**Interactive effect of elevated temperature and carbon dioxide on LAI and NDVI in wheat crop**


## Abstract

Climate change, characterized by elevated temperature and increased atmospheric carbon dioxide ($CO_2$) concentration, poses significant challenges to global agricultural systems. This study investigates the effects of elevated temperature and $CO_2$ on key growth parameters, including Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI) in wheat (Triticum aestivum L.). Controlled environment experiments were conducted to simulate future climate conditions, combining varying temperature regimes with elevated $CO_2$ level. Maximum LAI found under $ECO_2$ condition followed by AMB, ECT and ET respectively. LAI showed the same trend with respect to treatments irrespective of the $CO_2$ and temperature level i.e. SCU> NCU> NANO> CONTROL. NDVI also maximum at anthesis stage compared to maximum tillering and near maturity stage. With respect to fertilizer treatments, NDVI showed the same trend as LAI under different interactions of elevated $CO_2$ and temperature. However, higher temperatures alone negatively affected these parameters by accelerating senescence and reducing leaf expansion. When elevated $CO_2$ and temperature were combined, a partial mitigation of temperature stress was observed, although the extent of mitigation varied depending on the growth stage. This study highlights the complex interactions between temperature and $CO_2$, underscoring the need for adaptive agronomic strategies to sustain wheat productivity in changing climate.

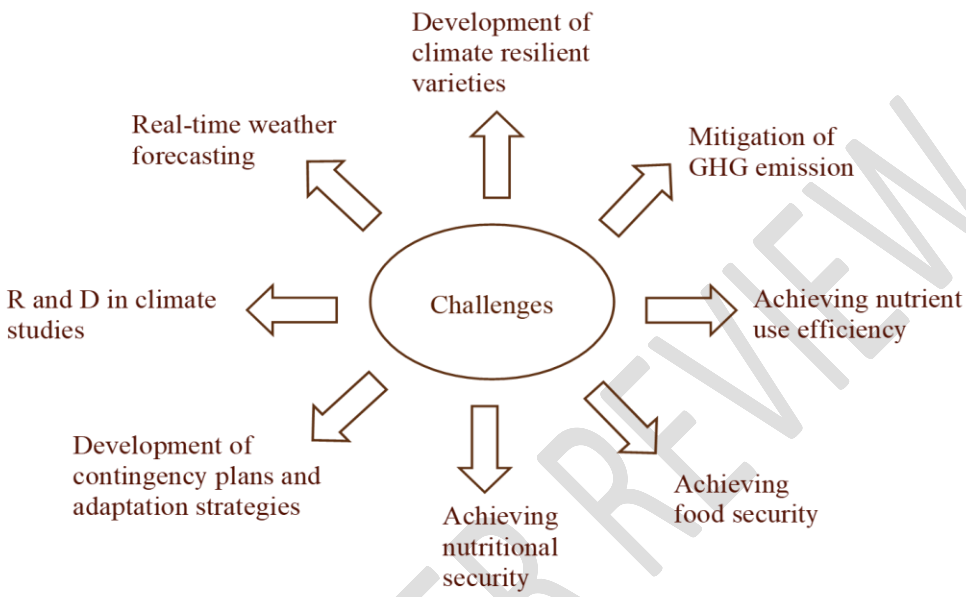


**Key words:** LAI, NDVI, Elevated $CO_2$, Elevated temperature, Climate change


## 1. Introduction

Agriculture is the primary sector on which majority of the Indian population relies upon and it is entirely dependent on regional climatic conditions. It is well known that changing climate definitely has an impact on global agricultural patterns and food security but the impact will vary according to regions and crops (Anderson et al., 2020). Global food production has to be accelerated by at least 50% in order to meet the estimated demand of world population by 2050 (Chakraborty et al., 2011). Meeting this projected demand has put forth the challenge in front of all researchers throughout the world. Already the concentration of major greenhouse gases like $CO_2$, $CH_4$ and $N_2O$ are continuously increasing in the atmosphere and reached the annual averages of 410 ppm, 1866 ppb and 332 ppb respectively (IPCC AR6, 2021). Intergovernmental panel on climate change (IPCC) stated that increasing temperature of earth surface due to global warming slightly offset by the increasing concentration of aerosol in atmosphere (cooling) but still net positive radiative forcing is there (warming). In addition to this, out of 0.43 $W/m^2$ increase in radiative forcing relative to $5^{th}$ report, 0.34 $W/m^2$ is caused due to increase in GHG concentrations. Due to warming of the atmosphere, frequency of occurrence of extreme events like heat waves, flood and agricultural drought is increasing (IPCC AR6, 2021). Effect of drought on growth and yield of wheat crop is much more severe under high temperature compared to low temperature (Shah et al., 2003). Besides this phenological stages duration of wheat crop is reducing by 5.50 and 5.70 days per decade from sowing to anthesis and sowing to maturity, respectively, due to increasing temperature (Ahmed et al., 2019). Elevated temperature also hastened the crop maturity and reduced the grain yield and protein content of crop (Nuttall et al., 2017).

