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Response of coconut seedlings to elevated CO_2 and high temperature in drought and high nutrient conditions

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Abstract

The interaction effect of climate change variables elevated CO_2 and elevated temperature (ET) with drought and nutrients on growth and development of coconut seedlings was studied in an open top chamber (OTC) at Central Plantation Crops Research Institute (CPCRI), Kasaragod. Seedlings were exposed to ambient (normal CO_2 and temperature), elevated CO_2 (550 and 700 ppm), ET (3 °C above ambient) and ET + elevated CO_2 (550 ppm CO_2 + 3 °C). In each OTC, a set of seedlings were subjected to drought (50% FC) and another set was maintained at 150 per cent recommended dose of fertilizer (RDF). Seedlings in elevated CO_2 treatments accumulated significantly higher biomass. It was 1.13 and 1.98 kg seedling^{-1} with 550 and 700 ppm CO_2 respectively as against 1.10 in ambient treatment. It was the least in ET treatment (0.91). The stomatal conductance (gs) and transpiration (Tr) of plants grown under elevated CO_2 was reduced without affecting the photosynthesis. As a consequence, the whole plant WUE of coconut seedlings grown under elevated CO_2 was high both under control and drought condition. The WUE significantly reduced both in high temperature and drought stressed plants. Elevated CO_2 to certain extent compensated for water stress and high temperature induced reduction in growth of coconut.

Keywords: Climate change, coconut, elevated CO_2, photosynthesis, water use efficiency

Introduction

Coconut is one of the major plantation crops grown in India (approximately 2 m ha) along the coasts and hilly areas. It is grown between 20° N and 20° S latitude. The optimum weather conditions for growth and nut yield in coconut are well distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27 °C, abundant sunlight ranging from 250 to 350 Wm^{-2} with at least 120 hours per month of sun shine period. Since, it is humid tropical crop it grows well above 60 per cent humidity (Child, 1974; Murray, 1977). The recommended irrigation levels are 200 litre per palm once in 4 days or at the rate of 66 per cent E_o through drip irrigation (Rajgopal and Kasturi Bai, 1999). Any deviations from these optimal conditions cause the palms to experience stress conditions.

Future scenarios of atmospheric greenhouse gases indicate that CO_2 could increase from current levels of 380 ppm to between 500 and 970 ppm by the end of the twenty-first century (IPCC, 2007). If the predicted increase in greenhouse gas concentrations is then translated into temperature changes, a global temperature increase of between 1 and 5.5 °C is predicted for 2100. Coconut, being a C3 crop, is likely to benefit due to an increase in CO_2 (Naresh Kumar *et al*., 2008) as in case of other C3 species. Since, climate change is projected to raise temperatures and affect rainfall patterns, it is important to understand the impacts of high temperature and drought on coconut. Furthermore, the increased biomass production by changes in atmospheric CO_2 concentrations is likely to impose higher plant nutrient demand, acquisition and utilization (Cavagnaro *et al*., 2011). In this study,

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an attempt is made to understand the interaction effect of climate change variables, elevated CO_2 and high temperature, with drought and nutrients on growth and development of coconut seedlings.

Materials and Methods

The interaction effect of climate change variables elevated CO_2 and elevated temperature (ET) with drought and nutrients on growth and development of coconut seedlings was studied in an open top chamber (OTC) at CPCRI, Kasaragod. One year old Chowghat orange dwarf (COD) coconut seedlings grown in the nursery were transferred to big plastic buckets of 100 kg soil capacity in May 2011. Seedlings were grown in five OTCs.

The OTC grown seedlings were exposed to different climate variables from 20th November 2011 onwards. The different treatments were ambient (normal CO_2 and temperature), elevated CO_2 (550 and 700 ppm), elevated temperature ET (3 °C above ambient) and elevated CO_2 + ET (550 ppm CO_2 + 3 °C). Within the OTC, a set of seedlings were irrigated and maintained at field capacity as Control (FC; 19% soil moisture for the laterite soil). The soil moisture content of these pots was determined and the amount of water required to maintain the soil at FC was calculated daily using a soil moisture probe with a Delta T data logger. Drought treatment was created in a set of seedlings by irrigating them with only 50 per cent of the water applied to the control seedlings. Another set of seedlings were maintained at 150 per cent recommended dose of fertilizer (RDF). For this treatment, nutrients 0.75, 0.48, 1.8 kg of N, P and K, per seedling respectively were supplied while, the control treatment received 0.5, 0.32, 1.2 kg N, P, K through urea, single super phosphate and muriate of potash.

