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INTERACTIVE EFFECTS OF NUTRIENT MANAGEMENT AND ELEVATED CARBON DIOXIDE IN TOMATO

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ABSTRACT

The response of tomato (*Solanum lycopersicum* L.) to elevated carbon dioxide (eCO_2) conditions under different nutrient management practices was evaluated at College of Agriculture, Vellayani, Kerala Agricultural University during November 2021 to March 2022. The experiment was laid out in Completely Randomized Design with six treatments in three replications with provisions for entrapping CO_2 evolved to create eCO_2 conditions. The results revealed that the growth attributes, plant height, LAI, number of leaves and branches per plant were significantly higher under FYM + glyricidia, while root parameters were maximum in INM, on par with combination of FYM and glyricidia and sole FYM. Physiological parameters *viz*., chlorophyll content and photosynthetic rate were the highest in INM on par with FYM + glyricidia. Nevertheless, fruit set was poor irrespective of the nutrient management practice adopted. Artificial pollination was found pertinent under eCO_2. Monitoring the CO_2 release, among the treatments the total release (71,247 mg kg^{-1} soil) was maximum in vermicompost + poultry manure combination and the lowest (60,895 mg kg^{-1} soil) in FYM. Soil and air temperatures followed similar trends. Thus, it is evident that the CO2 evolution significantly influenced the vegetative growth and fruit setting in tomato and the higher temperature ensuing the increased CO_2 concentration modified fruiting behaviour in tomato.

Key words : Elevated CO_2, Nutrient, Manures, Organic, Quality, Temperature, Tomato.

Introduction

Tomato (*Solanum lycopersicum* L.) is the one of the most widely cultivated vegetable crops in the world and the second most consumed vegetable after potato. The crop belonging to the family Solanaceae, is a day neutral, self-pollinated crop of short duration and well suited for hi-tech farming. As a protective supplementary food, the fruits are rich in minerals (Fe, P, etc.) vitamins (A and C), essential amino acids, dietary fibres, pigments (lycopene and beta carotene) and enzymatic antioxidants. The production of tomato in India is 21.18 Mt (DoA & FW, 2022) and the major growing states in the country include Madhya Pradesh, Andhra Pradesh and Karnataka.

However, like all plants, tomatoes are significantly influenced by environmental factors, including atmospheric carbon dioxide (CO_2) levels. In recent decades, the concentration of CO_2 in the atmosphere has been steadily rising which hit a record of 426.91 ppm in 2024 (NOAA, 2024). This elevated CO_2 levels has profound implications for plant physiology and agricultural productivity, including tomato production.

In light of the increasing CO_2 concentrations in the atmosphere, promotion of organic farming practices entails an increased use of organic materials in soil which ultimately decompose and add to C storage. Howbeit, the enhanced microbial activity and soil respiration can add to CO_2 concentration in the atmosphere (Sadatshojaei *et al*., 2022). Organic nutrition can thus ensue disadvantages in terms of contributing to the CO_2 pool in the atmosphere, but it needs to be ascertained as to whether the benefits of increased photosynthesis offsets the contribution to the atmosphere through absorption and conversion to economic produce.

Understanding the impact of elevated CO_2 on tomato agronomy is crucial for predicting how future climate scenarios may affect tomato production systems. In this background, the interactive effect of organic nutrition and eCO_2 on the growth and fruiting behaviour in tomato was attempted.

Materials and Methods

The research was carried out at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University during November 2021 to March 2022. The site enjoyed a humid tropical climate located at 8º25'43" N latitude and 76º59'98" E and longitude 29 m above MSL. Soil texture was sandy clay loam and chemical analysis revealed it to be with slightly acidic (pH-6.20), medium in organic carbon (0.67%), available N (292 kg ha^{-1}), available K (135 kg ha^{-1}) and high in available P (30 kg ha^{-1}). The initial microbial enumeration studies showed counts (cfu g^{-1} soil) of bacteria (4.3 × 10^{6}), fungi (2.6 × 10^{4}) and actinomycetes (25.6 × 10^{5}).

The experiment was laid out in Completely Randomized Design with six treatments replicated thrice. The treatments included were T_1: Farm yard manure (FYM); T_2: Vermicompost; T_3: Poultry manure; T_4: FYM + Glyricidia leaves (2:1); T_5: Vermicompost + Poultry manure (2:1) and T_6: Integrated Nutrient Management (INM). The package recommendation for tomato 75:40:25 kg NPK ha^{-1} (KAU, 2016), was adopted for nutrient management.

Tomato, variety Manuprabha was grown in trenches which were kept covered with UV stabilized sheets fixed on metal frames from 4.30 pm to 9.30 am daily in order to trap the CO_2 released due to soil respiration and decomposition of organic matter inside the trench (Plate 1). The NPK content of organic sources used in the experiment is listed in the Table 1. In T_1 to T_5, the quantity of manures in the treatments was calculated based on their N content and the recommended basal dose of N, 75 kg ha^{-1}. Basal dose of rock phosphate and ash were given to supplement the P and K contents in the organic manures respectively as required (Table 2). Top dressing was done alternately in all treatments with vermicompost @ 1 t ha^{-1} and fermented oil cake (1 kg 10 L^{-1}) supernatant solution @ 50-100 mL per plant at 10 days interval up to 2 MAP. In T_6, the basal dose of FYM @ 20 t ha^{-1} and chemical fertilizers, urea (g46% N), rajphos (18% P_2O_5) and muriate of potash (60% K_2O) were applied in splits as per recommendation. Staking was done during 25-30 DAT and regular hand pollination was carried out taking into account the elongated styles of flowers with utmost care (Ozores-Hampton, 2014).

Plate 1 : General view of experiment.

Table 1 : Nutrient content in the different organic manures, per cent.

