Influence of open and polyhouse conditions on soil carbon dioxide emission from *Amaranthus* plots with different nutrient management practices under changing climate scenario

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A field study was conducted using *Amaranthus* to assess the impact of increased temperature in polyhouse with three different treatments, viz. 100% organic, 100% inorganic and 50% organic + 50% inorganic nutrition on growth, yield and carbon dioxide (CO_2) evolution compared to that of open natural condition. Among the different treatments applied, 100% application of organic manure resulted in maximum CO_2 emission in both open (538 mg) and polyhouse conditions (551 mg). The lowest value of CO_2 evolution (266 mg) was observed with 100% application of inorganic fertilizers under polyhouse conditions. In all the three treatments, CO_2 evolution almost reached a plateau and stabilized during the last two observations. At the last interval, CO_2 evolution ranged from 4.00 to 6.80 mg in all the treatments. However, cumulative CO_2 evolution showed that the emission was higher under open natural conditions (434 mg) compared to the polyhouse conditions (398 mg) at elevated temperature. This indicated that the microbial respiration was higher under natural conditions. Ambient air temperature and soil temperature were higher under polyhouse condition than open natural condition. However, soil moisture was higher under open condition than polyhouse condition for most observations. It could be observed from the experiment that *Amaranthus* production declined with increase in temperature, and maximum yield was obtained with 100% application of organic manure under open condition. Under elevated temperature condition in polyhouse, 50% application of inorganic fertilizer + 50% application of organic manure (T_3) registered the maximum crop production. This suggests that sufficient mitigation strategies need to be adopted for sustaining crop production under changing climate scenario.

Keywords: *Amaranthus*, carbon dioxide emission, crop productivity, soil temperature.

CHANGE in climate across the globe has emerged as one of the most prominent environmental issues and is a long-term threat to the ecosystem. Global average temperature rose by 0.8°C in the past 120 years, and is projected to be higher by 3–7°C by the next century under the existing practices[1]. Falling in line with the global trend, for India also IPCC has predicted a scaling-up of temperature by 0.5–1.2°C by 2020, 0.88–3.16°C by 2050 and 1.56–5.44°C by 2080 (ref. 1). For Kerala, the past 49 years data showed an increase of 0.64°C, 0.23°C and 0.44°C with respect to maximum, minimum and mean atmospheric temperature[2]. Another season-wise study by the Centre for Water Resources Development and Management (CWRDM), Kozhikode, exhibited an increasing trend of 0.60°C and 0.55°C during winter and summer respectively, for the past 27 years[3,4]. The inferences from these studies established the change in climate and its variability. Even though these changes will exacerbate serious issues in many sectors, agriculture is the foremost and predominant one, as it is linked to the basic need of future food security[4]. In most productive regions of the world, crop yield/productivity has reached a plateau or is even declining[5]; the likely impact of climate change on crop production adds to this already complex problem. The elevated levels of carbon dioxide (CO_2), temperature, difference in diurnal variation linked with the vulnerabilities associated with rainfall/precipitation, such as drought and flood will have a detrimental effect on the agriculture sector.

Crop production in terms of biomass and productivity is likely to reduce with elevated temperature, as increase in temperature decreases the crop cycle, improves the rate of respiration along with the reduced time for interception of radiation[6]. Influence of extremely high temperature, heat, frost and cold injury in wheat (*Triticum aestivum* L.) has been reviewed recently[7]. The study showed that heat and high temperature triggered a decrease in yield by reducing the number of grains produced and also shortening the maturity phase, whereas low temperature (frost) makes sterility in wheat and deformation of produced grains resulting in reduction of wheat productivity[7]. A worldwide assessment on yield of several crops for the last 20 years (1981–2002) showed that every year, approximately US$ 5 billion is being lost because of the negative impacts of increase in temperature on cereal crops such as barley, maize and wheat[8,9]. These earlier studies suggested that there exists a great challenge because of the rise in temperature and extreme climate events on future food security and sustainable agriculture.

