Journal of Agrometeorology 22 (4) : 419-428 (December 2020)

Effect of elevated CO_2 and elevated temperature on growth and biomass accumulation in *Valeriana jatamansi* Jones. under different nutrient status in the western Himalaya

MUNISH KAUNDAL[1] and RAKESH KUMAR[1,2]*

[1]*Academy of Scientific and Innovative Research, Ghaziabad, Uttar Pradesh, India;*

[2]Agrotechnology Division,CSIR-Institute of Himalayan Bioresource Technology, Post Box No 6, Palampur 176 061 (HP), India

**Corresponding author: rakeshkumar@ihbt.res.in*

ABSTRACT

Valeriana jatamansi is an important medicinal and aromatic plant used as sedative in modern and traditional medicines butthere is dearth of literature regarding how elevated CO_2 and temperature affect on this plant. Therefore,an experiment was conducted to study the effect of elevated CO_2 (550±50 μmol mol^{-1}) and elevated temperature (2.5±0.5°C above ambient) and vermicompost on growth, phenology and biomass accumulation in *V. jatamansi* under Free Air CO_2 Enrichment (FACE) and Free Air Temperature Increment (FATI) facilities at Palampur, India, during 2013-2015. Growth parameters and biomass accumulation into different parts were observed at 4, 12 and 16 months after exposure (MAE). Plant height, total dry biomass and leaf area plant^{-1} increased in elevated CO_2 treatment applied with vermicompost as compared to the other treatments. Elevated CO_2 significantly enhanced leaf area (3.5-23.5%), leaf biomass (12.7-33.2%), stem (15.3-15.6%), root (3.2-72.5%), rhizome (2.1-42.2%) and total biomass (7.7-52.7%), whereas elevated temperature increased aboveground biomass (15.0-45.3%), belowground biomass (11.6-55.5%) and total biomass (12.4-47.9%), respectively, as compared to ambient. Phenological stages were advanced by 1.2-3.9 days under FACE and FATI as compared to ambient. The results indicate that aboveground, belowground and total biomass increased under elevated CO_2 and elevated temperature as compared to ambient.

Keywords: *Valeriana* jatamansi, FACE, FATI, elevated CO_2, elevated temperature.

V. jatamansi Jones. Syn. *V. wallichii* DC (Indian valerian) belonging to family Valerianaceae, is a medicinal and aromatic plant, growing at an altitude of 1200-3000m amsl. Rhizomes and roots are known to produce a group of compounds known as valepotriates and essential oil. It is used as aphrodisiac, antispasmodic, antiseptic, expectorant, sedative, insecticidal, nerve tonic, febrifuge, ophthalmic, hypnotic and tonic useful in leprosy, epilepsy, cholera, neurosis, cough, asthma, chest pain, snakebite, scorpion sting and also used for curing blood diseases, burning sensation, skin disease, throat troubles and ulcers (Das *et al.*, 2011). Thus, the plant is in great demand for both pharmaceutical and perfumery industries. In India, plant is collected from the forests to fulfill the industrial demand. Due to over-exploitation of underground parts for its medicinal value, it is on the verge of becoming extinct and is being labeled as critically endangered species in the list of National Medicinal Plant Board, New Delhi, India and threatened species in western Himalaya (Kaul and Handa, 2000).

Increasing concentration of atmospheric CO_2 and air temperature are two most important factors which affect plant growth and development. During the last two centuries carbon dioxide (CO_2) concentration and atmospheric temperature has been rising at a rate of 2.4% per year to the level 405.7 μmol mol^{-1} (NOAA/ESRL, 2017) and is expected to be 550 μmol mol^{-1} by 2050 and rise above by 700 μmol mol^{-1} at the end of the present century and if emissions continues at such high level it will lead to a global warming of 1.4-5.8 °C in the year 2100 (IPCC, 2014). Plant growth and photosynthesis rate in C_3 plant species are known to be positively affected by elevated carbon dioxide. On the other hand, high temperature in early growth stages increased vegetative growth results in shortening growth phase due to increased ontogenic development, thus affect carbon fixation and reduction in biomass accumulation (Rakshit *et al.,* 2012).

Elevated CO_2 and temperature had great influence on quality, composition and yield of *V. jatamansiplants*

(Kaundal *et al.,* 2018). For last 30 years various experiments were conducted to study the effect of elevated CO_2 on growth, biomass and yield globally under staple crops and found that growth, biomass and yield increased under elevated CO_2 concentration (Weigel and Manderscheid, 2012; Butterly *et al.,* 2015; Cai *et al.,* 2016). Similarly, effect of elevated temperatures on growth, biomass and phenology were studied and researchers observed reduction in plant biomass and advancement in phenological stages on different plants (Rakshit *et al.,* 2012; Cai *et al.,* 2016). Vermicompost is important manure which provides additional nutrients and improves the quality and medicinal property.

There is less information on effect of elevated CO_2 and elevated temperature on medicinal plants in open field conditions, however, some studies were also reported in controlled conditions. To the best of our knowledge there is no report on elevated CO_2 and elevated temperature effect on *V. jatamansi* in open field condition, therefore, this experiment was conducted under open field condition to study the effect of elevated atmospheric CO_2 and elevated temperature on growth, phenology, and biomass production under varying nutrient in *V. jatamansi* in the western Himalayas.