Organic manure	N	P	K
FYM	1.41	0.74	0.76
Vermicompost	0.73	0.43	0.73
Poultry manure	1.80	0.67	0.71
Glyricidia leaves	3.51	0.47	1.08

Table 2 : Quantity of organic manures and fertilizers applied in tomato, g m^{-2}.

Treatments	T_1	T_2	T_3	T_4	T_5	T_6
FYM	265.5	-	0	177	-	500
Vermicompost	0	513.5	0	0	342	0
Poultry manure	0	-	208	0	69.5	0
Glyricidia leaves	0	0	0	50	0	0
Urea	0	0	0	0	0	8.15
Rajphos	0	0	0	0	0	22
MOP	0	0	0	0	0	2
Rock phosphate	10	9	12.5	12.5	10	-

Growth parameters *viz.*, plant height, leaf number per plant, leaf area index (LAI) and number of branches at 90 DAT, root length, root weight at harvest, physiological parameters *viz.*, chlorophyll content at flowering, photosynthetic rate and stomatal conductance at monthly interval using LCA-4 (Leaf Chamber Analyser or portable CO_2 analyser) manufactured by Analytical Development Co. Ltd, UK and yield parameters *viz.*, days to 50 per cent flowering, average fruit weight and yield per plant were recorded. The N, P, and K contents in plant samples were estimated as per the standard procedures. Nutrient uptake was estimated by multiplying the nutrient concentration with dry matter produced by plant and expressed as g per plant. The fruit quality was assessed in terms of ascorbic acid (Harris and Ray, 1935), lycopene content (Ranganna, 1976), sucrose (Xu *et al.*, 2015), catalase (Barber, 1980) and ascorbate peroxidase (Nakano and Asada, 1981) in the fresh fruits at second harvest. Microbial counts were enumerated by serial dilution agar plating technique (Johnson and Curl, 1972) using the media prescribed by Timonin (1940). Microclimatic parameters were recorded weekly in trenches throughout the crop duration. Parameters *viz.*,

CO_2 emission, relative humidity and air temperature by using Easy view® 80 CO_2 analyzer and soil temperature using soil thermometer. The data were subjected to statistical analysis with GRAPES software developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani, Kerala Agricultural University and the significant differences were computed.

Results and Discussion

Growth parameters

The biometric observations recorded in tomato grown in trenches under eCO_2 are presented in the Figs. 1, 2 and Table 3.

Plants were the tallest in T_6 (INM) with 79.33 cm at 90 DAT respectively, but comparable with T_1 (73.16 cm) and T_3 (72.33 cm). The shortest plants were observed in plants manured with vermicompost and poultry manure, T_5 (64.83 cm) at 90 DAT.

Leaf number and LAI also followed similar trends. The number of branches per plant in the trenches was higher in T_4 (FYM + glyricidia) *i.e.*, 12.33. The values were on par with T_6 and T_1 and T_5 recorded the lowest number of branches.

Root growth was the highest in INM (T_6) in terms of root depth (19.92 cm) and root weight (2.90 g) and the values were the lowest in T_5 at all stages.

The performance of the crop varied in trenches with the nutrient management practice and more importantly consequent to the CO_2 evolved by the decomposition of the organic sources added. The INM treatment was found superior on account of the steady supply of nutrients from the chemical and organic source (FYM) used throughout the growth phases. FYM + glyricidia could also elicit better growth owing to the rapid release due to lower C: N ratios with the higher N content in glyricidia being a leguminous crop, compared to the other sources. Use of organic sources for plant nutrition, in addition to the supply of nutrients, serve as sources for CO_2 emission (Shakoor *et al.*, 2021). This is evident from the data on the CO_2 evolution monitored during the study (Table 7). An increase in CO_2 concentration in the plant microclimate recorded positive impacts on growth by its effect on photosynthesis. This increase in growth with CO_2 enrichment observed is in accordance to earlier reports (Bernacchi *et al.*, 2000; Lee-Ho *et al.*, 2007; Li *et al.*, 2007; Mamatha *et al.*, 2014; Minu *et al.*, 2015). But the high CO_2 concentration is also associated with enhanced air and soil temperatures (Fig. 4 and 5), which constrained the growth of tomato as observed in T_5, combination of vermicompost and poultry manure.

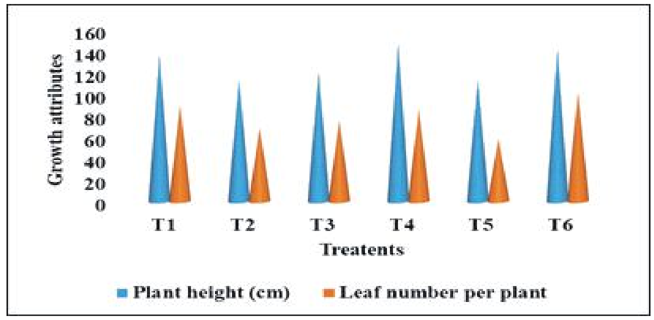

Fig. 1 : Variations in plant height (cm) and number of leaves per plant of tomato under eCO_2 at 90 DAT.

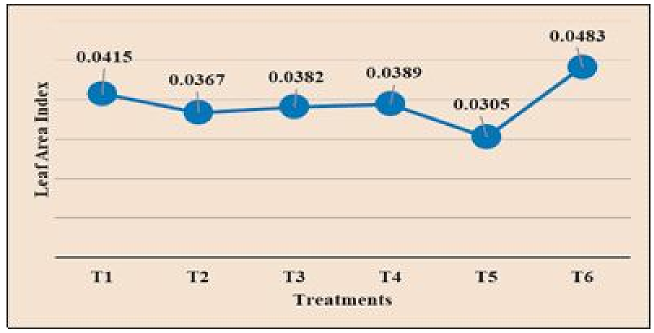

Fig. 2 : Influence of eCO_2 on leaf area index of tomato at 90 DAT.