However, it is a challenging task to understand the possible effect of increase in temperature on crop growth and yield, since each crop and its species need specific agro-climatic requirements that largely vary depending on other management practices also. Warming temperature associated with climate change will affect plant growth and development along with crop yield[10]. In the tropical region, apart from the reduction in crop yield,

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soil organic carbon (SOC) is rapidly being mineralized due to changes in climatic conditions, such as high temperature, aeration, moisture and increase in precipitation events. Breakdown and mineralization of soil organic matter (SOM) are largely governed by ecological climatic factors apart from soil moisture and temperature; a favourable condition will result in enhanced decomposition of SOM, and production and emission of CO_2 from agricultural lands[11]. Atmospheric and soil temperatures have a positive correlation with the emission of CO_2 from cultivated agricultural soils and even in natural conditions[12]. Losses of CO_2 and methane will be more when the soil temperature is increased, and this increase is due to the accelerated activity of soil microbes in the rhizosphere area and roots of plants[13].

In humid tropical Kerala also a clear rising pattern was seen with respect to atmospheric temperature, both minimum and maximum[3,4]. This will have an effect on soil carbon dynamics, since several soil reactions or functions are either directly or indirectly associated with temperature (because of its capability to retain water and nutrients). The primary reason attributed for the increase in temperature is due to the emission of CO_2 and other greenhouse gases[14]. At this stage, it is essential to understand the mechanisms that induce the soil carbon stability and C sequestration in any environment/ecosystem; this will help us develop approaches/strategies to improve the SOM.

Precision farming under polyhouse conditions is also gaining importance in Kerala and C dynamics under such a situation is seldom evaluated. Hence, with this background we studied the effects of elevated temperature on growth and yield of *Amaranthus* and their influence CO_2 evolution status under both open and polyhouse conditions.

The study was conducted in the R&D field area of Agricultural Water Management Division, CWRDM, Kozhikode. *Amaranthus* is a popular leafy vegetable in Kerala and pure seeds were purchased from the Agricultural Research Station (ARS), Kerala Agricultural University (KAU), Thrissur. Agronomic practices from land preparation to harvest were carried out according to the package of practices (POP)-recommendation of KAU. FAO–CROPWAT software was used for water requirement and scheduling of irrigation using drip irrigation method.

Nutrient management practice treatment comprises of (i) 100% application of organic manure (T_1); (ii) 100% application of inorganic fertilizers (T_2) and (iii) 50% application of inorganic fertilizers + 50% application of organic manure (T_3), these were tested under open and polyhouse conditions. Recommended dose of fertilizers by KAU are 100 : 50 : 50 kg of N, P and K. These nutrients were applied to the individual treatments based on the nutrient content present in the organic manure and inorganic fertilizers.

Several designs of field chambers were used to assess the influence of elevated temperature on crop biometry (phenology) and yield of plants. To simulate the polyhouse conditions, 1 sq. m closed chamber polyhouses were constructed and used for the study. Elevated temperature is possible under these polyhouses, because they trap heat from sunlight in the daytime and hold this increased temperature during night, since they are covered with poly-sheets. UV-stabilized polythene sheets and GI wires were used for the construction of closed polyhouses. The polyhouse chambers were used to cover the crops and these are easily movable structures. On an average, air temperature difference inside and outside the polyhouse was about 2.0–6.0°C.

Soil temperature, atmospheric temperature and humidity were measured using standard instruments in both open and polyhouse conditions. Soil moisture was also monitored using continuous soil moisture probe (ITC Ltd, Australia). Crop biometric data on the number of leaves, plant height (cm), shoot and root weight (units) were recorded at 10 days interval after planting and at final harvest. Raw data were processed for mean values from the replications and used for statistical analysis by IN STAT software V. 3.36 for different tests.

Using the standard method of alkali trap, CO_2 emission from soil was calculated[15]. In this method alkali solution (NaOH/KOH) was used to trap the emitted CO_2 by adding barium chloride ($BaCl_2$) in excess and the evolved CO_2 is precipitated as $BaCO_3$. Briefly, known concentration of NaOH solution was kept in an open jar on the surface soil, and the intended area of target was covered with another jar which was closed from the top. The same was replicated for the control; however, in control area, the alkali-incubated jar did not have any direct interaction with the soil because it was sealed. Figure 1 shows a schematic diagram of the experiment. The alkali solutions used to trap the emitted CO_2 were back-titrated to quantify the amount of NaOH that has not reacted with CO_2 in both the control, i.e. no direct contact with the soil, and those remaining in contact with the soil. The amount of CO_2 emitted from the soil during contact with alkali was