The above treatments were continued till 31st May 2012. At the end of the experiment period, the amount of water added to each of the treatments was noted. A set of seedlings from control, drought and high nutrient treatments of each OTC were uprooted along with the roots for assessing the below and above ground biomass. Seedlings were separated into roots, shoot and leaf. They were weighed after drying to a constant weight. The water use efficiency (WUE) was calculated as total dry matter produced during experimental period to the total water consumed and expressed as gram biomass per liter water.

Photosynthesis and transpiration of the top most fully opened leaf was measured using a portable photosynthesis system (Licor 6400) between 9.30 and 11.30 am. Measurements were made in triplicate in reference CO_2 concentration at a fixed light intensity of 1000 μmol m^{-2} s^{-1}. The chlorophyll fluorescence indices of the same leaf were measured using chlorophyll fluorescence meter.

The spindle leaf initiation date (date when the spindle leaf emerged from the crown is visible) for different treatments were noted. At every 4 days interval, the spindle leaf growth was recorded keeping a fixed point from the bucket level as reference for the measurement, till the leaf lamina split into leaflets. The spindle leaf growth rate was computed for all the treatments.

The length of individual leaf was measured from base to apex of the leaf and width was measured by stretching the middle leaflets of each leaf on either side of petiole to maximum. Leaf area was calculated by using the linear regression equations developed by Mathes *et al.* (1989). The data was analysed in two way factorial analysis using SAS 9.2 software. Mean values were compared for significance using the F-protected LSD test.

Results and Discussion

At the end of the experimental period, coconut seedlings grown in ambient treatment accumulated 1.10 kg biomass (Table 1). During the same period seedlings in elevated CO_2 accumulated 1.13 and 1.98 kg biomass with 550 and 700 ppm CO_2 respectively. It was significantly low in ET (0.91) and ET + elevated CO_2 (0.98) treatment. Amongst the different plant parts, leaf weight was significantly high in 700 ppm CO_2 treatment and in rest of the treatments it was on par with the ambient treatment. Root and shoot weight on the other hand was significantly high in both the treatments of 550 and 700 ppm CO_2. These findings are in conformity with the earlier findings in coconut seedlings (Muralikrishna *et al.*, 2013).

Table 1. Root, shoot and leaf weight, total biomass (kg seedling^{-1}) and water use efficiency (g biomass litre^{-1} water) of COD seedlings with various climate change variables and drought and nutrient treatments

OTC	Root	shoot	Leaf	Biomass	WUE
ET	0.194^{b}	0.345^{d}	0.370^{c}	0.910^{d}	1.370^{d}
ET+CO_2	0.218^{b}	0.380^{c}	0.389^{c}	0.979^{c}	1.612^{c}
700 ppm CO_2	0.269^{a}	0.487^{a}	0.460^{a}	1.980^{a}	2.428^{a}
550 ppm CO_2	0.246^{a}	0.446^{b}	0.433^{ab}	1.125^{b}	2.144^{b}
Ambient	0.218^{b}	0.406^{c}	0.398^{bc}	1.097^{c}	1.787^{c}
Treatments					
Control	0.272^{b}	0.523^{a}	0.461^{b}	1.256^{b}	2.332^{b}
Drought	0.113^{c}	0.234^{c}	0.238^{c}	0.585^{c}	0.768^{c}
Nutrient	0.302^{a}	0.482^{b}	0.532^{a}	1.316^{a}	2.505^{a}
CD at 5%					
OTC	0.025	0.03	0.041	0.052	0.206
Treatments	0.016	0.02	0.027	0.034	0.134