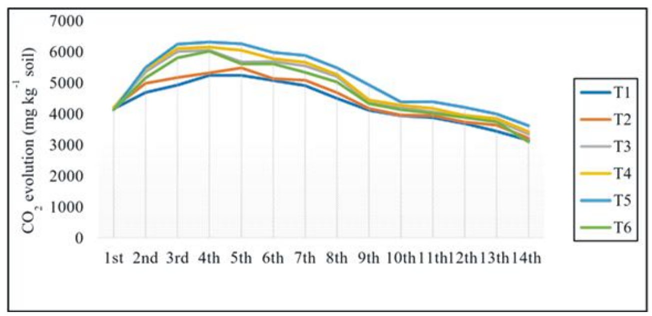

Fig. 3 : Carbon dioxide evolution over crop period.

Physiological Parameters

Perusal of the data on the physiological attributes in Table 4 revealed significantly higher chlorophyll content (1.57 mg g^{-1}) in T_6 on par with T_1 (1.55 mg g^{-1}) and T_2 (1.56 mg g^{-1}). The lowest chlorophyll content (0.92 mg g^{-1}) was recorded in T_5. Photosynthetic rate was found to be decrease with advancing age, irrespective of treatments. It was significantly the highest in T_6 (INM) at 30 and 60 DAT (26.32 and 19.27 µmol CO_2 m^{-2} s^{-1} respectively) followed by T_4 (25.41 and 18.22 µmol CO_2 m^{-2} s^{-1} respectively) and the lowest in T_5 (20.38 and 16.01 µmol CO_2 m^{-2} s^{-1} respectively). The effect of nutrient sources was non-significant at 90 DAT. However, the treatments failed to exert significant influence on stomatal conductance in tomato at all stages of observation.

Changes in external environment of plants impose physiological alterations within them. Chlorophyll content in the plants plays key role in keeping plants green and

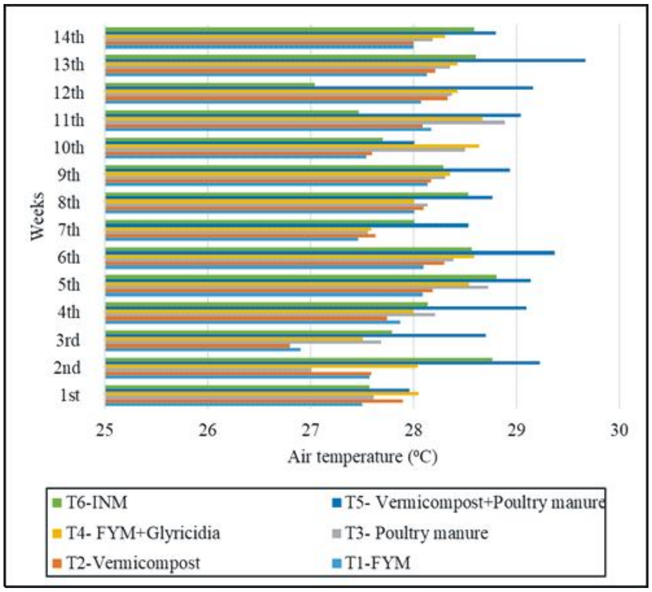

Fig. 4 : Weekly average values of air temperature under eCO_2 conditions, °C.

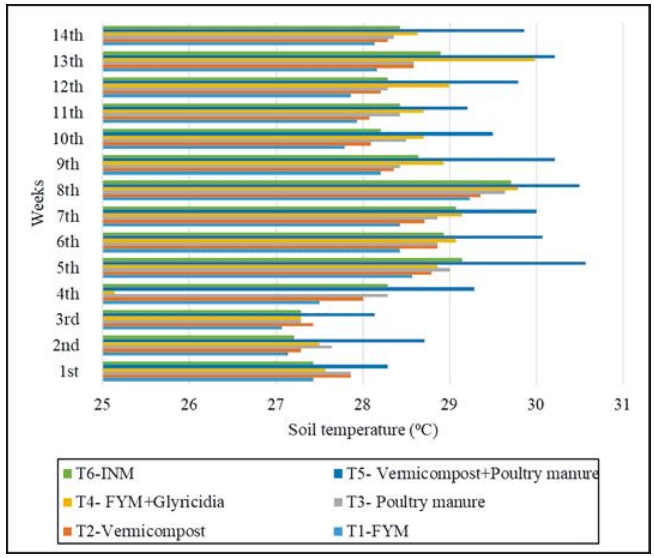

Fig. 5 : Weekly average values of soil temperature under eCO_2 conditions, °C.

an increase with increased CO_2 has been reported (Haque *et al.*, 2005; Chatti, 2016). In contrast despite the higher eCO_2 noted in $T_{5,}$ the chlorophyll content estimated was found lower. This could be ascribed to the increased temperature associated with eCO_2 (Fig. 4 and 5) which would have reduced the total chlorophyll content (Berova *et al.*, 2013).

Enrichment of CO_2 increases plant photosynthetic rates (Taub, 2010; Thompson *et al.*, 2017) and the increase is more pronounced in C_3 plants than in C_4 plants as there is high affinity for the RuBisCO enzyme to increased $CO_{2.}$ This enables it to function even under eCO_2 and further, the higher CO_2 compensation point in C_3 plants leads to increased photosynthesis (Amthor and Loomis, 1996; Poorter *et al.*, 2003). Tomato is a C_3 plant with an inherent mechanism to enhance photosynthesis under eCO_2 concentrations and this is affirmed in the present study. But the increased CO_2 associated with high temperature showed negative effect on photosynthesis rate (Camejo *et al.*, 2005) as recorded in T_5, combination of vermicompost and poultry manure.