**Fig 1: The challenges faced by the agricultural sector under future $CO_2$ and temperature levels**






Climate change is real and its impacts on human, livestock, agriculture and environment is clearly visible on the earth. Elevated atmospheric $CO_2$ is a major component of climate change and has increased from the pre-industrial level of 280 ppm to 415 ppm at present. Air temperature is an important factor determining the spatiotemporal patterns of phenology of wheat crop (Ren et al., 2019). Variations in the temperature leads to uncertainties in the global rainfall pattern which may have an impact on the yield of the wheat crop (Gul et al., 2020). For each degree rise in temperature, 7% decrease in the wheat yield was reported by Fatima et al., (2020). On the other hand, increasing $CO_2$ levels are known to be beneficial for crop growth and improving the crop yields (Yadav et al., 2021). However, consistent yield reduction in wheat was predicted for many parts of Mexico due to increasing temperature despite the stimulating effect of elevated $CO_2$ concentrations (Hernandez – Ochoa et al., 2018). Increasing $CO_2$ concentration in the atmosphere has increased the plant growth and productivity but interactive effect of both elevated $CO_2$ and temperature is poorly studied (Pan et al., 2018; Zarnetske et al., 2021). There are various studies on growth parameters like photosynthetic rate and stomatal conductance (Wang et al., 2020, Huang et al., 2021) and yield of different crops (Ben mariem et al., 2021, Lenka et al., 2021). But very studies focused on LAI and NDVI which are indirectly helps us to know about photosynthesis efficiency and carbohydrate assimilation (Parida et al., 2024). Hence this study was conducted with the objective:

To measure the LAI and NDVI of wheat crop at different crop growth stages in different fertilizer treatments under interactions of elevated temperature and $CO_2$.

## 2. Materials and methods

The present work entitled **"Interactive effect of elevated temperature and carbon dioxide on LAI and NDVI in wheat crop"** was carried out at an experimental field of Division of Environmental Sciences, ICAR-Indian Agricultural Research Institute (IARI), New delhi-110012. Details of materials used and methods followed in the study are described below:

### 2.1 Study area

The experiment work was carried out at Genetic-H field of Division of Environmental sciences, IARI-New Delhi. The experiment field is situated at 28˚35' N and 77˚12' E, at an altitude of 228 m above mean sea level. The region has semi-arid and subtropical type of climate with mean annual rainfall of 750 mm.

### 2.2 Experimental setup

Wheat crop (HD2967) was taken for experiment during the Rabi season of the year 2021-2022 during November-April in free air temperature and carbon dioxide enrichment facility (T-FACE) under two levels of temperature (Elevated+ ambient) and two levels of carbon dioxide (Elevated+ ambient).

Four different fertilizer treatments of neem coated urea (NCU), sulphur coated urea (SCU), liquid Nano-urea (Nano) and no fertilizer (Control) were applied to each of the T-FACE rings. The whole experiment was conducted in a Completely Randomised design (CRD).

**Fig 2: wheat crop grown in T-FACE facility at Genetic-H field, ICAR-IARI, New Delhi**

### 2.3 Experiment details

Each T-FACE ring had a circular area of 28m$^2$. The experimental area was divided into four different quadrants to take the four different fertilizer treatments viz. NCU, SCU, Nano and control. Two levels of temperature: ambient and elevated (ambient +1.5$^o$C) and two levels of $CO_2$ concentrations: ambient (398-418 ppm $CO_2$) and elevated (550±25 ppm of $CO_2$) was maintained in the rings. In order to study the interactive effects of both $CO_2$ and temperature along with different N fertilizer, four interactive levels were taken viz. 1. Elevated $CO_2$ and ambient temperature (EC), 2. Elevated $CO_2$ and elevated temperature (ECT), 3. Ambient $CO_2$ and ambient temperature (AMB), 4. Ambient $CO_2$ and elevated temperature (ET). Required concentration of $CO_2$ was maintained inside the free air temperature (FACE) rings using rota meters and solenoid valves. The temperature inside the free air temperature (FATE) and free air temperature and carbon dioxide (T-FACE) rings was elevated using infra-red heaters. An infra-red radiometer (Apogee Sl-111) was used for monitoring the canopy temperature inside each of the rings. There were total 16 different treatment under 4 different temperature and $CO_2$ interactions.