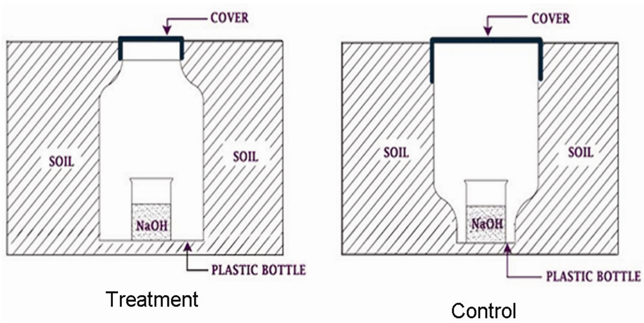

Figure 1. Schematic diagram of CO_2 evolution experiment carried out in control and treatment.

calculated using eq. (1) below. CO_2 evolution study was done at periodical intervals of 1, 2, 4, 8, 10, 15 and 30 days.

$$\text{Milligrams of } CO_2 = (B - V)NE, \quad (1)$$

where B is the titration value of control; V the titre value of sample; N the normality of HCL and E is the equivalent weight of CO_2.

The experimental field soil belongs to laterite type and is known as Kunnamangalam soil series. The soil falls under the category of Mixed; Isohyperthermic, Typic Kanhaplustults according to USDA taxonomy. The texture of the soil is sandy loam having 62%, 20% and 18% of sand, silt and clay respectively. Chemically the surface soils fall under extremely acidic category (pH of 4.05), are high in organic carbon (2.38%), and medium in plant available nitrogen, phosphorus and potassium with the values of 288.8, 19.0 and 182 kg ha^{-1} respectively. The soil has 153 mg kg^{-1} calcium, 150 mg kg^{-1} magnesium and 1.93 mg kg^{-1} boron. The average values of these nutrients showed that the experimental plot is more or less uniform in initial soil fertility conditions, even though they are heterogeneous. However, the soil showed significant differences between depths with subsurface soils (15–30 cm and 30–45 cm) showing declining values for most of the available nutrients. With respect to other physical properties, bulk density (BD) of surface soil sample showed a value of 0.95 and subsurface soil had a value of 1.07 g/cm^3. As reported earlier, BD usually increases with soil depth as subsurface layers have reduced organic matter, aggregation and root entrance in contrast with surface layers and accordingly, contain less pore space. Subsurface layers are also subject to the compacting weight of the surface soil above them. Less pore space in the subsurface is additionally evident from the results[16–18]. Figure 2 shows the meteorological parameters recorded during the experimental period. The recorded mean maximum and minimum temperatures during the experimental period were 30.6°C and 22.5°C respectively.

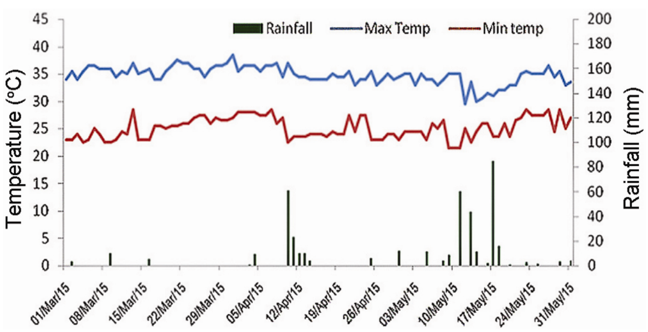

Figure 2. Maximum and minimum temperature and rainfall observed during the experiment.

Figure 3 shows average CO_2 evolution (mg) from the *Amaranthus* plot for different nutrient management practices in open and polyhouse conditions at definite frequency intervals of 1, 2, 4, 6, 8, 10 and 15 days. The results show that CO_2 evolution is highest at one-day interval than the others, irrespective of the treatments. T_1 (100% organic) and T_2 (100% inorganic) treatments recorded the maximum value of CO_2 evolution (mg) under open conditions, whereas T_3 (50% organic + 50% inorganic) recorded the peak value of CO_2 evolution under polyhouse condition at one-day interval. Under polyhouse conditions, CO_2 evolution declined sharply in for one- and two-day intervals, which is not observed in open conditions. This may be because elevated temperature up to 6°C could have caused sudden shock to the microbial population and deleterious effect on the microbial activities, and hence decomposition and release of CO_2 might have been hampered. However, after two days the microbes might have adapted to the conditions and decomposition might have increased; even then CO_2 evolution was lesser in polyhouse conditions of elevated temperature than open condition. In all the three treatments after 10 and 15 days interval, CO_2 evolution almost reached a plateau and stabilized. At the last interval, CO_2 evolution had values of less than 10.0 mg in all the treatments. The values ranged from 4.00 to 6.80 mg of CO_2.