Yield Attributes and yield

The data on the yield parameters in tomato are presented in Table 4. The plants manured with FYM (T_1) and INM (T_6) flowered earlier (31.3 and 31.7 days, respectively) followed by those in vermicompost application (T_2). Severe flower drop was observed and fruit set in plants was poor. Hand pollination was done in all the treatments. However, the treatments T_3, T_4 and T_5 failed to set fruits. The average fruit size varied from 4.19 g (T_2) to 12.85 g (T_1) and yield per plant was also low, the highest (63.03 g plant^{-1}) recorded being in T_1 and minimum (16.66 g plant^{-1}) in T_2.

On investigation of the causes of the poor fruit set in the trenches, it was observed that flowering though delayed was satisfactory, but extensive flower drop was seen (Plate 4). Further explorations showed variations in the development of the reproductive structures from that under normal conditions (Plate 2). Tomato, is a self-pollinated crop with flowers having both male and female parts. The stigma is enclosed in the flower, and when pollen falls on the stigma, fertilization process occurs under normal condition (Thomas, 1996). Under eCO_2 conditions, with the associated higher temperatures, stigma can protrude out of flower which it difficult for the pollen to reach the stigma. This was seen in the present experiment (Plate 2). The phenomenon of 'protrusion of stigma' was earlier elucidated by Faruq *et al.* (2012) and Alsamir *et al.* (2021) in tomato. Chatti and Manju (2018) reported that under eCO_2 conditions, reproduction of the plants is more affected than vegetative growth. These were attributed to the adverse effects of eCO_2 on reproductive structures, morphology of flowers, pollen number and pollen viability (Koti *et al.*, 2004; Bergcy *et al.*, 2019; Arunima, 2021). The effect of eCO_2 concentrations becomes detrimental to plant growth due to the increasing temperatures associated with it (John, 2019). This has definitely influenced the plant growth in the trenches. In consonance with the earlier reports, vegetative biomass was higher but reproductive growth was found affected unfavourably. It is also reported that translocation to the sink gets impaired with higher temperatures, an after effect of eCO_2 and hence chances of low yields are high (Zhen *et al.*, 2020).

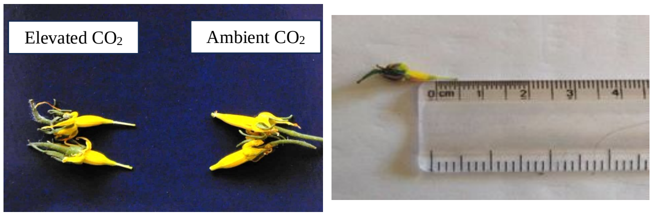

Plate 2 : Protrusion of stigma under eCO_2.

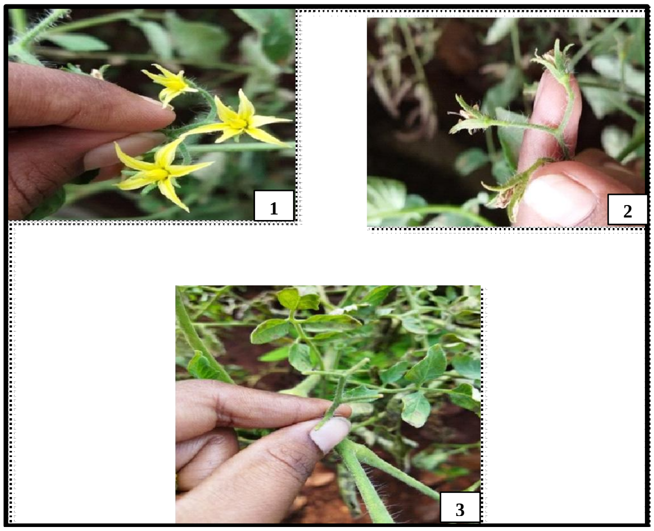

Plate 3 : Flower abortion under eCO_2.

Table 3 : Variations in growth parameters of tomato grown in trenches.

Treatment	Number of branches per plant 90 DAT	Root depth (cm) at harvest	Root weight (g) at harvest
T_1- FYM	10.3	18.41	2.80
T_2- Vermicompost	9.7	16.74	2.45
T_3- Poultry manure	7.7	17.81	2.30
T_4- FYM + glyricidia	12.3	17.91	2.07
T_5- Vermicompost + poultry manure	5.7	15.63	2.05
T_6 - INM	11.3	19.92	2.90
SEm (±)	1.20	0.49	0.08
CD (0.05)	3.703	1.511	0.265

Pressman *et al*. (2002) documented loss of pollen viability, decreased pollen number under eCO_2 and male sterility in tomato when grown under high temperature conditions. However, after receiving pollen produced at 25°C, the sterile male plants were able to produce fruits. Keeping this in mind, hand pollination was done on the plants to overcome the above problem. However, the operation could not yield the favourable results expected, as flower drying and shedding were apparent due to increased temperature within the trenches (Plate 3). Flower abortion was quoted as one major reason to reduce the yield of tomato under eCO_2 environments (Rahman *et al*., 1998; Sato *et al*., 2006; Ruan *et al*., 2010; Rieu *et al*., 2017).

Quality Attributes of fruit

The data on fruit quality parameters are presented in Table 5. INM was found superior. The quality attributes *viz.*, sucrose content (0.67 mg g^{-1} of fresh fruit), ascorbic acid content (25.13 mg 100 g^{-1}), lycopene content (3.21 mg 100 g^{-1}), catalase activity (22.37 units min^{-1} g^{-1}) and ascorbate peroxidase activity (8.80 units min^{-1} g^{-1}) were significantly higher for T_6 and the FYM applied treatment (T_1) recorded the lowest values for fruit quality parameters.

