Dry matter partitioning and growth analysis of soybean grown under elevated CO_2 and soil moisture levels

The growth of plants is influenced by above- and below-ground environmental conditions. Elevated CO_2 tends to enhance growth and yield of majority of the agricultural plants[1,2] and generally increase plant productivity and water-use efficiency[3]. However, the long-term response depends on environmental constraints. It is expected to increase the incidence of extreme weather events, viz. heat waves, heavy rains, drought, floods, etc. making agricultural production more unpredictable and difficult due to climate change[3,4]. Under the climate change scenario, many of the environmental factors, e.g. water, temperature, light, nutrition, salinity, air pollutants, etc. have significant interacting effects with increased CO_2 concentration influencing greatly on root dynamics of many plant species[5,6]. The findings of increased CO_2 on crops vary with different soil moisture regimes[7]. The altered physiology of crop plants with climate change[8] and shift in rainfall pattern at regional scale leading to decreased soil water availability, ultimately impacting on crops yield and food security[9]. The interactive feedback of elevated CO_2 and plant water stress affect carbohydrate concentration in plants[10]. This study presents the combined feedback of CO_2 enrichment and soil moisture levels on partitioning of dry matter, root growth parameters and growth analysis of soybean plants during vegetative stages of growth.

The study was conducted under control environment using rhizotrons at USDA-ARS National Laboratory for Agriculture and Environment (NLAE) in Ames, Iowa, USA. S21-N6 (Maturity group 2) genotype of soybean was planted at a spacing of 60 × 10 cm in each soil monolith. Soil moisture was maintained uniformly in the soil profile for initial 15 days after sowing (DAS). All environmental parameters were adjusted and controlled automatically by a computer. Two CO_2 concentrations, viz. 380 and 800 μmol mol^{-1}, and three soil moisture levels, namely low, normal and high were studied. The concentration of CO_2 used in the study is just double that of current levels in understanding the physiological response of the crop, and photosynthesis-related genes like RUBISCO may be highly sensitive to CO_2 (ref. 11). In each chamber CO_2 levels were monitored using LICOR infrared gas analyzer (LI-800 Gas Hound CO_2 Analyzer, LI-COR, NE, USA). The response of soybean to elevated CO_2 with soil moisture regimes was assessed at V-3/V-4 (29 days after planting (DAP)), V-6 stage (44 DAP) and at R3 (58 DAP) growth stage of soybean crop. Dry matter partitioning was assessed at all the three stages and expressed in percentage to total dry matter production. Root to shoot ratio (RSR), i.e. ratio of total aboveground dry weight of plant to the total root weight was calculated at 29 and 44 DAS. Net assimilation rate (NAR) and relative crop growth rate (RGR) were also calculated[12]. Effects of CO_2 levels, soil moisture and interactions were studied and interpreted using the least significant difference at $P = 0.05$.

The RSR of soybean was significantly lower at 29 DAS under elevated CO_2 (11%), but it was higher by 7% at 44 DAS over plants under ambient CO_2 (Figure 1). Review of the available literature[13] revealed that substantial variation in RSR of crop plants with CO_2 doubling where it decreased by 8.5% to an increase of 6.4%, except in sweet potato where it increased by 34.9%. Increased RSR was attributed to propositional allocation of more C to belowground parts of plant. In the present study, high CO_2 might have inhibited the growth at early stage of crop but due to adaptive mechanism of plants to high CO_2, plants were recovered and responded physiologically increased growth at later stage. Our study showed that at early stage of crop plant, growth was inhibited under high CO_2 and at later stage adaptive mechanism of plants to increased CO_2 and