This indicates that the applied nutrients might have been mineralized and CO_2 evolution may have reached

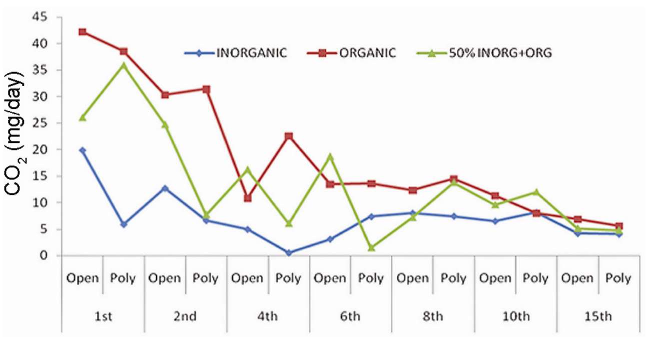

Figure 3. Average CO_2 evolution (mg) for different treatments under open and polyhouse conditions.

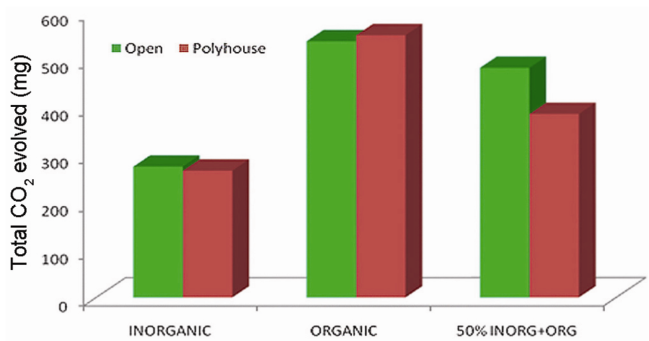

Figure 4. Total CO_2 evolution (mg) for different treatments under open and polyhouse conditions.

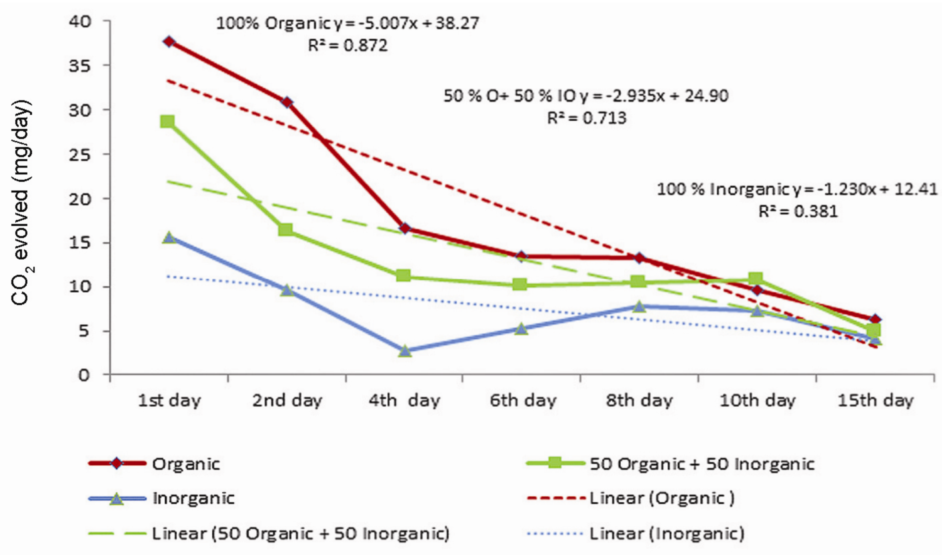

Figure 5. CO_2 evolution (mg) for different nutrient management treatments.

stabilized values after 15 days (i.e. after 45th day of initiation of the experiment). This is in accordance with findings from earlier studies which established a positive correlation on CO_2 evolution by respiration of microbes and soil temperature[19,20]. Some studies have confirmed that respiration from soil will stabilize with elevated temperature at a particular level in natural ecosystems[21,22]. The reasons discussed are probable changes in community arrangement of these microbes, which have an influence on the whole microbial sensitivity to temperature[23]; changes in availability of substrate linked with associated differences in water and temperature of the soil[24]; reduction in quantity and quality of crop residues with respect to time[25], and alteration in relative quantity of labile pool of carbon to that of SOC[26]. By considering all these points, the reasons for adjustment of microbial respiration from soil in this study to increased temperature could be a mixture of many factors in each treatments. However, this needs to be studied in detail to find the mechanisms behind and explain in detail about the relationship between temperature and soil respiration.