The better availability of the nutrients from the integrated sources would have induced better quality in INM. The effect of eCO_2 on quality has been reported to be positive (Ibrahim and Jaafar, 2012). Plants start to experience heat stress with an increase in temperature and under such situations, they adapt by increasing cell osmotic potential through high production of sugars and carbohydrates. Under eCO_2 condition, a temperature rise has been observed which could have resulted in a higher production of sugars and hence sucrose content. Vitamin C and lycopene content increased with increase in CO_2 (Islam *et al*., 1996; Boufeldja *et al*., 2022).

Antioxidants (catalase, ascorbate peroxidase etc.) are compounds produced by plants in response to external stress? Enrichment of CO_2 resulted in an increased photosynthetic rate and carbohydrate production which can serve as the raw material for production of antioxidants (Ajay, 2019). and hence support the results of the study. However, the variations recorded may need a further detailed investigation on the effect of the different CO_2 concentrations at the different stages of fruit development for a precise reasoning

Soil Microbial counts

The influence of the nutrient management practices on the soil biological properties are depicted in Table 6.

The significantly highest microbial counts were

Table 4 : Influence of eCO_2 on physiology, yield and yield attributes of tomato.

Treatment	Chlorophyll content(mg g^{-1}) at flowering	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})			Stomatal conductance (mmol m^{-2} s^{-1})			Days to 50% flowering	Average fruit weight (g)	Fruit yield per plant (g $plant^{-1}$)
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT			
T_1- FYM	1.55	20.53	17.27	16.76	54.23	48.59	46.37	31.3	12.85	63.0
T_2- Vermicompost	1.56	21.39	16.20	16.08	53.22	48.54	45.73	33.7	4.19	16.7
T_3- Poultry manure	1.48	24.30	17.33	16.22	52.16	47.63	44.81	39.7	0	0
T_4- FYM + glyricidia	1.52	25.41	18.22	16.28	53.12	46.65	43.78	40.3	0	0
T_5- Vermicompost + poultry manure	0.92	20.38	16.01	15.45	52.16	46.60	43.51	41.3	0	0
T_6 - INM	1.57	26.32	19.27	16.90	54.23	48.87	45.75	31.7	4.77	18.9
SEm(±)	0.02	0.75	0.68	0.29	1.07	0.57	0.75	0.5	-	-
CD (0.05)	0.066	2.301	2.099	NS	NS	NS	NS	1.779	-	-

Table 5 : Quality parameters and nutrient uptake of tomato as influenced by nutrient sources under eCO_2.

Treatment	Sucrose content (mg g^{-1})	Ascorbic acid (mg 100 g^{-1})	Lycopene (mg 100 g^{-1})	Catalase (units min^{-1} g^{1})	Ascorbate peroxidase (units min^{-1} g^{-1})	N uptake g $plant^{-1}$	P uptake g $plant^{-1}$	K uptake g $plant^{-1}$
T_1- FYM	0.51	22.13	2.98	19.34	7.30	3.97	0.53	1.75
T_2- Vermicompost	0.56	23.90	3.00	21.19	7.55	3.58	0.46	1.60
T_3- Poultry manure	0	0	0	0	0	2.79	0.42	1.53
T_4- FYM + Glyricidia	0	0	0	0	0	2.39	0.40	1.52
T_5- Vermicompost+ Poultry manure	0	0	0	0	0	2.09	0.37	1.44
T_6 – INM	0.67	25.13	3.21	22.37	8.80	4.00	0.57	1.79
SEm(±)	-	-	-	-	—	0.12	0.02	0.06
CD (0.05)	-	-	-	-	-	0.346	0.050	0.180

Table 6 : Effect of nutrient sources on soil microbial counts under eCO_2 conditions.

Treatment	Bacteria (x 10^6) cfu g^{-1} soil	Fungi (x 10^4) cfu g^{-1} soil	Actinomycetes (x 10^5) cfu g^{-1} soil
T_1- FYM	7.3	3.0	32.7
T_2- Vermicompost	8.3	3.3	33.3
T_3- Poultry manure	9.7	4.7	38.3
T_4- FYM + Glyricidia	12.0	5.3	40.3
T_5- Vermicompost+ Poultry manure	14.0	6.7	45.3
T_6 - INM	7.0	3.0	31.3
SEm (±)	0.4	0.4	2.3
CD (0.05)	1.256	1.110	6.998

Table 7 : Weekly total values of CO_2 evolved in trenches, mg kg^{-1} soil.

Week after planting	T_1- FYM	T_2- Vermicompost	T_3- Poultry manure	T_4- FYM+Glyricidia	T_5- Vermicompost + Poultry manure	T_6- INM
1st	4160	4195	4199	4187	4124	4127
2nd	4684	4978	5352	5443	5489	5154
3rd	4922	5168	6004	6103	6241	5802
4th	5236	5314	6043	6146	6311	6015
5th	5236	5477	5668	6048	6252	5607
6th	5072	5131	5682	5772	5977	5603
7th	4903	5079	5541	5657	5875	5336
8th	4495	4680	5193	5263	5477	5020
9th	4110	4168	4376	4443	4927	4328
10th	3940	3958	4201	4272	4381	4132
11th	3877	3937	4056	4171	4387	4015
12th	3683	3730	3909	3944	4202	3883
13th	3436	3629	3781	3844	3991	3736
14th	3141	3210	3344	3418	3613	3090
Total	60895	62654	67349	68711	71247	65848

enumerated in T_5 (vermicompost and poultry manure), and the lowest counts in T_6. Microbial population is crucial for organic matter decomposition. Application of organic manures augments the soil floral population and diversity (Lazcano *et al.*, 2013) and this will vary with the quantum applied. The organic nutrition treatments were benefitted by the larger quantum and further top dressings with nutrient sources rich in microflora (fermented neem cake solution, vermicompost). Higher decomposition of organic matter and CO_2 evolution are the reflection of higher microbial activity and this is evident as higher microbial population was found in T_5 and lower in INM and T_1 (FYM).