MATERIALS AND METHODS

The experiment was conducted at the research farm of CSIR-Institute of Himalayan Bioresource Technology (Council of Scientific and Industrial Research) Palampur (1325 m amsl altitude, 32°06'05''N latitude, 76°34'10"E longitude), in the mid hills of western Himalaya, India. Soil of potting mixture was acidic in reaction (pH 6.8), low available N (0.008%), high available P (0.019%) and available K (0.043%). Throughout the crop growth season from November 2013 to March 2015, mean maximum monthly temperature varied from 14.2-30.9 ºC between 2013-15, respectively. *V. jatamansi* response to elevated CO_2 (550±50 µmol mol^{-1}) and elevated temperature (2.5-0.5ºC higher than ambient) were studied under the FACE and FATI facilities of the institute. Experiment consisted of three octagonal rings.

The ring with ambient CO_2 concentration was taken as ambient or ring 1. Second ring was termed as FACE with enriched CO_2 (550±50 µmol mol^{-1} of CO_2) during daytime (8:30 am to 5:30 pm) released from a multiple set of 40 kg cylinders. Third ring with elevated temperature 2.5±0.5 ºCwith infra red (IR) heaters and air blowers (referred as FATI). The mixing of CO_2 (99.99% pure CO_2; outlet CO_2 pressure 4.5 kg cm^{-2} from manifold system connected with CO_2 gas cylinder) and air were done in pressurized CO_2 and air mixing chamber with air filter regulator which was attached to high capacity air compressor (outlet air pressure kg cm^{-2}). The CO_2 enrichment air was pushed inside the ring through perforated polyvinyl tubes regulated by solenoid valves (Kaundal, 2018).

Experimental details

The experiment was conducted using a two factor completely randomized design (CRD) with six treatments, three environmental conditions (ambient CO_2, elevated CO_2 and elevated temperature) and two compost levels *viz.*, with vermicompost (200 g pot^{-1}) and without vermicompost (control). Good quality seeds of *V. jatamansi* variety 'Himbala' were raised in nurseryduring May 25, 2013 and seed were emerged 20 days after sowing (DAS). In each ring, 50 pots (Size 35 cm x 35 cm x 23 cm) were placed. Vermicompost @ (200 g pot^{-1}) was added to each pot during cropping season. First dose (50 g pot^{-1}) was applied at 15 days after transplanting (DAT), second dose (50 g pot^{-1}) at 120 DAT. Third dose (50 g pot^{-1}) on 1st October 2014 and fourth dose (50 g pot^{-1}) on 22 January during 2015. Vermicompost contains N (0.5%), P_2O_5 (0.3%) and K_2O (0.8%).

Five plants were selected randomly for dry matter accumulation studies from each treatment during both the years. Dry matter accumulation into different plant parts (leaves, stem, flower and roots), and growth parameters *viz.*, plant height, number of leaves plant^{-1}, leaf area plant^{-1}, root length, root volume, number of lateral roots, number of branches plant^{-1}, were recorded. All statistical analyses were performed at a 95% confidence level.

RESULTS AND DISCUSSION

Growth parameters

Significantly higher plant height was recorded in FATI (22.6 cm) as compared to FACE (18.5 cm) and ambient (13.8 cm) at 12 MAE due to high temperature under FATI environment, which coincides with winter months.High temperature stimulated growth which results in taller plant as compared to control. Oh-e *et al*. (2007) had also observed increased plant height in rice plants grown under elevated temperature. However, at 16 MAE, plant height was significantly higher in FACE (51.9 cm) as compared to FATI (48.3 cm) and ambient (47.0 cm), which may be due to enhanced cell division, cell expansion and cell differentiation

Table 1: Effect of vermicompost on dry biomass (g plant^{-1}) of different plant parts in *V. jatamansi* at different time intervals

Treatment	Leaf			Root			Rhizome		Above ground			Below ground			Total		
Vermicompost	4 MAE	12 MAE	16 MAE	4 MAE	12 MAE	16 MAE	4 MAE	12 MAE	4 MAE	12 MAE	16 MAE	4 MAE	12 MAE	16 MAE	4 MAE	12 MAE	16 MAE
Without VC	1.6	9.1	3.8	2.5	17.9	2.5	14.5	10.3	6.4	9.1	12.7	2.5	32.4	18.9	8.9	41.6	31.5
With VC	3.4	9.9	4.2	3.3	19.5	3.3	16.4	10.8	9.1	9.9	13.8	3.3	36.0	20.0	12.5	45.9	33.7
SEm(±)	0.2	0.4	0.2	0.2	1.1	0.2	1.0	0.4	0.4	0.4	0.4	0.2	1.8	0.5	0.5	2.0	0.8
LSD (P=0.05)	0.6	NS	NS	0.6	NS	NS	NS	NS	1.0	NS	NS	0.6	NS	NS	1.5	NS	NS
% change	111.8	8.4	11.2	31.3	9.0	31.3	13.4	5.3	41.9	8.4	8.7	35.1	11.0	5.9	40.0	10.4	7.0

SEm (±): Standard error of mean, LSD: least significant difference, VC: vermicompost, NS: notsignificant, MAE: months after exposure

under the influence of elevated CO_2. These results are in agreement with Rao *et al*. (2010) who obtained significantly higher plant height under elevated CO_2 as compared to ambient (Fig. 1a). At 12 MAE, numbers of leaves plant^{-1} were significantly higher in FACE (149.0) as compared to FATI (113.0) and ambient (130.7). Likewise, at 16 MAE, numbers of leaves were significantly higher in FACE as compared to ambient (Fig. 1b). This may be due to the fact that elevated CO_2 act as C fertilizer which increased leaf number and leaf biomass under elevated CO_2 level. Similarly, leaf number increased in *Salviasclarea* (Kumar *et al*., 2017).