Figure 4 shows cumulative CO_2 evolution from the *Amaranthus* plot for different organic and inorganic treatments in open and polyhouse conditions. The results demonstrate that maximum CO_2 evolution (551 mg) was observed with 100% application of organic manure under polyhouse conditions. This was followed by the same treatment under open cultivation conditions with a value of 538 mg. The lowest value of CO_2 evolution (266 mg) was observed with 100% application of inorganic fertilizers under polyhouse conditions. This is because under 100% application of organic manures, it was applied in higher quantities in bulk and hence mineralization and decomposition of SOM might have resulted in greater CO_2 evolution[17,26]. However, with respect to 100% application of inorganic fertilizers, the quantity applied was less and hence the CO_2 evolution values were less. This is because the readily available inorganic nutrients applied in the root zone might have resulted in enhanced plant uptake of nutrients[16–18] and hence the readily available nutrients for decomposition and mineralization of organic matter might be less, resulting in lower CO_2 evolution (mg) values. This is evident from the regression equations in Figure 5, where the R^2 values are higher under 100% organic (0.872) than the other two nutrient management practices.

Cumulative CO_2 evolution from the *Amaranthus* plot showed that emission was higher under open natural conditions (434 mg) compared to polyhouse conditions (398 mg). This indicated that the microbial respiration was higher under natural conditions and this confirms that CO_2 evolution is affected by variation in structural community of microbes; sensitivity of temperature by microbes, difference in availability of substrates; alteration in soil temperature and water content, changes in soil properties, etc.[26,27]. This confirmed the fact that in polyhouse because of the elevated temperature, microbial respiration might have hampered for the initial days and recovered after the acclimations to the polyhouse conditions, which might have resulted in less quantity of CO_2 evolution under ployhouse conditions.

Figure 6 shows soil temperature from the experimental plots under open cultivated and polyhouse conditions on a daily basis during the experimental period. Soil temperature for surface soil of 0–15 cm depth ranged between 25.2°C and 30.2°C for open cultivated conditions and between 26.7°C and 31.2°C for polyhouse conditions. In general, the polyhouse condition registered higher soil temperature compared to the open cultivated condition. The soil temperature might have increased under polyhouse condition because of the high ambient air temperature inside the polyhouse. Barnard and Leadley[28] showed that the response of denitrification to temperature was positive under laboratory conditions, whereas it was opposite in the case of field and mesocosm experiments, signifying an adaptation of microbes favouring denitrification to temperature over time and natural field conditions. This emphasizes the requirement for continuous field studies on the influence of climate change and weather variability on soil microbial population, which is the basic prerequisite for nutrient cycling in soils. It will help researchers assess whether acclimatization/adaptation is really occurring in natural environment, and if so, what are all the processes involved in such adaptation.

From the present study, it can be inferred that increase in temperature along with sufficient source of organic manure as substrate increased the CO_2 evolution rate and total cumulative evolution (Figures 4 and 5) under polyhouse conditions.

Figure 7 presents soil moisture from the experimental plots measured using continuous soil moisture probe under open cultivated and polyhouse conditions during the experimental period. The results indicate that soil moisture is higher under open condition compared to polyhouse condition in most of the observations. Under polyhouse condition on some days it has reduced drastically. This is in contrast with the general observation that under polyhouse condition, soil moisture is high compared to open condition. However, in this study, since it is a small structure of 1 sq. m, the increase in ambient air temperature inside the polyhouse and high soil temperature might have increased evaporation loss, thereby reducing soil moisture. All these factors might have contributed to the low productivity under polyhouse condition compared to open condition.

The biometric results showed non-significant improvement between the open and polyhouse conditions up to the second observations with plant height and number of leaves respectively. However, from the third to final observation open condition performed better and it was statistically significant compared to polyhouse condition in both plant height and number of leaves respectively (Table 1).