**Table 1: treatment details**

| | |
|---|---|
| T1 | Elevated $CO_2$ and ambient temperature - NCU |
| T2 | Elevated $CO_2$ and ambient temperature - SCU |
| T3 | Elevated $CO_2$ and ambient temperature – Nano liquid urea |
| T4 | Elevated $CO_2$ and ambient temperature - Control |
| T5 | Elevated $CO_2$ and elevated temperature - NCU |
| T6 | Elevated $CO_2$ and elevated temperature - SCU |
| T7 | Elevated $CO_2$ and elevated temperature - Nano liquid urea |
| T8 | Elevated $CO_2$ and elevated temperature - control |
| T9 | Ambient $CO_2$ and ambient temperature - NCU |
| T10 | Ambient $CO_2$ and ambient temperature - SCU |
| T11 | Ambient $CO_2$ and ambient temperature – Nano liquid urea |
| T12 | Ambient $CO_2$ and ambient temperature - Control |
| T13 | Ambient $CO_2$ and Elevated Temperature -NCU |
| T14 | Ambient $CO_2$ and Elevated Temperature -SCU |
| T15 | Ambient $CO_2$ and Elevated Temperature - Nano liquid urea |
| T16 | Ambient $CO_2$ and Elevated Temperature - control |



## 2.4 Crop Management

Wheat crop (variety- HD2967) was grown inside the T-FACE rings (Fig:1) in Rabi season of the year 2021 during November month at Genetic-H field, IARI- New delhi. The crop was sown manually on 15$^{th}$ November at a seed rate of 10g/m$^2$ at a spacing of 15cm*10 cm. Recommended dose of phosphorous was applied through Di ammonium phosphate (10g/m$^2$) and potassium was applied as Muriate of potassium (6g/m$^2$) as a basal dose. NCU (Neem coated urea), SCU (Sulphur coated urea), liquid Nano Urea (IFFCO developed) and control (No N fertilizer) were the four fertilizer treatments taken in each of the T- FACE rings. The different nitrogen (N) fertilizers were applied in 3 split doses at crown root initiation (CRI), tillering and booting stages, respectively. Each split of N fertilizer was applied @ 40 kg according to the different treatments. Treatments details are given in Table 2.

### 2.5 Canopy analyzer and green seeker recordings

Leaf area index was calculated by using canopy analyser and readings are taken at maximum tillering and anthesis stages. Besides this NDVI (Normalized Difference Vegetation Index) values for each treatment are taken by using handheld green seeker at maximum tillering and anthesis stages of wheat.

$$\mathbf{NDVI = (NIR\text{-}Red) / (NIR + Red)}$$

Where NIR and Red is near infra-red and visible red light respectively.

**Fig 3: Using the canopy analyser and green seeker at Genetic-H field, IARI-New delhi**

### 2.6 Statistical Analysis

The design of the experiment was completely randomized design (CRD). There were total 16 treatments with 3 replications. The data obtained from the treatments were analyzed using SPSS software. Analysis of variance was done to test whether the differences were statistically significant. The differences were considered significant at $P \leq 0.05$.