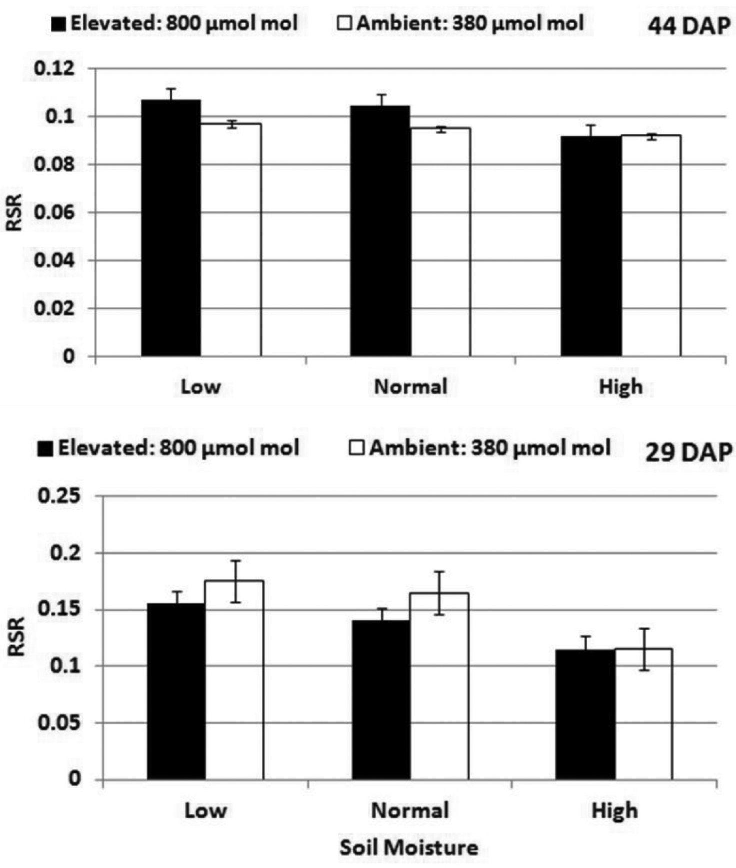

Figure 1. Elevated CO_2 and soil moisture levels on root–shoot ratio (RSR) of soybean. (Elevated: 800 μmol mol^{-1} and ambient: 380 μmol mol^{-1}).

	29 DAS			44 DAS			58 DAS		
	Roots	Leaves	Stem	Roots	Leaves	Stem	Leaves	Stem	Pods
CO_2	NS	NS	NS	NS	*	NS	NS	NS	NS
Soil moisture	*	*	NS	NS	*	NS	*	NS	*
CO_2 × SM	NS	nS	NS	NS	NS	NS	*	NS	NS

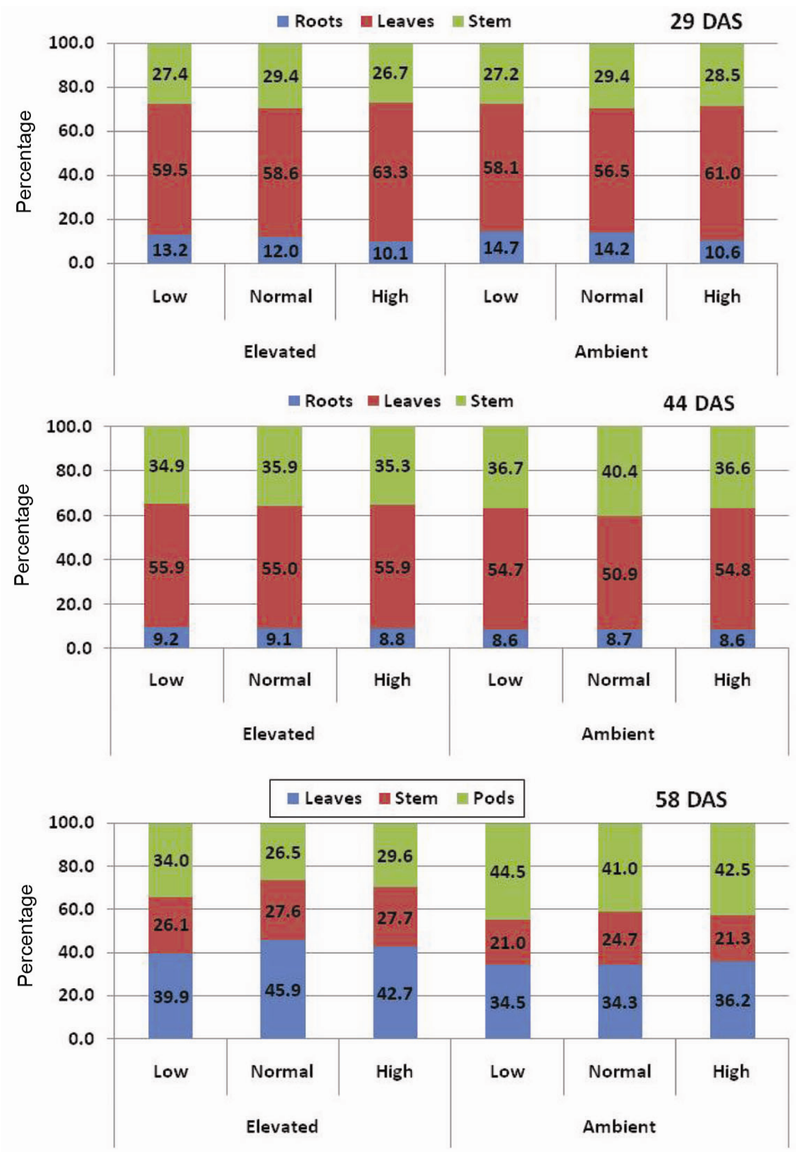

Figure 2. Dry matter partitioning percentage of soybean under elevated CO_2 and soil moisture levels.