Table 2 presents results of root and shoot weight of *Amaranthus*. Both mean root and shoot weights were higher in the case of open cultivated plants and were statistically significant compared to polyhouse cultivated plants. Mean shoot and leaf yield of *Amaranthus* was reduced by 20.4% under polyhouse conditions compared to open conditions (Table 2). The temperature data revealed that it was higher under polyhouse chamber, on some days it went up to 6°C higher than the open condition. Crop production with respect to the entire biomass and productivity may likely be affected with increase in temperature, since under elevated/increased temperature crop length will be shortened, respiration will be enhanced and radiation interception will decline ultimately resulting in lower yield (Figure 8).

Increase in average temperature above the climatic requirement of crops will have a definite impact and reduction in crop yield/productivity and this has been confirmed by earlier studies. A study from Punjab, India using paddy showed that the rice grain yield would be affected to the tune of 5.4%, 7.4% and 25.1% when the increase in temperature is 1°C, 2°C and 3°C respectively, keeping all other weather parameters stable[29].

In the case of nutrient management practices, nutrients supplied through 100% organic sources performed better

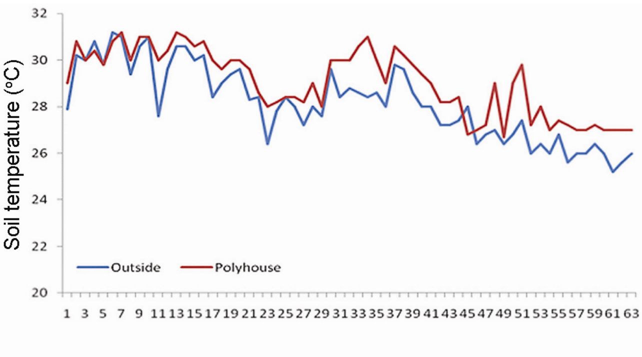

Figure 6. Soil temperature at depth of 15 cm under open and polyhouse conditions.

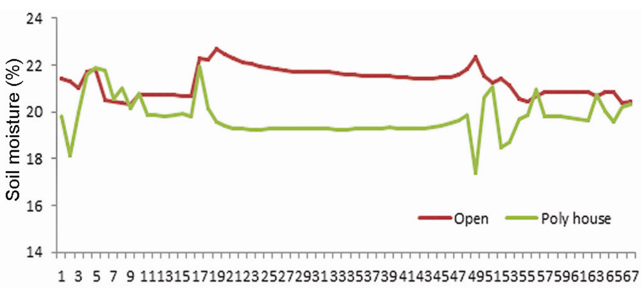

Figure 7. Soil moisture under open and polyhouse conditions.

Figure 8. Photograph showing plant height variations of *Amaranthus* under open and polyhouse conditions in the field.

Table 1. Plant height and number of leaves of *Amaranthus* under open and polyhouse conditions

	Plant height			Number of leaves		
Observations	Open	Polyhouse	*t* stat	Open	Polyhouse	*t* stat
First	5.8	4.8	NS	4.8	4.1	NS
Second	11.0	10.3	NS	8.3	7.2	NS
Third	32.3	28.5	S	32.7	18.0	S
Fourth	64.5	58.7	S	69.6	42.1	S
Fifth	95.9	81.8	S	81.9	62.0	S

NS, Nonsignificant; S, Significant.

Table 2. Influence of nutrients and elevated temperature on *Amaranthus* – root and shoot weight

	Root weight (g)				Shoot + leaves weight (g)			
Treatment	Open	Polyhood	Mean	SEd	Open	Polyhood	Mean	SEd
T_1, Organic – 100%	12.69	3.70	8.20	0.45	82.72	33.23	57.98	1.45
T_2, Inorganic – 100%	5.05	5.74	5.40		40.95	49.92	45.44	CD ($P = 0.05$)
T_3, 50% organic + 50% inorganic	5.43	8.41	6.92	CD ($P = 0.05$)	37.58	50.78	44.18	3.06
Mean	7.72	5.95	6.84		53.75	44.64	49.20	
SEd	0.36	1.21	SEd	1.56				
CD (P=0.05)	0.82		CD ($P = 0.05$)	3.24				

in root and shoot weight; it was significant statistically over the other two treatments. Earlier studies on leafy vegetables also indicated that they prefer organic source of nutrients or organic manure complimented with inorganic fertilizers than the use of inorganic fertilizers alone[30,31]. However, T_2 and T_3 showed statistically on par values with respect to shoot weight and significant values for root weight. These results conflict with the shoot and leaf weight; the probable reason for this might be the difference in photosynthates partitioning between the different plant parts. The root : shoot ratio showed that allocation of biomass from root to shoot is more and hence better quantity of shoots achieved in the study indicated that is economically viable, since shoot is the economically important part of *Amaranthus*.