## 3. Results

### 3.1 Leaf area index (LAI)

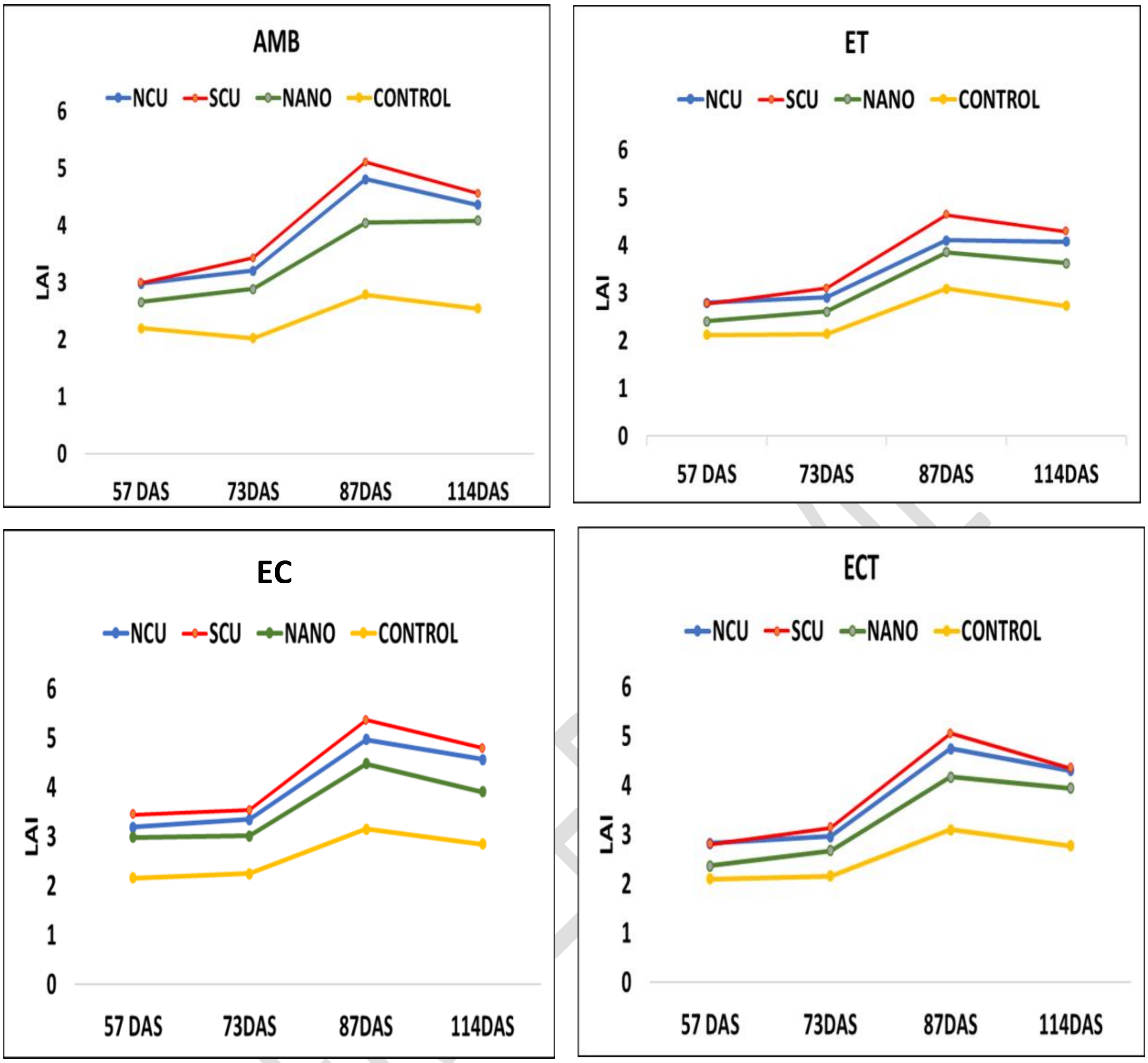
LAI was measured four times (T1= 57DAS, T2= 73DAS, T3= 87DAS, T4= 114DAS) during the entire crop duration by using a Canopy analyzer. LAI showed the same trend with respect to all N fertilizers along with control irrespective of the $CO_2$ and temperature levels i.e. SCU> NCU> NANO> Control (Fig:4). SCU treatment recorded highest values under all interactions with increasing values from 57- 87 DAS and thereafter value decreased compared to 87DAS (Table:2). Highest LAI recorded under SCU at 87DAS in decreasing order was EC> AMB> ECT> ET (Fig: 4). Maximum LAI was recorded in SCU treatment under ECO2 condition at 87DAS i.e. 5.36 and minimum at 57DAS in control treatment under ECT condition i.e. 2.10 (Table:2). Highest values of LAI were recorded under EC conditions irrespective of the treatments and days after sowing. Lowest LAI was recorded at 57DAS irrespective of the treatments and days after sowing.