feedback of plants was physiologically positive. The result is in conformity with that of an earlier study[3]; however, some studies have reported slightly faster growth at vegetative stage of soybean crop[2]. At early stage (29 DAS), RSR was greater by 43.4% and 32.6% under low and normal soil moisture respectively over high soil moisture conditions, but in the later stage of the crop (44 DAS) the trend was similar (10.9% and 8.7%). This reveals that plants under water stress tend to allocate more carbon to roots for increased uptake of soil water and nutrients by increasing root and soil surface contacts. But, under optimal conditions, CO_2 enrichment did not alter the partitioning of photosynthetic assimilates. At 44 DAS, elevated CO_2 failed to produce more dry matter, but at 29 DAS dry matter portioning was slightly greater under elevated CO_2 levels (Table 1 and Figure 2). At 58 DAS, soybean plants exposed to elevated CO_2 produced greater dry matter in leaves (93.8%); shoot (83.5%) and total (56.0%). The findings on dry matter portioning is in conformity with many earlier studies, where annual crops showed greater total dry matter production of soybean[15], dry bean[16], peanut[17] and cowpea[18] under elevated CO_2 levels. At later stage partitioning of assimilated carbon towards the growing organs was greater when soybean plants were exposed to elevated CO_2 levels. However, initial carbon allocation to the roots was higher in plants under ambient CO_2 condition (13.2%) compared to elevated CO_2 levels (11.8%). At 44 DAS, plants allocated more carbon to roots (9.1%) under elevated CO_2 levels against plants under ambient CO_2 condition (8.6%).

Partitioning of carbon to leaves was significantly greater under elevated CO_2 levels (55.6%) over plants exposed to ambient CO_2 (53.4%) at 44 DAS. In later stage, accumulated carbon was transported to pods from leaves and stem and showed greater carbon partitioning to pods under ambient CO_2 condition (42.6%) against elevated CO_2 levels (30%). Plants under elevated CO_2 levels allocated more carbon to the leaves, thus increasing leaf area thickness and the number of leaves.

Soil moisture showed significant influence on dry matter partitioning of soybean, where plants under low soil moisture condition allocated more carbon to roots, while those under high soil moisture allocated more carbon to leaves. Under normal soil moisture, plants showed balanced carbon allocation to all the parts. Above- and below-ground dry matter accumulation is affected differently by moisture stress, with above-ground plant parts generally being sensitive than below-ground parts[19], because the transpiring plant parts usually develop greater water deficits for prolonged period[20]. At 44 DAS, significantly more carbon was allocated to leaves when plants were exposed to low and high soil moisture conditions. Significantly greater amount of carbon was allocated to pods at low soil moisture (39.2%) and to leaves at normal to high soil moisture levels (40.1% and 39.5%) at 58 DAS. However, carbon allocation to stem was not significant for all the soil

Table 1. Dry matter partitioning of soybean under CO_2 and soil moistures level at different growth stages

	Dry weight (g plant^{-1})											
	Leaves			Stem			Root		Pods	Total		
	29 DAS	44 DAS	58 DAS	29 DAS	44 DAS	58 DAS	29 DAS	44 DAS	58 DAS	29 DAS	44 DAS	58 DAS
CO_2 levels												
Elevated	0.58	2.81	5.11	0.27	1.82	4.73	0.12	0.45	4.97	0.94	5.07	17.20
Ambient	0.53	3.14	11.39	0.26	2.24	2.56	0.11	0.50	4.58	0.89	5.87	10.98
Change (%)	8.9	–10.7	–55.1	3.1	–18.7	84.7	3.6	–10.4	8.6	5.9	–13.7	56.6
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Soil moisture levels												
Low	0.53	2.92	4.38	0.25	1.91	2.84	0.13	0.46	4.42	0.90	5.28	11.63
Normal	0.55	3.18	7.76	0.28	2.31	4.97	0.12	0.53	5.78	0.95	6.01	18.50
High	0.57	2.84	4.89	0.26	1.86	3.13	0.10	0.43	4.14	0.91	5.12	12.14
LSD	NS	NS	**	NS	NS	**	NS	NS	**	NS	NS	**
CO_2 × moisture	*	NS	**	**	NS	*	**	NS	NS	*	NS	NS

*Significant at $P = 0.01$; **significant at $P = 0.05$.