In general, mean shoot and leaf yield was higher under open condition than polyhouse condition and it was statistically significant; however, the individual nutrient management treatment showed different results between open and polyhouse conditions. Except nutrients supplied through 100% organic sources, the other two treatments showed higher shoot and leaf weight for polyhouse condition at increased temperature than open condition. This indicated that under increased temperature, the readily available nutrients supplied through inorganic fertilizers under polyhouse condition might have contributed to higher growth in shoot and leaf. This confirms the fact that yield can be improved even under adverse climate conditions, if the adaptation strategies with nutrient/water management practices are followed.

A field experiment conducted with *Amaranthus* to assess the impact of increased temperature in polyhouse with three different treatments, viz. 100% organic, 100% inorganic and 50% organic + 50% inorganic nutrition compared to that of open natural condition showed that crop production declined with increase in temperature under polyhouse conditions.

- Maximum *Amaranthus* yield was obtained with 100% application of organic manures (T_1) under open condition.
- In polyhouse condition, maximum *Amaranthus* yield was obtained with 50% application of inorganic fertilizers + 50% application of organic manures (T_3).
- Mean yield decline of 20.4% was noticed under polyhouse conditions than the open condition. However, with inorganic fertilizer and 50% organic + 50% inorganic fertilizers, the recorded yield was higher under polyhouse condition than open conditions.
- The yield can be improved even under adverse climate conditions, if adaptation strategies with nutrient management practices are followed.
- Among the different treatments applied, 100% application of organic manure resulted in maximum CO_2 emission in both open (538 mg) and polyhouse (551 mg) conditions.
- The lowest value of CO_2 evolution of 266 mg was observed with 100% application of inorganic fertilizers under polyhouse condition.

Thus sufficient and proper mitigation strategies need to be adopted for sustaining crop production under changing climatic scenario.