Root length was significantly higher in FATI as compared to ambient and FACE at 4 and 12 MAE (Fig. 1c). Root volume increased by 10.9-53.9% under FACE as compared to ambient at 12 and 16 MAE (Fig. 1d). This increase was due to high carbon gain in elevated CO_2 which increased lateral root production, root number, length and diameter. Similar results were also reported by Madhu and Hatfield (2013) in soybean.

Leaf area was significantly affected by environmental conditions at 4, 12 and 16 MAE (Fig. 1e). During early stage of exposure (at 4 MAE) leaf area was significantly higher in FATI (538.0 cm^2) as compared to FACE (362.5 cm^2) and ambient (350.1cm^2). Increase in leaf area at 4 MAE under FATI was due to increase in length and width of the leaves due tohigh temperature during the initial stages. However, at 12 and 16 MAE, leaf area was significantly higher in FACE as compared to ambient. This may be due to due to higher vegetative growth *viz*., increased number of leaves (Fig.1b) under elevated CO_2 conditions. Elevated CO_2 causes stimulation of the leaf expansion rate and leaf area development. This may due to the fact that cell production and cell expansion, determining final leaf area, both depend upon atmospheric CO_2 level (Ferris *et al.,* 2001). On the other hand, decreased leaf area at 12 MAE was due to decrease in leaf number at elevated temperature conditions. The present results corroborate the findings of Zhou *et al*. (2011) who also reported decreased leaf area in *Phalarisarundinacea* at elevated temperature. Leaf chlorophyll content (CCI) was significantly higher in ambient as compared to elevated CO_2 and elevated temperature conditions at 12 MAE (Fig.1f). Likewise, at 16 MAE, CCI content decreased under FACE by 11.2-19.3% and FATI by 6.1-15.3% as compared to ambient, respectively. Lower chlorophyll content under FACE and FATI may be due to dilution of chlorophyll content as well as degradation of content by excess utilization under high photosynthetic

