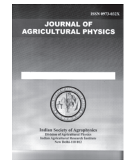
Vol. 15, No. 1, pp. 69-73 (2015)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in



Research Article

Biomass Partitioning of Cowpea as Affected by Elevated CO_2, Cyanobacterial Inoculation and Different Doses of Phosphorus

SUMIT KUMAR DEY[1], B. CHAKRABARTI[1]*, R. PRASANNA[2], D. PRATAP[1], S.D. SINGH[1], T.J. PURAKAYASTHA[3] AND H. PATHAK[1]

[1]Centre for Environment Science and Climate Resilient Agriculture, [2]Division of Microbiology, [3]Division of Soil Science and Agricultural Chemistry
ICAR-Indian Agricultural Research Institute, New Delhi-110012

ABSTRACT

An experiment was conducted in free air carbon-dioxide enrichment facility (FACE) ring to study the impact of increased CO_2 level, cyanobacteria inoculation and phosphorus doses on biomass partitioning in cowpea. The crop was grown under elevated (550 ± 20 ppm) and ambient (400 ppm) CO_2 concentration with 5 doses of P with and without cyanobacterial inoculation. Elevated CO_2 level increased the partitioning of biomass to root, stem and leaf throughout the crop growth period. At 45 DAS, stem biomass was 8.45 g plant^{-1} under elevated CO_2 condition, while ambient CO_2 treatment recorded stem biomass of 6.49 g plant^{-1}. Similar trend was also observed in root and leaf biomass of the crop. Application of phosphorus (P) and cyanobacteria further increased the partitioning of biomass to the plant parts.

Key words: Elevated CO_2, Phosphorus, Cyanobacteria, Biomass partitioning, Cowpea

Introduction

Global climate change has emerged as a challenge due to its potential impact on biological systems. Presently, CO_2 concentration in the atmosphere is steadily increasing at the rate of nearly 2 ppm yr^{-1}. An increase in CO_2 concentration generally increases plant productivity (Drake and Gonzàlez-Meier, 1997). Among the crops, legumes may have advantages over non-leguminous crops due to its ability to fix atmospheric greater nitrogen (N) under elevated CO_2 (Zanetti *et al*., 1996; Ross *et al*., 2004). Growth response of different crop species to increased CO_2 concentration is different (Hunt *et al*., 1991; Poorter *et al*., 1996), and is also dependent on the nutrient status of soil. As phosphorus (P) plays an important role in N fixation, we have studied the response of cowpea, a leguminous crop under varying P doses, with the hypothesis that P application will further increase growth and biomass partitioning of the crop under elevated CO_2 condition. Cyanobacterial strains liberate a variety of extracellular substances like plant-hormones and other metabolites which have impact on plant growth (Prasanna *et al*., 2011; Manjunath *et al*., 2011). We have further studied the role of cyanobacteria under elevated CO_2 condition in enhancing the growth of cowpea.

*Corresponding author,
Email: bidisha2@yahoo.com

Materials and Methods

The experiment was conducted during July to October months of 2014 at the ICAR-Indian

Agricultural Research Institute farm, New Delhi. Elevated CO_2 concentration (550 ± 20 ppm) was maintained using FACE (Free Air Carbon-dioxide Enrichment) facility. The FACE ring is made up of eight horizontal pipes which release CO_2-enriched air at the crop canopy level. CO_2 concentration inside the ring was measured by non-dispersive infrared gas analyzer (IRGA) and data was logged automatically in the computer at every 5 minutes interval (Chakrabarti *et al.*, 2012).

Cowpea (var. Pusa Sukomal) was grown in pots both inside and outside the FACE facility. Recommended doses of N and K were applied as basal. Five different levels of P were applied through single super phosphate: 75% of recommended dose of P (RDP), 100 % RDP, 125% RDP, 150% of RDP and a control (no phosphatic fertilizer applied). Cowpea seeds were inoculated with crop-specific *Rhizobium* inoculants available in the Division of Microbiology and the cyanobacterium *Calothrix* sp. inoculation was done in soil.