Spindle leaf initiation and spindle leaf growth in coconut is most sensitive to climate change and abiotic stresses. From the Fig. 2 it is clear that seedlings grown in elevated CO_2 had higher spindle leaf growth rate up to 60 days from the initiation. Seedlings in ambient treatment had spindle leaf growth rate of 1.5 while it was 2 cm day^{-1} in elevated CO_2. It was only 1.3 with ET and 1.7 with elevated CO_2 + ET. Coconut seedlings in the OTC with normal moisture and recommended dose of nutrients under ambient atmospheric CO_2 had a photosynthesis rate (Pn) of 10.14 (Table 2) which is slightly less than reported values of 14-15 µmol CO_2 m^{-2} s^{-1} for dwarfs (Gomes *et al.*, 2007). This difference could be because our measurements were in OTC as against the field grown seedlings. It was significantly higher in elevated CO_2 treatment

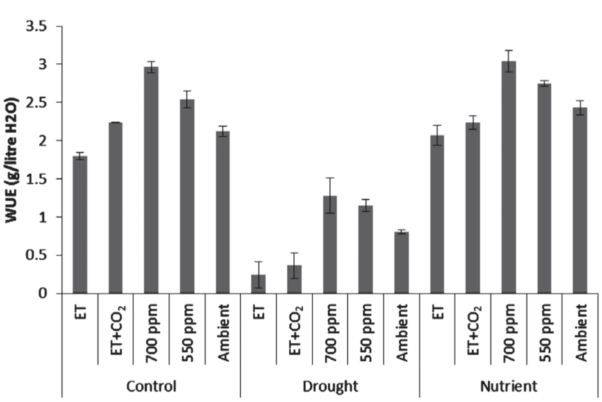

Fig. 1. The interaction effect of climate change variables with drought and high nutrients on the WUE of OTC grown COD seedlings (Bars indicate the standard deviation)

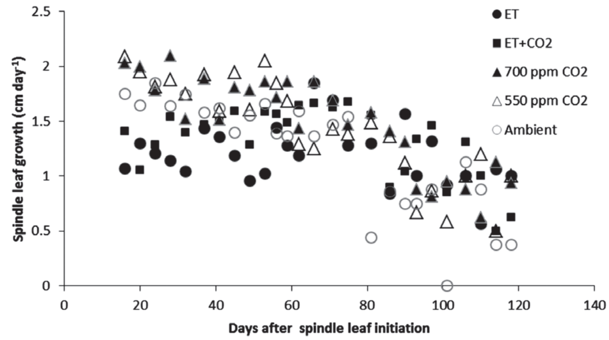

Fig. 2. Spindle leaf growth rate of seedlings in different climate variable treatments

(14.37) but non-significant in ET treatment. Almost similar trend was observed in seedlings grown with 150 per cent RDF. The gs and the Tr, on the other hand were significantly low in elevated CO_2 treatments. While plants under ET and drought had low Pn and high gs and Tr (Table 2). In 700 ppm CO_2 treatment the gs and Tr were 0.125 and 2.58 as against 0.192 mole m^{-2} s^{-1} and 3.41 mmol m^{-2} s^{-1} of ambient treatment respectively. Elevated CO_2 to certain extent alleviated the effect of both high temperature and drought.

Chlorophyll fluorescence data was measured in the same leaf where the Pn was measured

Table 2. Photosynthesis (Pn), stomatal conductance (gs), transpiration (Tr) and leaf area of COD seedling in OTC with climate change variables, drought and high nutrients

Treatments	Climate variables	Pn (µmole m^{-2}s^{-1})	gs (mole m^{-2}s^{-1})	Tr (mmole m^{-2}s^{-1})	Leaf area (cm^{2} palm^{-1})
Control	ET	11.83	0.216	3.81	35607
	ET+CO_2	11.02	0.148	3.64	19403
	700 ppm	14.37	0.125	2.58	34537
	550 ppm	14.60	0.165	3.08	22555
	Ambient	10.14	0.192	3.41	23192
Drought	ET	10.34	0.165	3.69	23706
	ET+CO_2	8.66	0.134	3.69	24841
	700 ppm	12.33	0.105	2.51	18027
	550 ppm	10.82	0.120	2.32	36749
	Ambient	6.57	0.122	3.00	31499
Nutrient	ET	10.08	0.205	4.25	14678
	ET+CO_2	11.78	0.169	5.35	31654
	700 ppm	16.22	0.146	3.26	28594
	550 ppm	13.68	0.158	3.18	24444
	Ambient	8.60	0.194	3.90	30496
CD at 5%					
Climate variable		2.2	0.033	0.63	NS
Treatments		1.46	NS	NS	5589
CxT		1.21	NS	NS	NS