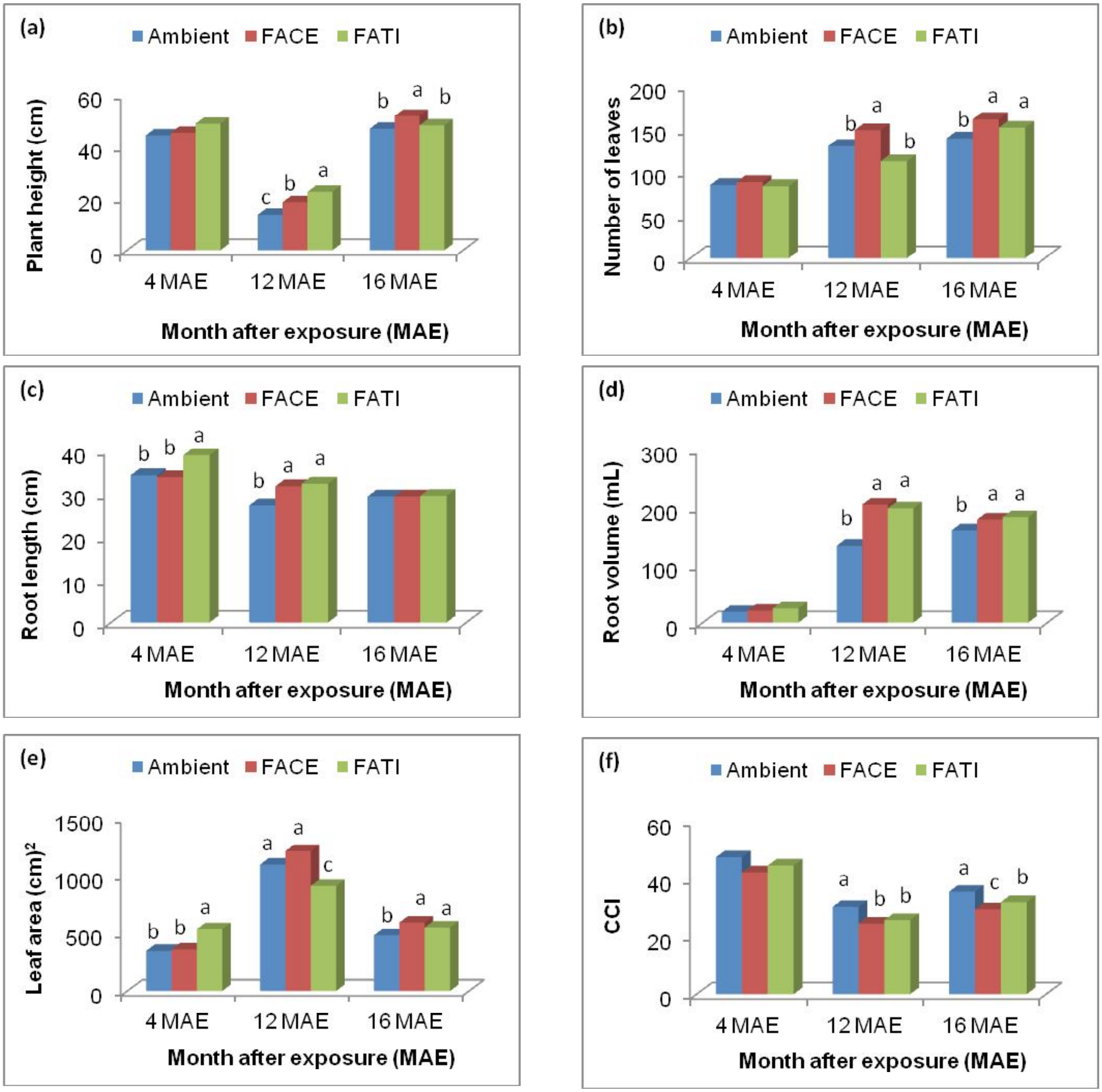

Fig. 1: Effect of elevated CO_2 (550±50 µmol mol^{-1}) and temperature (2.5-3.0°C above ambient) on growth parameters of *V. jatamansi* (g plant^{-1}) at different intervals. Bars with same letter are not significantly different at P= 0.05.

rate in elevated CO_2. The present results are in accordance with Kim and You (2010) in *Phytolaccainsularis.* Lower CCI under elevated temperature may be due to more negative effect of high temperature on chlorophyll content. Similarly, decrease in chlorophyll a, b and total chlorophyll content was observed in maize and rice under elevated temperature (Kumar *et al*., 2012). The interaction effect between environmental conditions and vermicompost was not significant for these parameters.

Biomass accumulation

Biomass accumulation into different plants parts (leaf, stem, flower, root and rhizome) and total biomass was significantly influenced by the environmental conditions at different dates of observations (Fig.2a-f). Likewise leaf area, dry leaf biomass was significantly higher in FATI at 4 MAE

Table 2: Effect of vermicompost on specific leaf area ($cm^2\ g^{-1}$), specific leaf weight ($g\ cm^2$) and leaf area ratio ($cm^2 g^{-1}$) of *V. jatamansi* at different intervals.

Treatment	Specific leaf area			Specific leaf weight			Leaf area ratio		
	4 MAE	12 MAE	16 MAE	4 MAE	12 MAE	16 MAE	4 MAE	12 MAE	16 MAE
Environmental conditions									
Ambient	145.1	136.8	117.3	0.0072	0.0075	0.0086	5.8	16.3	4.2
FACE	167.5	112.9	129.3	0.0061	0.0092	0.0080	5.4	14.1	4.6
FATI	193.4	99.0	187.4	0.0062	0.0103	0.0055	6.7	12.6	5.3
SEm (±)	10.5	7.1	8.4	0.0007	0.0005	0.0004	0.4	0.6	0.2
LSD (P=0.05)	30.5	20.8	24.5	NS	0.0015	0.0011	NS	1.8	0.6
Vermicompost									
Without VC	163.5	118.5	150.4	0.0064	0.0088	0.0072	5.5	14.4	4.7
With VC	173.8	114.0	139.0	0.0066	0.0092	0.0076	6.4	14.2	4.6
SEm (±)	8.5	5.8	6.9	0.0005	0.0004	0.0003	0.3	0.5	0.2
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

SEm (±): Standard error of mean, LSD: least significant difference, VC: vermicompost, NS: notsignificant, , MAE: months after exposure

Table 3: Effect of environmental conditions and vermicompost on phenological stages of *V. jatamansi*

Treatment	Phenological stages				
	Bud initiation	Flower initiation	50 % flowering	Seed setting	Seed maturity
Environmental conditions					
Ambient	73.75	97.91	114.58	127.41	155.33
FACE	73.16	97.41	116.66	127.41	153.50
FATI	70.58	92.75	112.75	124.83	149.25
LSD (P=0.05)	NS	2.57	1.50	1.14	1.15
% change between FACE & Ambient	(-)0.8	(-)0.5	1.8	0.0	(-)1.2
% change between FATI & Ambient	(-)4.3	(-)5.3	(-)1.6	(-)2.0	(-)3.9
Vermicompost					
With VC	73.27	95.66	114.72	127.38	153.33
Without VC	71.72	96.38	114.61	125.72	152.05
LSD (P=0.05)	NS	NS	NS	0.93	0.94
% change	(-)2.1	0.8	(-)0.1	(-)1.3	(-)0.8

LSD: least significant difference, VC: vermicompost, NS: not significant

as compared to ambient and FACE (Fig.2a). However, at 12 MAE and 16 MAE, dry leaf biomass was significantly higher in FACE as compared to ambient and FATI. Elevated CO_2 recorded 12.7-33.2% higher dry leaf biomass as compared to ambient. Increase in leaf biomass was due to increased leaf number under elevated CO_2 conditions. Similarly, dry leaf biomass significantly increased in *Hypericum perforatum* and *Echinacea purpurea* at elevated CO_2 conditions (Save