Leaf, stem and root biomass were monitored by destructive sampling at 25, 45 and 65 days after showing (DAS). The design of the experiment was factorial completely randomized design (CRD) with 20 treatments. Statistical analysis of the data was performed using SAS (ver. 9.3) developed by SAS Institute Inc.

Results and Discussion

Biomass partitioning

The crop grown under elevated CO_2 concentration accumulated higher biomass, which was reflected in higher leaf, stem and root biomass of the crop at different growth stages (Table 1). The P levels also significantly increased in leaf, root and stem biomass at different growth stages. The positive effect of CO_2, cyanobacteria and P application on biomass partitioning led to higher above ground biomass of the crop at different crop growth stages.

Root biomass

Elevated CO_2 caused higher root growth of the crop. At 25, 45 and 65 DAS, root biomass was 0.73, 2.01 and 1.77 g plant^{-1}, respectively under elevated CO_2 while in ambient condition, the values were 0.51, 1.39 and 1.19 g plant^{-1} (Table 2). Earlier workers also reported increased root growth in response to enriched CO_2 condition due to increased supply of photosynthate to roots (Jin *et al.*, 2012; Laby *et al.* 2000).

Initially, cyanobacteria showed no effect on root biomass but at later stages (45 & 65 DAS), cyanobacterial inoculation significantly increased the root biomass of the crop (Table 2). Higher rhizosphere activity in cyanobacteria treatments during the flowering stage of the crop might have

Table 1. Significant effect of CO_2, cyanobacterial inoculation (Cya) and P doses and their interaction on cowpea root, leaf and stem biomass

Biomass	DAS	CO_2	Cya	P	CO_2 x Cya.	CO_2× P	Cya × P	CO_2 × Cya × P
Root	25	S*	NS	S	NS	NS	NS	NS
	45	S	S	S	S	S	NS	NS
	65	S	S	S	NS	NS	NS	NS
Leaf	25	S	S	S	NS	S	NS	NS
	45	S	S	S	NS	S	NS	NS
	65	S	S	S	NS	NS	NS	NS
Stem	25	S	S	S	NS	NS	NS	NS
	45	S	S	S	NS	NS	NS	NS
	65	S	S	S	NS	NS	NS	NS

*Significant at $P<0.05$; NS = Non-significant

Table 2. Impact of elevated CO_2, cyanobacterial inoculation and phosphorus dose on root biomass in cowpea (g plant^{-1}) at 25, 45 and 65 DAS

P Levels (mg kg^{-1} soil)	Phosphorus	Ambient CO_2	Elevated CO_2	Without Cyanobacteria	With Cyanobacteria
			25 DAS		
P	0.50 $^{B\#}$	0.40 ^{A}	0.60 ^{A}	0.49 ^{A}	0.51 ^{A}
8	0.62 ^{A}	0.51 ^{A}	0.74 ^{A}	0.61 ^{A}	0.63 ^{A}
12	0.63 ^{A}	0.51 ^{A}	0.75 ^{A}	0.61 ^{A}	0.64 ^{A}
16	0.65 ^{A}	0.53 ^{A}	0.78 ^{A}	0.67 ^{A}	0.64 ^{A}
20	0.68^{A}	0.59 ^{A}	0.78 ^{A}	0.66 ^{A}	0.71 ^{A}
Mean		*0.51* ^{B}	*0.73* ^{A}	*0.61* ^{A}	*0.63* ^{A}
			45 DAS		
Control P	1.48 ^{D}	1.24 ^{H}	1.73 ^{D}	1.35 ^{A}	1.61 ^{A}
8	1.61 ^{C}	1.31 ^{G}	1.91 ^{C}	1.48 ^{A}	1.74 ^{A}
12	1.75 ^{B}	1.45 ^{F}	2.06 ^{B}	1.62 ^{A}	1.89 ^{A}
16	1.82 ^{A}	1.48 ^{EF}	2.17 ^{A}	1.67 ^{A}	1.98 ^{A}
20	1.86 ^{A}	1.52 ^{E}	2.19 ^{A}	1.74 ^{A}	1.97 ^{A}
Mean		*1.39* ^{B}	*2.01* ^{A}	*1.57* ^{B}	*1.84* ^{A}
			65 DAS		
Control P	1.15 ^{B}	0.95 ^{A}	1.36 ^{A}	1.02 ^{A}	1.29 ^{A}
8	1.33 ^{B}	1.05 ^{A}	1.60 ^{A}	1.19 ^{A}	1.47 ^{A}
12	1.55 ^{A}	1.26 ^{A}	1.84 ^{A}	1.44 ^{A}	1.66 ^{A}
16	1.67 ^{A}	1.32 ^{A}	2.03 ^{A}	1.48 ^{A}	1.86 ^{A}
20	1.70 ^{A}	1.39 ^{A}	2.02 ^{A}	1.60 ^{A}	1.80 ^{A}
Mean		*1.19* ^{B}	*1.77* ^{A}	*1.35* ^{B}	*1.61* ^{A}