indicated that Fv/Fm (dark adapted values) which reflects the maximum potential quantum efficiency of PSII, was on par in ambient and elevated CO_2 seedlings while it was less at ET treatments (Table 3). It was the least in drought treatment. Yield indicates the proportion of light absorbed by chlorophyll associated with PSII was the least in ET treatment and it increased with increasing CO_2. However, even with high CO_2 the yield under drought was low because most of the energy is wasted for non-photochemical quenching (qN).

Table 3. Chlorophyll fluorescence indices in coconut leaves

	Treatment	Fv/Fm	Yield	qP	qN
Ambient	Control	0.774	0.413	0.865	0.071
	150 % RDF	0.762	0.562	0.961	0.081
	Drought	0.672	0.386	0.816	0.189
700 ppm CO_2	Control	0.735	0.510	0.953	0.019
	150 % RDF	0.786	0.473	0.919	0.019
	Drought	0.605	0.271	0.866	0.258
ET	Control	0.669	0.318	0.880	0.037
	150 % RDF	0.691	0.415	0.902	0.027
	Drought	0.531	0.128	0.635	0.018
ET+550ppm CO_2	Control	0.625	0.639	0.985	0.004
	150 % RDF	0.697	0.553	0.955	0.069
	Drought	0.601	0.414	0.919	0.135

The whole plant WUE was significantly high in elevated CO_2 treatments. It was 2.14 and 2.43 g biomass l^{-1} water in 500 and 700 ppm CO_2 respectively as against 1.79 g biomass l^{-1} water in ambient treatment (Table 1). The reduced gs and Tr without affecting the Pn as observed in Table 2 could have resulted in higher WUE under elevated (CO_2). WUE was significantly low in ET (1.37) and in ET + CO_2 it was on par with ambient treatment. WUE increased marginally with 150 per cent RDF (Fig. 1). Interestingly, with drought, the WUE of all the treatments were less than half that of the control or 150 per cent RDF grown seedlings. This is in contrary to the WUE observed in other annual crops where, the WUE increases with water deficit stress (Hebbar *et al.*, 1994). This suggests that the coconut cultivar COD - selected for this study is found to have insensitive stomata (non-significant difference in gs for control and drought treatments in Table 2). Thus, the photosynthesis per unit water transpired is low, and as a consequence the WUE significantly reduced in stressed seedlings. Elevated CO_2 to certain extent compensated for water stress and high temperature induced reduction in growth of coconut. WUE of seedlings in ambient and 700 ppm CO_2 treatments were 0.8 and 1.3 g biomass l^{-1} water respectively under drought condition. Earlier workers too reported wide variability in WUE values between the varieties of coconut (Kasturi Bai *et al.*, 1996; Kasturi Bai and Rajagopal, 1999; Gomes *et al.*, 2002; Passos *et al.*, 1999). However, these were intrinsic WUE measurements and to our knowledge there were no reports on whole seedling WUE of coconut. Here we report the wide variability in whole plant WUE of coconut seedlings with climate change variables.

Thus, this study shows that coconut seedlings show positive response to elevated CO_2. The response was better under higher nutrient supply. The stomatal conductance and transpiration of plants grown under elevated CO_2 was reduced without affecting the photosynthesis. As a consequence, the whole plant WUE of coconut seedlings grown under elevated CO_2 was high both under control and drought condition. The WUE significantly reduced both in high temperature and drought stressed plants. Elevated CO_2 to certain extent compensated for water stress and high temperature induced reduction in growth of coconut.

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