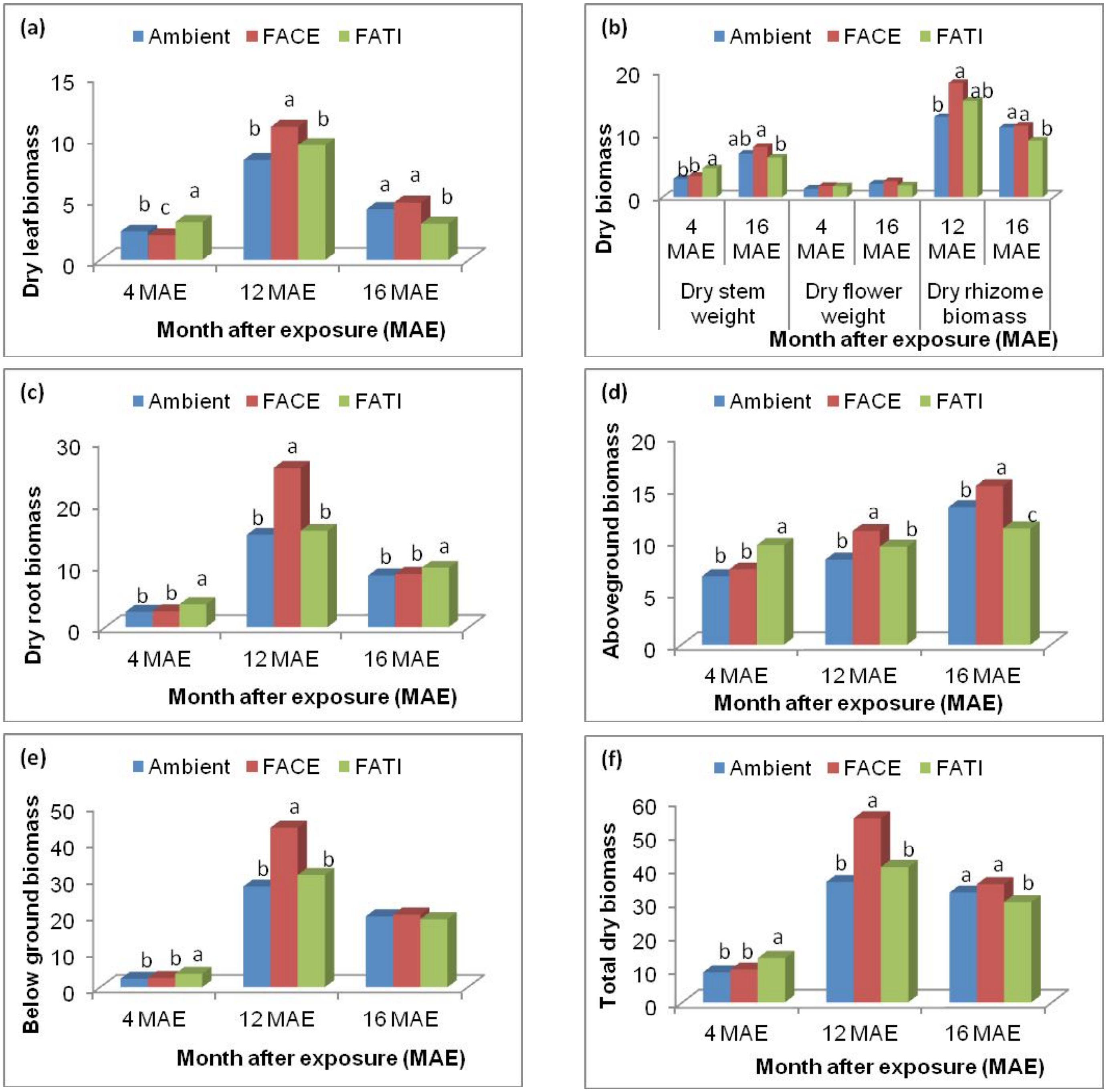

Fig. 2: Effect of elevated CO_2 (550±50 µmol mol^{-1}) and temperature (2.5-3.0^{o}C above ambient) on biomass on *V. jatamansi* (g plant^{-1}) at different intervals. Bars with same letter are not significantly differentat P= 0.05.

et al., 2007).

Dry stem biomass was significantly higher in FATI as compared to FACE and ambient at 4 MAE (Fig. 2b). This may be due higher growth rates at initial stages which increased stem biomass, however, at 16 MAE, reduction in stem biomass was observed which may be due to decrease in net photosynthetic rates due to high temperature under FATI. Dry stem biomass increased by 15.3-15.6% under FACE as compared to ambient at 4 and 16 MAE. Similar results were reported in *Wollemianobilis* (Lewis *et al*., 2015).

Dry rhizome was higher in FACE as compared to ambient at 12 and 16 MAE (Fig.2b). Dry rhizome increased by 2.1-42.2% in FACE as compared to ambient. These results are in agreement with the findings of Ghasemzadeh *et al.* (2011) who also observed increased rhizome biomass in two Malaysian young varieties of *Zingiber officinale*at elevated CO_2 conditions. Dry root biomass was significantly higher in FACE at 12 MAE as compared to FATI and ambient (Fig.3c). Increase in root biomass under FACE may be due to high carbon gain in elevated CO_2 which might have increased lateral root production, root number and diameter. The present results are in accordance with Madhu and Hatfield (2013) who reported that roots become more numerous, longer and thicker, when exposed to elevated CO_2 as a result of branching and extension of roots in many plant species.