1. IPCC, Summary for Policymakers. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Solomon, S. D. *et al.*), Cambridge University Press, Cambridge, UK, 2007.
2. Rao, G. S. L. H. V., Kesava Rao, A. V. R., Krishnakumar, K. N. and Gopakumar, C. S., Impact of climate change on food and plantation crops in the humid tropics of India. In ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture, 2009, p. 127.
3. Surendran, U., Sushanth, C. M., Mammen, G. and Joseph E. J., Modeling the impacts of increase in temperature on irrigation water requirements in Palakkad district – a case study in humid tropical Kerala. *J. Water Climate Change*, 2014, **5**, 471–487.
4. Surendran, U., Sushanth, C. M., Mammen, G. and Joseph, E. J., FAO-CROPWAT model-based estimation of crop water need and appraisal of water resources for sustainable water resource management: pilot study for Kollam district – humid tropical region of Kerala, India. *Curr. Sci.*, 2017, **112**, 76–86.
5. Pathak, H., Ladha, J. K., Aggarwal, P. K., Peng, S., Das, S. and Singh, Y., Climatic potential and on farm yield trends of rice and wheat in the Indo-Gangetic plains. *Field Crops Res.*, 2003, **80**, 223–234.
6. Rawson, H. M., Gifford, R. M. and Condon, B. N., Temperature gradient chambers for research on global environment change. I. Portable chambers for research on short stature vegetation. *Plant Cell Environ.*, 1995, **18**, 1048–1054.
7. Barlow, K. M., Christy, B. P., O'Leary, G. J., Riffkin, P. A. and Nuttall, J. G., Simulating the impact of extreme heat and frost events on wheat crop production: a review. *Field Crops Res.*, 2015, **171**, 109–119.
8. Lobell, D. B. and Field, C. B., Global scale climate–crop yield relationships and the impacts of recent warming. *Environ. Res. Lett.*, 2007, **2**, 014002; doi:10.1088/1748-9326/2/014002.
9. Lobell, D. B., Schlenker, W. and Costa-Roberts, J., Climate trends and global crop production since 1980. *Science*, 2011, **333**, 616–620.
10. Hatfield, J. L. and Prueger, J. H., Temperature extremes: effect on plant growth and development. *Weather Climate Extr.*, 2015, **10**, 4–10.
11. Rustad, L. E., Huntington, T. G. and Boone, R. D., Controls on soil respiration: implication for climate change. *Biogeochemistry*, 2000, **48**, 1–6.
12. Raich, J. W., Potter, C. S. and Bhagavatti, D., Interannual variability in global soil respiration, 1980–94. *Global Change Biol.*, 2002, **8**, 800–812.
13. Pendall, E. *et al.*, Below-ground process responses to elevated CO_2 and temperature: a discussion of observations, measurement methods and models. *New Phytol.*, 2004, **162**, 311–322.
14. Solomon, S., Plattner, G. K., Knutti, R. and Friedlingstein, R., Irreversible climate change due to carbon dioxide emissions. *Proc. Natl. Acad. Sci. USA*, 2009, **106**, 1704–1709.
15. Coleman, D. C., Anderson, R. V. and Cole, C. V., Tropic interactions in soils as they affect energy and nutrient dynamics. IV. Flows of metabolic and biomass carbon. *J. Microb. Ecol.*, 1978, **4**, 373–380.
16. Surendran, U. and Vani, D., Influence of arbuscular mycorrhizal fungi in sugarcane productivity under semi arid tropical agro ecosystem. *Int. J. Plant Prod.*, 2013, **7**, 269–278.
17. Surendran, U., Ramasubramoniam, S., Raja, P., Kumar, V. and Murugappan, V., Budgeting of major nutrients and the mitigation options for nutrient mining in semi arid tropical agro ecosystem of Tamil Nadu, India using NUTMON model. *Environ. Monitor. Assess*, 2016, **188**, 1–17.
18. Surendran, U., Ramesh, V., Jayakumar, M., Marimuthu, S. and Sridevi, G., Improved sugarcane productivity with tillage and trash management practices in semi arid tropical agro ecosystem in India. *Soil Till. Res.*, 2016, **158**, 10–21.
19. Eliasson, P. E., McMurtrie, R. E. and Pepper, D. A., The response of heterotrophic CO_2 flux to soil warming. *Global Change Biol.*, 2005, **11**, 167–181.
20. Fang, C. *et al.*, Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature*, 2005, **433**, 57–59.
21. Melillo, J. M., Steudler, P. A. and Aber, J. D., Soil warming and carbon-cycle feedbacks to the climate system. *Science*, 2002, **298**, 2173–2176.
22. Zhang, W. *et al.*, Soil microbial responses to experimental warming and clipping in a tallgrass prairie. *Global Change Biol.*, 2005, **11**, 266–277.
23. Balser, T. C. *et al.*, Bridging the gap between micro- and macro-scale perspectives on the role of microbial communities in global change ecology. *Plant Soil*, 2006, **289**, 59–70.
24. Davidson, E. A. and Janssens, I. A., Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, 2006, **440**, 165–173.
25. Rustad, L., Campbell, J. and Marion, G., A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. *Oecolagia*, 2001, **126**, 543–562.
26. Fierer, N., Craine, J. M. and McLauchlan, K., Litter quality and the temperature sensitivity of decomposition. *Ecology*, 2005, **86**, 320–326.
27. French, S., Levy-Booth, D., Samarajeewa, A., Shannon, K. E., Smith, J. and Trevors, J. T., Elevated temperatures and carbon dioxide concentrations: effects on selected microbial activities in temperate agricultural soils. *World J. Microbiol. Biotechnol.*, 2009, **25**, 1887–1900.
28. Barnard, R. X. and Leadley, P. W., Global change, nitrification, and denitrification: a review. *Global Biogeochem. Cycle*, 2005, **19**, GB1007.
29. Aggarwal, P. K., Assessment of climate change impacts on wheat production in India. In *Global Climate Change and Indian Agriculture – Case Studies from ICAR Network Project* (ed. Aggarwal P. K.), ICAR, New Delhi Publication, New Delhi, 2009, p. 512.
30. Akanni, D. I., Ojeniyi, S. O. and Awodun, M. A., Soil properties, growth yield and nutrient content of Maize, Pepper and *Amaranthus* as influenced by organic and organomineral fertilizer. *J. Agric. Sci. Technol.*, 2011, **1**, 1074–1078.
31. Olowoake, A. A. and Ojo, J. A., Effect of fertilizer types on the growth and yield of *Amaranthus caudatus* in Ilorin, Southern Guinea, Savanna Zone of Nigeria. *Adv. Agric.*, 2014; http://dx.doi.org/10.1155/2014/947062.

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