Microclimate

Tables 7 and Figs. 3, 4 and 5 depict the microclimatic parameters recorded in the trenches during the period of the experiment. Among the treatments, vermicompost + poultry manure application (T_5) revealed the highest CO_2 release (71,247 mg kg^{-1} soil) and the least (60,895 mg kg^{-1} soil) was seen in sole FYM treatment, T_1. The CO_2 release declined in the order, $T_5>T_4>T_3>T_6>T_2>T_1$. The data (Fig. 4) recorded reveal that air temperature was comparatively higher in T_5 and the lowest in T_1. The relative humidity in the trenches remained the same in all the treatments, 100 per cent, irrespective of the nutrient sources used for nutrient management in tomato. The soil temperature recorded was comparatively higher in T_5 and was the lowest in T_1.

The quantity of CO_2 emission depends on factors *viz.*, type and amount of soil organic matter, temperature, moisture, microbial activity, etc. Under open conditions, the dilution of CO_2 in the air above occurs whereas, in the trenches that were kept covered from 4.30 pm to 9.30 am daily, on the contrary, it gets trapped enhancing the concentration in the plant microclimate, thus having a prominent role in deciding the plant performance. Nutrient addition through different sources stimulates microbial activity and soil respiration (Salinas-Alcantara *et al.*, 2022).

Plate 4 : Severe flower drop under eCO_2.

Exploring the CO_2 emissions from the different sources, there was a steady increase until the fourth/ fifth week after transplanting (early flowering stage) and later on declined irrespective of the sources used which might be due to reduction in C source for decomposition at later crop stage (Fig. 3). Comparing the CO_2 evolution among the different sources, the total release was maximum in the vermicompost + poultry manure combination (71247 mg kg^{-1} soil). The variations may be attributed to the composition of the materials, soil properties including microbial activity, temperature, moisture content etc. (Thomas and Spurway, 1999). It is also evinced that the N rich poultry manure (1.80%) when added to vermicompost (0.73%) could lower its C: N ratio augmenting mineralisation and respiration through microbial activity. The combined effect would have led to the enhanced CO_2 release recorded in comparison to the other treatments. Green manure application recorded enhanced organic matter degradation and CO_2 emission (Hassan *et al.*, 2013) and the combination of fresh glyricidia leaves, a green manure crop with FYM amplified the CO_2 emission than the sole FYM. Integrated application of organic manures along with chemical fertilizers exhibited a pronounced CO_2 emission than the sole application of organic manures *viz.*, vermicompost (T_2) and FYM (T_1) (Kaur *et al.*, 2005; Ingle *et al.*, 2014; Bhatt *et al.*, 2016) The total CO_2 release followed a trend of $T_5 > T_4 > T_3 > T_6 > T_2 > T_1$.

Rise of CO_2 in environment is associated with rise in temperature (Fecht, 2021) and this fact was proven in the present study. Both soil and air temperature recorded were higher in trenches as compared with the values in open condition (air temperature – 24.84 to 25.80 °C and soil temperature – 2521 to 27. 57 °C) which is in accordance with Arunjith (2021). Concentration of CO_2 was found to be higher in treatment manured with poultry manure and vermicompost (T_5) which made T_5 to evince higher temperatures. Less CO_2 concentration in treatments manured with sole FYM and vermicompost treatment showed lesser temperature (Fig. 4 and 5).

Conclusion

Addition of organic manures in soil enhances the release of CO_2 and it gets amplified with the blending of various organic manures with inorganic sources. Integration of vermicompost and poultry manure (2:1) along with alternate application of vermicompost @ 1 t ha^{-1} and supernatant solution of fermented neem cake @1 kg 10 L^{-1} at 10 days interval upto 2MAP caused greater CO_2 emission, air and soil temperature and microbial activity. This elevated CO_2 greatly influence the tomato growth and yield. Vegetative biomass was found higher for application of FYM + glyricidia leaves (2:1) and in INM. Higher CO_2 concentration adversely affected the reproductive structure and thus fruit yield of tomato. Stigma protrusion and severe flower drop was observed with increased CO_2 associated with higher air and soil temperature. Fruit setting was poor and the artificial pollination could result in higher fruit set and yield in INM, 75:40:25 kg of N, P and K ha^{-1} as chemical fertilizer along with FYM @ 20 t ha^{-1}.

References

Ajay, L.G. (2019). Influence of CO_2 enrichment and associated high temperature on reproductive physiology of tomato (*Solanum lycopersicum* L.) *M.Sc. (Ag) thesis*. Kerala Agricultural University, Thrissur. 191p.

Alsamir, M., Mahmood T., Trethowan R. and Ahmad N. (2021). An overview of heat stress in tomato (*Solanum lycopersicum* L.). *Saudi J. Biol. Sci.*, **28(3)**, 1654-1663.

Amthor, J.S. and Loomis R.S. (1996). Integrating knowledge of crop responses to elevated CO_2 and temperature with mechanistic simulation models: Model components and research needs, In: Koch, G.W. and Mooney H.A. (eds), *Carbon dioxide and Terrestrial Ecosystems*. Academic Press, San Diego, CA. pp. 317-346.

Arunima, A.S. (2021). Management of elevated CO_2 induced high temperature through nutrient and biofertilizer application in tomato (*Solanum lycopersicum* L.) *M.Sc. (Ag) thesis*. Kerala Agricultural University, Thrissur. 130p.

Arunjith, P. (2021). Resource management for source-sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]. *Ph.D. thesis*. Kerala Agricultural University, Thrissur, 245p.