#Values followed by same letters in a column are not significantly different.

resulted in higher biomass allocation to roots at later growth stages. The P application also significantly improved root growth of the crop over the control. At 45 DAS, increase in P dose up to 16 mg kg^{-1} soil significantly enhanced the root biomass of the crop. Beneficial effect of P application and cyanobacteria on root growth was more pronounced in high CO_2 treatment at 45 DAS (Table 2). This shows that during the flowering stage of the crop, when the root activity was maximum, elevated CO_2 along with addition of P and cyanobacteria had significant positive impact on root growth of cowpea.

Stem biomass

Elevated CO_2 had positive effect on stem biomass in all three growth stages. At 25, 45 and 65 DAS, stem biomass was 1.83, 8.45 and 8.11 g plant^{-1} under elevated CO_2 condition while under ambient CO_2 treatment, biomass were recorded as 1.36, 6.49 and 6.35 g plant^{-1}, respectively (Table 3). Cyanobacteria inoculation and P application significantly increased biomass of the stem throughout the growth stages. At 45 DAS, stem biomass was 7.75 g plant^{-1} in cyanobacteria applied treatments while in treatments without cyanobacteria, stem biomass was 7.2 g plant^{-1}. Increase in P dose up to 12 mg kg^{-1} soil significantly enhanced stem biomass of the crop.

Leaf biomass

Leaf biomass of the crop was 1.66, 6.71 and 6.25 g plant^{-1} at 25, 45 and 65 DAS in high CO_2 treatment while at ambient CO_2 level, values were 1.27, 5.05 and 4.76 g plant^{-1}respectively (Table 4). Cyanobacteria application also significantly increased leaf biomass of the crop. Leaf biomass was 5.58 g plant^{-1} in ambient treatment while in

Table 3. Impact of elevated CO_2, cyanobacterial inoculation and phosphorus doses on stem biomass (g $plant^{-1}$) at 25, 45 and 65 DAS in cowpea

P Levels	Mean				
(mg kg^{-1} soil)	Phosphorus	Ambient CO_2	Elevated CO_2	Without Cya.	With Cya.
			25 DAS		
Control P	$1.21^{C\#}$	1.04^{A}	1.37^{A}	1.16^{A}	1.25^{A}
8	1.48^{B}	1.26^{A}	1.69^{A}	1.41^{A}	1.54^{A}
12	1.71^{A}	1.43^{A}	1.99^{A}	1.62^{A}	1.80^{A}
16	1.79^{A}	1.55^{A}	2.02^{A}	1.75^{A}	1.82^{A}
20	1.79^{A}	1.52^{A}	2.06^{A}	1.69^{A}	1.90^{A}
Mean		*1.36^{B}*	*1.83^{A}*	*1.53^{B}*	*1.66^{A}*
			45 DAS		
Control P	5.40^{C}	4.60^{A}	6.20^{A}	5.20^{A}	5.60^{A}
8	6.98^{B}	5.98^{A}	7.98^{A}	6.52^{A}	7.44^{A}
12	8.10^{A}	7.11^{A}	9.09^{A}	7.87^{A}	8.33^{A}
16	8.46^{A}	7.36^{A}	9.57^{A}	8.29^{A}	8.63^{A}
20	8.43^{A}	7.42^{A}	9.44^{A}	8.14^{A}	8.72^{A}
Mean		*6.49^{B}*	*8.45^{A}*	*7.20^{B}*	*7.75^{A}*
			65 DAS		
Control P	6.41^{B}	5.51^{A}	7.31^{A}	5.96^{A}	6.85^{A}
8	6.95^{AB}	5.96^{A}	7.94^{A}	6.27^{A}	7.62^{A}
12	7.66^{A}	6.75^{A}	8.57^{A}	7.37^{A}	7.95^{A}
16	7.48^{A}	6.59^{A}	8.37^{A}	7.13^{A}	7.83^{A}
20	7.67^{A}	6.94^{A}	8.39^{A}	7.19^{A}	8.15^{A}
Mean		*6.35^{B}*	*8.11^{A}*	*6.78^{B}*	*7.68^{A}*