At 4 MAE, aboveground biomass and belowground biomass was significantly higher in FATI as compared to ambient and FACE (Fig. 2d-e).This may be due to high temperature in the initial stages of crop development which tend to increase plant growth by accelerating net photosynthesis. However, at 12 and16 MAE, aboveground biomass was significantly higher in FACE as compared to FATI and ambient (Fig. 2d). Elevated CO_2 recorded significantly higheraboveground dry biomass by 10.0-33.2% and elevated temperature by 15.0-45.3% at 4 and 12 MAE, respectively, as compared to ambient. High biomass allocation towards aboveground biomass was due to high photosynthetic rates which ultimately produced higher leaf, stem and flower biomass under elevated CO_2 conditions. These findings are in confirmation with the findings of Weigel *et al*. (2012) who reported increased aboveground biomass in *Hordeum vulgare, Loliummultiflorum, Beta vulgaris* and *Triticumaestivum.* At 16 MAE, aboveground biomass decreased by 15.6% in FATI as compared to ambient. This may be due to the fact that higher temperature advanced phenological stages which results in shortening the time of carbon fixation and biomass accumulation. Similarly, reductions in aboveground dry biomass by elevated temperature as compared to ambient have been reported in wheat and rice (Cai *et al*.,2016; Kaur *et al.* 2019).

Belowground dry biomass at 12 MAE significantly increased by 8.0-58.4% under elevated CO_2 and by 11.6-55.5% under elevated temperature, respectively, as compared to ambient (Fig. 2e).Increased belowground biomass was due to high carbon gain at elevated CO_2 which led to increased lateral root production, root and rhizome number. These results are in line with findings of Ma *et al*. (2007) who also observed increased belowground biomass under elevated CO_2 conditions.

Significantly higher total dry biomasswas observed in FACE at 12 and 16 MAE as compared to FATI and ambient (Fig. 2f).Total dry biomass increased significantly by 7.7-52.7% under elevated CO_2 as compared to ambient. The increase in total dry biomass of the plants could be attributed due to higher CO_2 stimulated higher vegetative growth of plant and resulted in higher biomass accumulation under enriched carbon. The present results were also supported Vagheera *et al.* (2015) who reported increased total dry biomass under elevated CO_2 in black gram. However, reduction in total dry biomass was observed under elevated temperature at later stages of crop growth (16 MAE) than ambient. Likewise, reduction in biomass at elevated temperature was observed at later stages of crop development in wheat and rice (Cai *et al*., 2016).

Leaf indices

Leaf indices *viz*., specific leaf area (SLA), leaf area ratio (LAR) and specific leaf weight (SLW) were significantly influenced by elevated temperature and elevated CO_2 at all the date of observation (Table 2). At 4 MAE, SLA significantly increased by 33.3-59.8% under elevated temperature and by 10.2-15.5% under elevated $CO_{2,}$ respectively, as compared to ambient. This may be due to increased leaf area (Fig.2e) and leaf biomass under elevated temperature (Fig. 2a). However, at 12 MAE, SLA decreased by 27.7% under elevated temperature as compared toambient conditions. This might be due to increased leaf biomass and decreased leaf area under FATI. LAR increased by 26.3% under FATI and 10.1% under FACE, respectively, as compared to ambient at 16 MAE, which may be due to increased leaf area (Fig. 1e) and higher biomass under FATI and FACE as compared to ambient. However, at 12 MAE, LAR decreased by 23.1% under FATI and 13.9% under FACE, respectively, which may be due to decreased leaf area under FATI and also due to low temperature as well as dormant period of the crop. Similar results have been reported in *Brassicanapus* (Qaderi *et al*., 2006). SLW decreased by 7.6-14.3% under FATI and by 13.5-36.2% in FACE at 4 and 16 MAE, respectively, as compared to ambient conditions. This could be due to decreased leaf dry biomass at elevated temperature (Fig.2a). However, at 12 MAE, SLW significantly increased by 37.5% under FATI as compared to ambient, which may be due to decreased leaf area at elevated temperature. The present results were also supported by Qaderi *et al*. (2006) at elevated carbon dioxide in *B. napus* and Zhou *et al*. (2011) at elevated temperature in *P. arundinacea*.

Plant phenology

Significantly, lesser number of days were taken to flower initiation in *V. jatamansi* plants grown in FATI conditions as compared to ambient and FACE (Table 3). Likewise, significantly minimum numbers of days were recorded to 50% flowering, seed setting and seed maturity by FATI as compared to ambient and FACE and the latter two did not differ from each other for flower initiation and seed maturity. Phenological stages were advanced under elevated temperature which could be attributed due to the reasons that increase in temperature accelerates vegetative development, stimulated growth and accelerated phenological stages, so plants exposed to elevated temperatures showed early flowering (Table 3). Flower initiation was 5.3 days earlier under FATI as compared to ambient. Likewise, seed setting and maturity were advanced by 2.0 and 3.9 days earlier in FATI as compared to ambient. The results are in consonance with findings of Fang *et al.* (2013) in winter wheat and Cai *et al.* (2016) in wheat and rice. Das *et al.* (2020) recorded that occurrence of different phenological stages was earlier under elevated CO_2 - temperature conditions in rice.