**Table 2: LAI of different N fertilizers under interaction of elevated $CO_2$ and elevated temperature**

| N Fertilizer | Ambient $CO_2$ | | Elevated $CO_2$ | |
|---|---|---|---|---|
| | **Ambient temp.** | **Elevated temp.** | **Ambient temp.** | **Elevated temp.** |
| **NCU** | 2.98 | 2.79 | 3.19 | 2.82 |
| **SCU** | 3.00 | 2.78 | 3.45 | 2.81 |
| **NANO-UREA** | 2.66 | 2.41 | 2.98 | 2.37 |
| **CONTROL** | 2.20 | 2.12 | 2.16 | 2.10 |
| **Mean (57DAS)** | 2.71 | 2.53 | 2.95 | 2.52 |
| **CD ($p \leq 0.05$)** | $CO_2$: NS; Temp: NS; Fertilizer: 0.27; $CO_2$X temp: NS; $CO_2$X Fertilizer: NS; Temp X fertilizer: NS; $CO_2$X Temp X Fertilizer: NS | | | |
| **NCU** | 3.21 | 2.90 | 3.35 | 2.96 |
| **SCU** | 3.43 | 3.10 | 3.53 | 3.14 |
| **NANO-UREA** | 2.89 | 2.61 | 3.01 | 2.67 |
| **CONTROL** | 2.03 | 2.14 | 2.25 | 2.16 |
| **Mean (73DAS)** | 2.89 | 2.69 | 3.04 | 2.73 |
| **CD ($p \leq 0.05$)** | $CO_2$: NS; Temp: NS; Fertilizer: 0.27; $CO_2$X temp: NS; $CO_2$X Fertilizer: NS; Temp X fertilizer: NS; $CO_2$X Temp X Fertilizer: NS | | | |
| **NCU** | 4.81 | 4.10 | 4.97 | 4.74 |
| **SCU** | 5.11 | 4.64 | 5.36 | 5.05 |
| **NANO-UREA** | 4.05 | 3.85 | 4.48 | 4.17 |
| **CONTROL** | 2.79 | 3.09 | 3.15 | 3.10 |
| **Mean (87DAS)** | 4.19 | 3.92 | 4.49 | 4.26 |
| **CD ($p \leq 0.05$)** | $CO_2$: NS; Temp: NS; Fertilizer: 0.27; $CO_2$X temp: NS; $CO_2$X Fertilizer: NS; Temp X fertilizer: NS; $CO_2$X Temp X Fertilizer: NS | | | |
| **NCU** | 4.36 | 4.08 | 4.57 | 4.30 |
| **SCU** | 4.56 | 4.29 | 4.79 | 4.35 |
| **NANO-UREA** | 4.08 | 3.62 | 3.91 | 3.94 |
| **CONTROL** | 2.55 | 2.73 | 2.85 | 2.77 |
| **Mean (114DAS)** | 3.89 | 3.68 | 4.03 | 3.84 |
| **CD ($p \leq 0.05$)** | $CO_2$: NS; Temp: NS; Fertilizer: 0.27; $CO_2$X temp: NS; $CO_2$X Fertilizer: NS; Temp X fertilizer: NS; $CO_2$X Temp X Fertilizer: NS | | | |



**Fig 4: Leaf area index of different treatments under ambient $CO_2$ and ambient temperature condition on different days after sowing**




### 3.2 Normalized difference vegetation index (NDVI)

NDVI values were directly recorded by using the Green Seeker instrument at three different crop growth stages i.e. at maximum tillering, anthesis and near maturity stage in wheat crop. Highest NDVI values were observed at the anthesis stage. Overall NDVI values ranged from 0.51- 0.83 (Table: 3). Highest NDVI values were recorded in the SCU treatment under EC condition at all the stages as compared to other treatments. Maximum greenness showed at anthesis stage irrespective of the treatments and $CO_2$, temperature levels while minimum at near maturity stage. Maximum NDVI value recorded in SCU under EC condition at anthesis stage i.e. 0.83. Minimum NDVI value recorded in control treatment under ECT condition at near maturity stage i.e. 0.51. Higher NDVI values are recorded under SCU treatment in contrasting to control irrespective of $CO_2$ and temperature levels (Table:3). Nano and NCU showed average performance under all the levels of $CO_2$ and temperature at all the stages by considering SCU and control performance as two extremes. Both LAI and NDVI decreased under elevated temperature condition (ET) due to accelerated phenological development and increased stress, which limits the crop's photosynthetic capacity and biomass accumulation.

