact of elevated temperature on number of buds and leaves

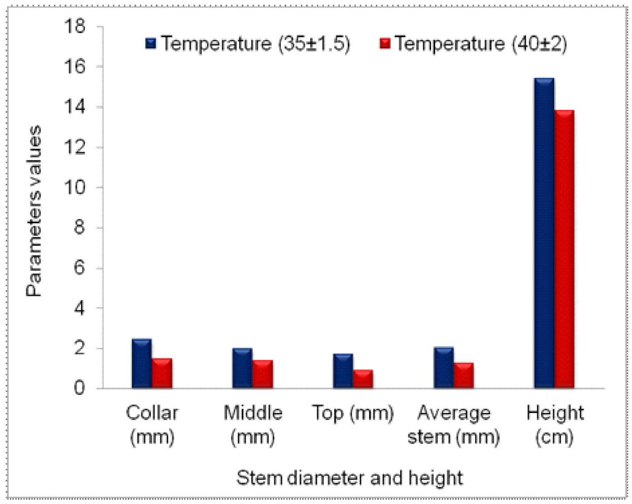

Fig 10. Impact of elevated temperature on stem diameter and plant height

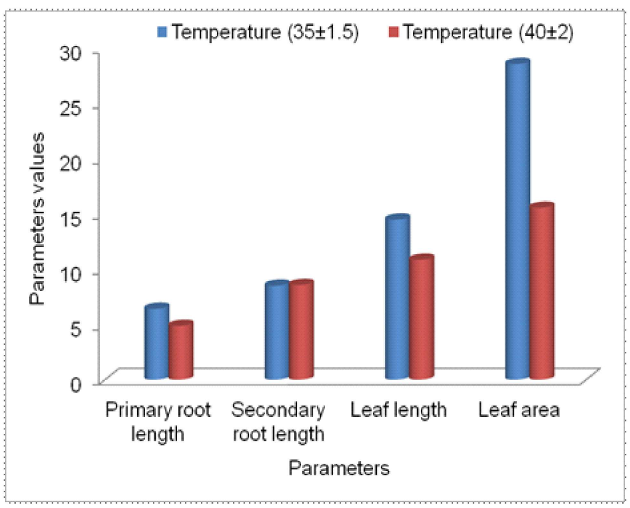

Fig 11. Impact of elevated temperature on root and leaf length

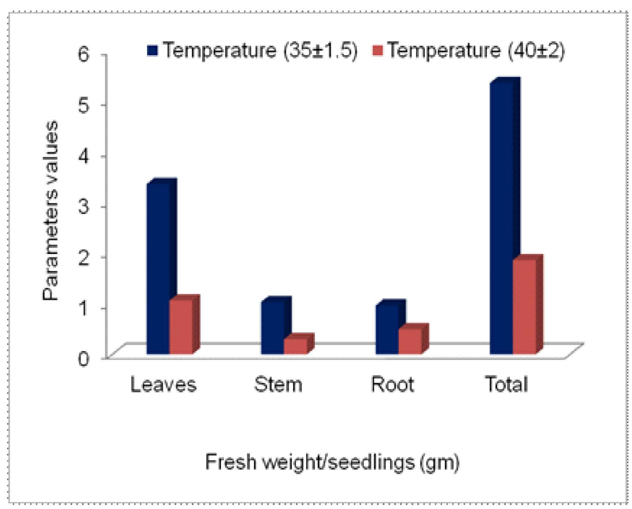

Fig 12. Impact of elevated temperature on fresh weight of plant parts

was observed in ambient atmospheric conditions as compared to elevated temperature conditions. Similarly, higher root length was observed under ambient conditions as compared to the elevated conditions.

Height growth is often suboptimal at the native site in provenance studies; survival and fitness are usually optimized near the site of origin, demonstrating that local adaptation is not driven only by growth (Rehfeldt et al 1999). The results indicated that decreased growth in response to warming can occur even when trees have sufficient water and nutrients and are not necessarily related to drought stress. While warming-related drought can reduce tree growth and survival (van Mantgem and Stephenson 2007), the declines in forest productivity have also been attributed to increasing temperatures when associated changes in the water stress have been ruled out (Piao et al 2008).

CONCLUSION

The present study concluded that an increase in temperature in present scenario of climate change will have positive as well as negative impacts on growth and physiological conditions of silver oak. The study gave an idea about changes in growth and physiological characters of silver oak with increase in temperature under the elevated atmospheric conditions. The plant under the study was found to be physiologically less adaptable and, thereby, intolerant to wide range of temperature regimes as observed in the present study. It was found that this plant will not be able to survive if the future temperature goes up by 5°C but may survive if the limit goes beyond this boundary. Therefore, such type of important tree cannot be promoted for planting to fight with the changing climatic conditions.

ACKNOWLEDGEMENT

The authors are thankful to Indian Council of Forestry Research and Education, Ministry of Environment, Forest and Climate Change, Government of India for support and encouragement.

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