Effect of vermicompost

Root length and root volume were higher in plants applied with vermicompost. Vermicompost recorded significantly higher leaf areaat 4 MAE as compared to control, which might be due to increased number of leaves. Similarly, increase in leaf area due to application of vermicompost were also observed *Centellaasiatica* and *V. radiata* (Chiluvuru *et al*., 2009). Dry biomass (leaf, root, aboveground, belowground and total biomass) was significantly affected by vermicompost application at initial stages (4 MAE) of plant growth and it was significantly higher in plants applied with vermicompost as compared to control (Table 1). Application of vermicompost provides nutrients such as nitrates, phosphates, exchangeable calcium and magnesium in plant available forms which ultimately helps in increasing the rate of mineralization and humification. Similar results have been earlier reported by Chiluvuru *et al*. (2009) in *V. radiata* and *C. asiatica* and Sahoo *et al*. (2017) in *Piper longum*. However, at later stages (12 and 16 MAE) effect of vermicompost were not significant. This may be due to depletion of nutrients in later stages of crop growth.

CONCLUSIONS

In the present study, effect of elevated CO_2 and elevated temperature on plant growth and biomass of *V. jatamansi* was evaluated. Elevated CO_2 significantly increased biomass accumulation in leaf, stem, rhizome and total dry biomass as compared to other environmental conditions at 12 and 16 MAE. The effect of rise in temperature leads to earlier seed maturity and all the phenological stages were advanced as compared to ambient. Since, elevated CO_2 and elevated temperature significantly affected the phenology, growth parameters, the result indicates that elevated CO_2 in future could have positive effect on *V. jatamansi*. But how these plants will respond under interactive effect of elevated CO_2 and elevated temperature. Growth parameters and biomass were not significantly affected by the application of vermicompost at later stages of growth. So, it is necessary to have more studies on plant parameters with interactive effect of elevated CO_2 and elevated temperature.

ACKNOWLEDGEMENTS

The authors are grateful to the Director, CSIR-IHBT, Palampur, India for providing necessary facilities during the course of study. Authors are also gratified to the Academy of Scientific and Innovative Research (AcSIR) and Council of Scientific and Industrial Research, India, New Delhi for providing financial grant under CSIR network project entitled "Plant diversity: Studying adaptation biology and understanding/exploring medicinally important plants for useful bioactives" (SIMPLE).

REFERENCES

Butterly, C.R., Armstrong, R., Chen, D. and Tang, C. (2015). Carbon and nitrogen partitioning of wheat and field pea grown with two nitrogen levels under elevated CO_2. *Plant Soil*., 391:367-382.

Cai, C., Yin, X., He, S., Jiang, W., Si, C., Struik, P.C., Luo, W., Li, G., Xie, Y. and Xiong, Y. (2016). Responses of wheat and rice to factorial combinations of ambient and elevated CO_2 and temperature in FACE experiments. *Glob. Change Biol*., 22:856-874.

Das, P., Deka, R. L., Goswami J. and Barua, S. (2020). Effect of elevated CO_2 and temperature on growth and yield of winter rice under Jorhat condition. *J Agrometeorol*., 22 (2): 109-115.

Chiluvuru, N., Tartte, V., Kalla, C.M. and Kommalapati, R. (2009). Plant bioassay for assessing the effects of vermicompost on growth and yield of and two important medicinal plants *Vigna radiata* and *Centellaasiatica*. *J. Dev. Sustain. Agric*., 4:160-164.

Das, J., Mao, A.A. and Handique, P.J.(2011). Terpenoid compositions and antioxidant activities of two Indian valerian oils from the Khasi Hills of north-east India. *Nat. Prod. Commun*., 6(1):129-132.

Fang, S., Su, H., Liu, W., Tan, K. and Ren, S. (2013). Infrared warming reduced winter wheat yields and some physiological parameters, which were mitigated by irrigation and worsened by delayed sowing. *Plos One,* 8(7):1-12.

Ferris, R., Sabatti, M., Miglietta, F., Mills, R.F. and Taylor, G. (2001). Leaf area is stimulated in Populus by free-air CO_2 enrichment (POPFACE), through increased cell expansion and production. *Plant Cell Environ*., 24:305-315.

Ghasemzadeh, A. and Jaafar, H.Z.E. (2011). Effect of CO_2 Enrichment on Synthesis of Some Primary and Secondary Metabolites in Ginger (*Zingiberofficinale* Roscoe) *Int. J. Mol. Sci*., 12:1101-1114.

IPCC. (2014). The IPCC's fifth Assessment report. What's in it for Africa. pp. 59.

Kaul, M.K. and Handa, S.S. (2000). Response of medicinal plants to changed habitats and altitudes. *J. Trop. Med. Plants.,* 1:125-137.

Kaur, P., Kaur, H., Singh, H. and Sandhu, S.S. (2019). Effect of elevated temperature regimes on growth and yield of rice cultivars under temperature gradient tunnel (TGT) environments.*J. Agrometeorol.,*21(3): 241-248.