**Table 3: NDVI values of different treatments under interaction of elevated $CO_2$, temperature and N fertilizer in wheat crop taken though Green seeker at three different crop growth stages.**

| **N Fertilizer** | **Ambient CO2** | | **Elevated CO2** | |
|---|---|---|---|---|
| | **Ambient temp.** | **Elevated temp.** | **Ambient temp.** | **Elevated temp.** |
| **NCU** | 0.75 | 0.71 | 0.77 | 0.73 |
| **SCU** | 0.78 | 0.73 | 0.81 | 0.77 |
| **NANO-UREA** | 0.74 | 0.70 | 0.79 | 0.71 |
| **CONTROL** | 0.59 | 0.57 | 0.65 | 0.57 |
| **Mean (max tillering)** | 0.71 | 0.68 | 0.76 | 0.70 |
| **CD (p≤0.05)** | CO2: 0.03; Temp: NS; Fertilizer: 0.04; CO2X temp: 0.04; CO2X Fertilizer: NS; Temp X fertilizer: NS; CO2X Temp X Fertilizer: NS | | | |
| **NCU** | 0.78 | 0.76 | 0.80 | 0.73 |
| **SCU** | 0.82 | 0.78 | 0.83 | 0.76 |
| **NANO-UREA** | 0.68 | 0.69 | 0.71 | 0.68 |
| **CONTROL** | 0.57 | 0.57 | 0.68 | 0.59 |
| **Mean (Anthesis)** | 0.71 | 0.70 | 0.76 | 0.69 |
| **CD (p≤0.05)** | CO2: 0.03; Temp: NS; Fertilizer: 0.04; CO2X temp: 0.04; CO2X Fertilizer: NS; Temp X fertilizer: NS; CO2X Temp X Fertilizer: NS | | | |
| **NCU** | 0.71 | 0.68 | 0.74 | 0.69 |
| **SCU** | 0.75 | 0.72 | 0.77 | 0.70 |
| **NANO-UREA** | 0.65 | 0.62 | 0.66 | 0.62 |
| **CONTROL** | 0.53 | 0.52 | 0.56 | 0.51 |
| **Mean (near maturity)** | 0.66 | 0.64 | 0.68 | 0.63 |
| **CD (p≤0.05)** | CO2: NS; Temp: NS; Fertilizer: 0.05; CO2X temp: 0.05; CO2X Fertilizer: NS; Temp X fertilizer: NS; CO2X Temp X Fertilizer: NS | | | |

## 4. Discussion

Growth of wheat crop was measured in terms of leaf area index (LAI), normalized difference vegetation index (NDVI) at maximum tillering and anthesis stage. Both LAI and NDVI values were higher under elevated $CO_2$ concentrations and resulted in higher total dry matter. The LAI was observed to be higher under EC treatment in our study. Increasing $CO_2$ concentrations under FACE system has been reported to increase the LAI by 4 up to 22% with increased N supply in wheat crop (Dier et al., 2018). Normalized difference vegetation index (NDVI) usually measures the reflectance in NIR region. Higher reflectance means higher canopy cover which has higher NDVI value (Venkatesh et al., 2022). In our study too higher NDVI was observed under EC. Among the fertilizers SCU performed the best under EC condition. The slow release of coated fertilizer enabled higher plant uptake of N resulting in higher NDVI and LAI in this treatment. However, elevated $CO_2$ often counteracts some of these adverse effects by enhancing photosynthesis and water-use efficiency, leading to an increase in LAI and NDVI under ECT compared to ET alone (Table 2&3). Understanding these interactions is crucial for predicting the performance of wheat under future climate scenarios and for developing adaptive management strategies, such as optimizing planting dates, selecting heat-tolerant varieties, and adjusting irrigation practices, to sustain productivity.

## 5. Conclusion

Study showed that elevated carbon dioxide enhances both LAI and NDVI, leading to greater total dry matter production. The use of slow-release fertilizers, such as sulphur-coated urea (SCU), has shown improved performance under EC conditions. The gradual release of nutrients enhances N uptake, contributing to higher LAI and NDVI. Conversely, ET often reduces these indices due to stress-induced physiological limitations. Understanding the interaction between EC, ET, and nutrient management is vital for predicting wheat performance under future climate scenarios. Adaptive strategies, including the development of heat-tolerant cultivars, optimization of fertilizer use, and modification of agronomic practices, are essential for sustaining productivity in the face of climate change.

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