Barber, J.M. (1980). Estimation of Catalase. *Z. Pflazen*, **97**, 135p

Bergcy, K., Nosenko T., Zhou L.Z., Fragner L., Weckwerth W. and Dresselhaus T. (2019). Male sterility in maize after transient heat stress during the tetrad stage of pollen development. *Plant Physiol.*, **181(2)**, 683-700.

Bernacchi, C.J., Coleman J.S., Bazzaz F.A. and Mc Connaughay K.D.M. (2000). Biomass allocation in old-field annual species grown in elevated CO_2 environments: no evidence for optimal partitioning. *Glob. Change Biol.*, **6**, 855-863.

Berova, M., Stoeva N., Zlatev Z. and Ganeva D. (2008). Physiological response of some tomato genotypes (*Lycopersicon esculentum* L.) to high temperature stress. *J. Central Europ. Agric.*, **9(4)**, 723-732.

Bhatt, B., Chandra R., Ram S. and Pareek N. (2016). Long-term effects of fertilization and manuring on productivity and soil biological properties under rice (*Oryza sativa*)–wheat (*Triticum aestivum*) sequence in Mollisols. *Arch. Agron. Soil Sci.*, **62(8)**, 1109-1122.

Boufeldja, L., Brandt D., Guzman C., Vitou M., Boudard F., Morel S., Servent A., DhuiqueMayer C., Ollier L., Duchamp O. and Portet K. (2022). Effect of elevated carbon dioxide exposure on nutrition-health properties of micro-tom tomatoes. *Molecules*, **27(11)**, 1-17.

Camejo, D., Rodriguez P., Morales M.A., Dell'Amico J.M., Torrecillas A. and Alarcon J.J. (2005). High temperature effects on photosynthetic activity of two tomato cultivars with different heat susceptibility. *J. Plant Physiol.*, **162(3)**, 281-289.

Chatti, D. (2016). Carbon dioxide enrichment induced drought tolerance responses in tomato (*Solanum lycopersicum* L.) and amaranthus (*Amaranthus tricolor* L.). *M.Sc. (Ag) thesis*. Kerala Agricultural University, Thrissur. 190p.

Chatti, D. and Manju R.V. (2018). Growth parameters contributing to increased drought tolerance responses in tomato (*Solanum lycopersicum* L.) under elevated carbon dioxide. *J. Pharmacog. Phytochem.*, **7(2)**, 833-837.

DoA & FW [Department of Agriculture & Farmers Welfare] (2022). Final estimates of 2020-21 and first advance estimates of 2021-22 of area and production of horticultural crops [online]. Available: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1810624 [28 March 2022].

Faruq, G., Nezhadahmadi A., Rahman M.M. and Prodhan Z. (2012). Heat tolerance in tomato. *Life Sci. J.*, **99**, 1936-1950.

Fecht, S. (2021). How Exactly Does Carbon Dioxide Cause Global Warming? [on-line] Present: https://news.climate.columbia.edu/2021/02/25/carbon-dioxide-cause-global-warming/ [25 Feb 2021].

Haque, M.S., Karim M.A., Haque M.M., Hamid A. and Nawata E. (2005). Effect of elevated CO_2 concentration on growth, chlorophyll content and yield of mung bean (*Vigna radiata* L. Wilczek) genotypes. *Jpn. J. Trop. Agr.*, **49**, 189-196.

Harris, L.J. and Ray S.N. (1935). Determination of plasma ascorbic acid by 2, 6-dichlorophenol indophenol titration. *Lancet*, **1**, 462.

Hassan, W., Chen W., Cai P. and Huang Q. (2013). Oxidative enzymes, the ultimate regulator: implications for factors affecting their efficiency. *J. Environ. Quality*, **42(6)**, 1779-1790.

Ibrahim, M.H. and Jaafar H.Z. (2012). Impact of elevated carbon dioxide on primary, secondary metabolites and antioxidant responses of *Eleais guineensis* Jacq. (Oil Palm) seedlings. *Molecules*, **17(5)**, 5195-5211.

Ingle, S.S., Jadhao S.D., Kharche V.K., Sonune B.A. and Mali D.V. (2014). Soil biological properties as influenced by long-term manuring and fertilization under sorghum (*Sorghum bicolor*) -wheat (*Triticum aestivum*) sequence in Vertisols. *Indian J. Agric. Sci.*, **84 (4)**, 452-457.

Islam, M.S., Matsui T. and Yoshida Y. (1996). Effect of carbon dioxide enrichment on physicochemical and enzymatic changes in tomato fruits at various stages of maturity. *Scientia Horticulturae*, **65**, 137-149.

John, A.A. (2019). Developing high temperature tolerance in tomato (*Solanum lycopersicum* L.) through selective fertilization technique. *M.S.c. (Ag) thesis*. Kerala Agricultural University, Thrissur. 113p.

Johnson, L.F. and Curl E.A. (1972). *Methods for Research in the Ecology of Soil Borne Plant Pathogen*. Burgers publication Co., Minneapolis, 247p.

KAU [Kerala Agricultural University] (2016). *Package of Practices Recommendations: Crops* (15^{th} Ed.). Kerala Agricultural University, Thrissur, 392p.

Kaur, K., Kapoor K.K. and Gupta A.P. (2005). Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. *J. Plant Nutr. Soil Sci.*, **168(1)**, 117-122.

Koti, S., Reddy K.R., Kakani V.G., Zhao D. and Reddy V.R. (2004). Soybean (*Glycine max*) pollen germination characteristics, flower and pollen morphology in response to enhanced ultraviolet-B radiation. *Ann. Bot.*, **94(6)**, 855-864.

Lazcano, C., Gomez-Brandon M., Revilla P. and Dominguez J. (2013). Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function. *Biol. Fertil. Soils*, **49(6)**, 723-733.