Kaundal, M. (2018). Effect of elevated CO_2 and elevated temperature on growth, biomass and selected bioactive molecules of *Valerianajatamansi* J. and *Hypericum perforatum* L. PhD. Thesis submitted to Academy of Scientific and innovative Research, New Delhi, India. Pp. 232.

Kaundal, M., Bhatt, V. and Kumar, R. (2018). Elevated CO_2 and elevated temperature effect on essential oil content and composition of *Valeriana jatamansi* Jones. with organic manure application in a western Himalayan region.*J. Essent. Oil-Bear. Plants.,*21(4):1041-1050.

Kim, H.R. and You, Y.H. (2010). Effects of elevated CO_2 concentration and increased temperature on leaf related-physiological responses of *Phytolaccainsularis* (native species) and *Phytolaccaamericana* (invasive species). *J. Ecol. Field Biol*., 33(3):195-204.

Kumar, M., Swarup, A., Patra, A.K., Chandrakala, J.U. and Manjaiah, K.M. (2012). Effects of elevated atmospheric CO_2 and temperature on phosphorus efficiency of wheat (*Triticum aestivum*L.) grown in an inceptisol of subtropical India. *Plant Soil Environ*., 58(5):230-235.

Kumar, R., Kaundal, M., Sharma, S., Thakur, M., Kumar, N., Kaur, T., Vyas, D. and Kumar, S. (2017). Effect of elevated [CO_2] and temperature on growth, physiology and essential oil composition of *Salvia sclarea* in the western Himalayas. *J. App. Res. Med. Arom. Plants.,* 6:22-30.

Lewis, J.D. Phillips, N.G., Logan, B.A., Smith, R.A., Aranjuelo, I., Clarke, S., Offord, C.A., Frith, A., Barbour, M., Huxman, T. and Tissue, D.T. (2015). Rising temperature may negate the stimulatory effect of rising CO_2 on growth and physiology of Wollemi pine (*Wollemianobilis*). *Funct. Plant Biol*., 42(9):836-850.

Ma, H., Zhu, J., Xie, Z., Liu, G., Zeng, Q. and Han, Y. (2007). Responses of rice and winter wheat to free air CO_2 enrichment (China FACE) at rice/wheat rotation system. *Plant Soil*, 294:137-146.

Madhu, M. and Hatfield, J.L. (2013). Dynamics of plant root growth under increased atmospheric carbon dioxide. *Agron. J.* 105:657-669.

NOAA/ESRL. (2017). Ed Dlugokencky and Pieter Trans. NOAA/ESRL, (www.esrl.noaa.gov/gmd/ccgg/trends/).

Oh-e, I., Kuniyuki, S. and Toshiro, K. (2007). Effect of high temperature on growth, yield and dry matter production of rice grown in the paddy field. *Plant prod. Sci.,* 10(4):412-422.

Qaderi, M.M., Kurepin, L.V. and Reid, D.M. (2006). Growth and physiological responses of canola (*Brassica napus*) to three components of global climate change: temperature, carbon dioxide and drought.*Physiol. Plant*., 128:710-721.

Rakshit, R., Patra, A.K., Pal, D., Kumar, M. and Singh, R. (2012). Effect of elevated CO_2 and temperature on Nitrogen Dynamics and Microbial Activity during wheat (*Triticum aestivum* L.) growth on a subtropical inceptisol in India. *J. Agron. Crop Sci*., 198:452-465.

Rao Srinivasa, N.K., Laxman, R.H. and Bhatt, R.M. (2010). Impact of climate change on vegetable crops. In: Challenges of climate change - Indian Horticulture. Singh, H.P., Singh, J.P. and Lal, S.S. Westville Publishing House, 114-123.

Sahoo, H.R. and Gupta, N. (2017). Of vermicompost in enhancing growth and development of *Piper longum*- A ret medicinal plant.*Sci. Agric*.,17(3):77-81.

Save, R., de Herralde, F., Codina, C., Sanchez, X. and Biel, C.(2007). Effects of atmospheric carbon dioxide fertilization on biomass and secondary metabolites of some plant species with pharmacological interest under greenhouse conditions. *Afinidad*., 64:237-241.

Vagheera, P., Vanaja, M., Satyavathi, P., Sathish, P., Kumar, G.V. and Anitha, Y.(2015). Interaction of elevated CO_2 and moisture stress on blackgram growth and yield. *Int. J. Appl. Biol. Pharma. Technol.,*6(2):168-173.

Weigel, H-J. and Manderscheid, R. (2012). Crop growth responses to free air CO_2 enrichment and nitrogen fertilization: Rotating barley, ryegrass, sugar beet and wheat. *Eur. J. Agron*., 43:97-107.

Zhou, X., Ge, Z.M., Kellomaki, S., Wang, K.Y., Peltola, H., Shurpali, N. and Martikainen, P.(2011). Effects of elevated CO_2 and temperature on leaf characteristics, photosynthesis and carbon storage in aboveground biomass of a boreal bioenergy crop (*Phalarisarundinacea* L.) under varying water regimes. *Glob. Change Biol. Bioenergy*, 3:223-234.

Received : October 2019 ; Accepted : November 2020