#Values followed by same letters in a column are not significantly different

Table 4. Impact of elevated CO_2, cyanobacterial inoculation and phosphorus doses on leaf biomass (g $plant^{-1}$) at 25, 45 and 65 DAS in cowpea

P Levels	Mean				
(mg kg^{-1} soil)	Phos.	Ambient CO_2	Elevated CO_2	Without Cya.	With Cya.
			25 DAS		
Control P	1.03^{D}	0.91^{F}	1.14^{FE}	0.97^{A}	1.09^{A}
8	1.31^{C}	1.17^{DE}	1.44^{C}	1.22^{A}	1.40^{A}
12	1.56^{B}	1.36^{CDE}	1.75^{B}	1.54^{A}	1.58^{A}
16	1.66^{AB}	1.42^{CD}	1.91^{AB}	1.61^{A}	1.72^{A}
20	1.76^{A}	1.48^{C}	2.04^{A}	1.72^{A}	1.80^{A}
Mean		*1.27^{B}*	*1.66^{A}*	*1.41^{B}*	*1.52^{A}*
			45 DAS		
Control P	3.61^{D}	3.16^{F}	4.06^{E}	3.19^{A}	4.03^{A}
8	5.26^{C}	4.48^{E}	6.05^{C}	4.96^{A}	5.56^{A}
12	6.26^{B}	5.21^{D}	7.31^{B}	5.92^{A}	6.61^{A}
16	7.03^{A}	6.12^{C}	7.94^{AB}	6.89^{A}	7.17^{A}
20	7.22^{A}	6.26^{C}	8.18^{A}	6.94^{A}	7.50^{A}
Mean		*5.05^{B}*	*6.71^{A}*	*5.58^{B}*	*6.17^{A}*
			65 DAS		
Control P	4.00^{C}	3.36^{A}	4.64^{A}	3.74^{A}	4.26^{A}
8	4.78^{BC}	4.04^{A}	5.52^{A}	4.59^{A}	4.97^{A}
12	5.52^{B}	4.76^{A}	6.29^{A}	5.20^{A}	5.85^{A}
16	6.36^{A}	5.60^{A}	7.12^{A}	6.03^{A}	6.70^{A}
20	6.86^{A}	6.05^{A}	7.67^{A}	6.67^{A}	7.05^{A}
Mean		*4.76^{B}*	*6.25^{A}*	*5.24^{B}*	*5.77^{A}*

#Values followed by same letters in a column are not significantly different elevated CO_2 treatment, it was 6.17 g plant^{-1} during the flowering stage (45 DAS). Allocation of biomass to leaves increased with P application to the crop. In control, where no P was applied, 34.4% of total biomass was allocated to leaves while maximum P dose resulted in translocating 41.2% of total biomass to leaves at 45 DAS. P application rate up to 16 mg kg^{-1} soil significantly enhanced leaf dry weight of the crop at 45 and 65 DAS. Increase in plant growth in response to increased P dose has been earlier observed in several leguminous species (Israel, 1987; 1993).

Conclusions

Elevated CO_2 increased the root, stem and leaf biomass of the crop. It is likely that higher photosynthetic activity of the crop under elevated atmospheric CO_2 condition has led to accumulation of more carbon assimilates, which was eventually partitioned to different plant parts. Phosphorus and application of cyanobacteria further increased the partitioning of biomass to those above mentioned plant parts.

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Received: April 16, 2015; Accepted: May 30, 2015