Lee-Ho, E., Walton L.J., Reid D.M., Yeung E.C. and Kurepin L.V. (2007). Effects of elevated carbon dioxide and sucrose concentrations on *Arabidopsis thaliana* root architecture and anatomy. *Can. J. Bot.*, **85**, 324–330.

Li, J., Zhou J.M. and Duan Z.Q. (2007). Effects of elevated CO_2 concentration on growth and water usage of tomato seedlings under different ammonium/nitrate ratios. *J. Environ. Sci.*, **19(9)**, 1100-1107.

Mamatha, H., Rao N.K., Laxman R.H., Shivashankara K.S., Bhatt R.M. and Pavithra K.C. (2014). Impact of elevated CO_2 on growth, physiology, yield, and quality of tomato (*Lycopersicon esculentum* Mill) cv. Arka Ashish. *Photosynthetica*, **52(4)**, 519-528.

Minu, M., Manju R.V., Stephen R., Reshma R.B. and Viji M.M. (2015). Effect of elevated CO_2 on growth and development of black pepper varieties. *J. Plant Sci. Res.*, **31**, 179182.

Nakano, Y. and Asada K. (1981). Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. *Plant Cell Physiol.*, **22(5)**, 867-880.

NOAA [National Oceanic and Atmospheric Administration] (2024). Global Monitoring Laboratory: Trends in atmospheric carbon dioxide. Present: https://gml.noaa.gov/ccgg/trends/ [05 July 2022].

Ozores-Hampton, M. (2014). Hand Pollination of Tomato for Breeding and Seed Production1. *Univ. Florida Inst. Food Agric. Sci.*, **HS1248**, 1-4.

Poorter, H., Hendrik and Navas M. (2003). Plant growth and competition at elevated CO_2: on winners, losers and functional groups. *New Phytologist*, **157(2)**, 175-198.

Pressman, E., Peet M.M. and Pharr M. (2002). The effect of heat stress on tomato pollen characteristics is associated with changes in carbohydrates concentration in the developing anthers. *Annals Bot.*, **90**, 631-636.

Rahman, S., Nawata E. and Sakuratani E. (1998). Effects of temperature and water stress on growth, yield and physiological characteristics of heat-tolerant tomato. *Jpn. J. Trop. Agric.*, **42**, 46-53.

Ranganna, S. (1976). *Manual of Analysis of Fruits and Vegetable Products*. McGraw Hill, New Delhi, 77p.

Rieu, I., Twell D. and Firon N. (2017). Pollen development at high temperature: from acclimation to collapse. *Plant Physiol.*, **173(4)**, 1967-1976.

Ruan, Y.L., Jin Y., Yang Y.-J., Li G.-J. and Boyer J.S. (2010). Sugar input, metabolism, and signaling mediated by invertase: roles in development, yield potential and response to drought and heat. *Mol. Plant*, **3 (6)**, 942-955.

Sadatshojaei, E., Wood D.A. and Rahimpour M.R. (2022). Potential and challenges of carbon sequestration in soils. In: Inamuddin, Ahamed M.A., Boddula R. and Altalhi T. (eds.). *Applied Soil Chemistry*, Scrivener publishing LLC. pp. 1-21.

Salinas-Alcantara, L., Vaca R., del Aguila P., de la Portilla-Lopez N., Yanez-Ocampo G., Sanchez-Paz L.A. and Lugo J.A. (2022). Impact of tillage and fertilization on CO_2 emission from soil under maize cultivation. *Agric.*, **12(555)**, 1-12.

Sato, S., Kamiyama M. and Iwata T. (2006). Moderate increase of mean daily temperature adversely affects fruit set of *Lycopersicon esculentum* by disrupting specific physiological processes in male reproductive development. *Ann. Bot.*, **97**, 731-738.

Shakoor, A., Shakoor S., Rehman A., Ashraf F., Abdullah M., Shahzad S.M., Farooq T.H., Ashraf M., Manzoor M.A., Altaf M.M. and Altaf M.A. (2021). Effect of animal manure, crop type, climate zone and soil attributes on greenhouse gas emissions from agricultural soils-A global meta-analysis. *J. Cleaner Prod.*, **278**, 1-13.

Taub, D. (2010). Effects of rising atmospheric concentrations of carbon dioxide on plants. *Nature Educ. Knowl.*, **3(10)**, 21.

Thomas, L.R. (1996). Tomato anatomy : Fruits and flowers. Section of Plant Biology Division of Biological Sciences, University of California, Davis. Available on: https://labs.plb.ucdavis.edu/rost/Tomato/Reproductive/flrfert.html.

Thomas, M.B. and Spurway M.I. (1999). A review of factors influencing organic matter decomposition and nitrogen immobilisation in container media. In: *The International Plant Propagators' Society Combined Proceedings*, **48**, 66-71.

Thompson, M., Gamage D., Hirotsu N., Martin A. and Seneweera S. (2017). Effects of elevated carbon dioxide on photosynthesis and carbon partitioning: a perspective on root sugar sensing and hormonal crosstalk. *Front. Physiol.*, **8 (578)**, 1-13.

Timonin, M.I. (1940). The interaction of higher plants and soil micro-organisms: i. Microbial population of rhizosphere of seedlings of certain cultivated plants. *Canadian J. Res.*, **18(7)**, 307-317.

Xu, W., Cui K., Xu A., Nie L., Huang J. and Peng S. (2015). Drought stress condition increases root to shoot ratio via alteration of carbohydrate partitioning and enzymatic activity in rice seedlings. *Acta. Physiol. Plant*, **37(2)**, 1-11.

Zhen, F., Liu Y., Ali I., Liu B., Liu L., Cao W., Tang L. and Zhu Y. (2020). Short-term heat stress at booting stage inhibited nitrogen remobilization to grain in rice. *J. Agric. Food Res.*, **2**, 1-10.