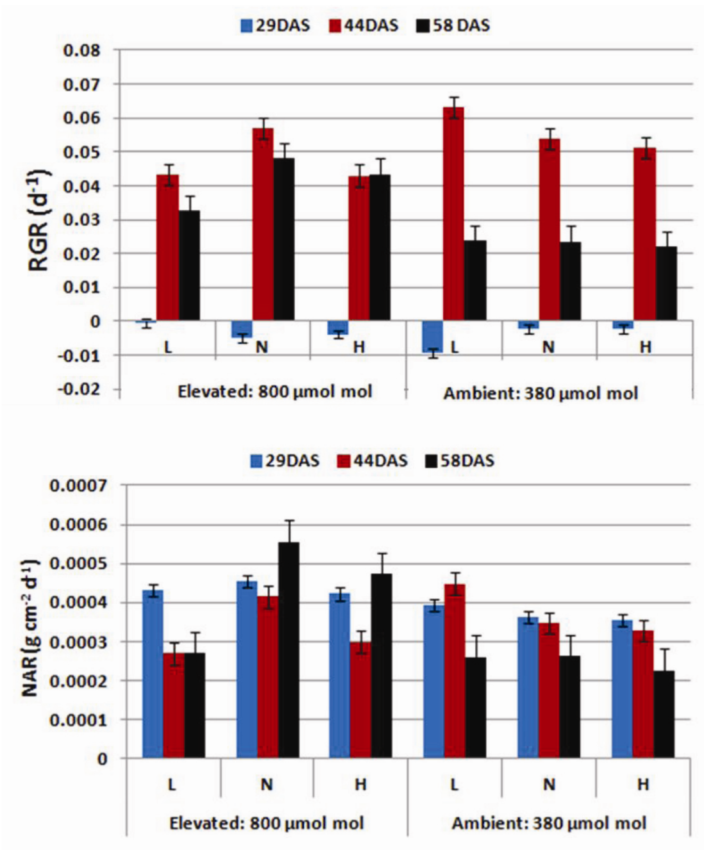

Figure 3. Net assimilation rate (NAR) and relative growth rate (RGR) of soybean under CO_2 and soil moisture levels (L, Low; N, Normal; H, High; Elevated: 800 µmol mol^{-1} and Ambient: 380 µmol mol^{-1}).

moisture levels. Interactive effect of CO_2 concentration and soil moisture levels on carbon partitioning of soybean were significant only for leaves at 58 DAS. The combined effect of increased CO_2 on crop plants varied with different soil moisture conditions[12], but earlier studies were conducted under favourable soil moisture status. Higher CO_2 concentration with soil moisture at normal status produced significantly more number of root nodules per plant indicating partitioning of carbon to root nodules which contributes greatly for nitrogen fixation. Increased carbon partitioning to root nodules may benefit seed protein content of soybean associated with decreased C : N ratio of leaves.

The effect of elevated CO_2 on NAR depends on the age of crop plant, duration of exposure and soil moisture status[1]. At initial stage (29 DAS), NAR was greater by 17.8% under elevated CO_2 levels over ambient CO_2 levels (Figure 3). However, NAR decreased at mid stage (44 DAS); this may be attributed to slow growth of plants under increased CO_2 condition. However, at later stage, i.e. 58 DAS, NAR increased by 73% under elevated CO_2 over ambient condition, which could be attributed to increased number of leaves, leaf area, specific leaf area (SLA), leaf area ratio (LAR), etc. RGR increased by 17.6% under ambient CO_2 level at 44 DAS. It increased sharply by 78.6% under elevated CO_2 levels at 58 DAS. Our results contradict another study[21], where greater NAR and RGR were reported at initial stage of crop, which decreased with age of the plant. In the present study, both RGR and NAR were greater under elevated CO_2 levels at 58 DAS. Soil moisture did not have a significant effect on RGR and NAR at all the growth stages of soybean. Interaction of CO_2 levels and soil moisture levels was significant only for NAR at 44 DAS. RGR and NAR were greater under normal soil moisture with elevated CO_2 levels. Partitioning of carbon to different parts of soybean was significantly affected by elevated CO_2 and showed positive feedback under optimum soil water for growth. Allocation of carbon to roots at early stage and above-ground parts during vegetative stage of soybean was greater under elevated CO_2 levels with normal soil moisture. Root nodulation and nitrogen fixation were found to increase under increased CO_2 levels, but partitioning of carbon towards grain and leaves needs further investigations. RGR and NAR were greater under normal soil moisture with elevated CO_2 levels associated with increased number of leaves, leaf area, SLA, LAR, etc.

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Aconite from Sikkim Himalaya, India

While working on the taxonomy of genus *Aconitum* from India, we collected specimens from East region of Sikkim Himalaya during September 2014, where we came across a small population of *Aconitum* taxon which was apparently different from other existing populations in the surrounding area. On critical examination, we observed that these specimens were strikingly different from the rest of the collections in Sikkim Himalaya. Detailed morpho-taxonomic studies revealed it to be an undescribed taxon, showing close affinity with *A. spicatum*. This new species is named as *Aconitum arunii* after Arun Kumar Pandey (Department of Botany, University of Delhi, India) to honour his remarkable contributions to the knowledge of angiosperm systematics of Indian flora. The new species is described here.

Aconitum arunii sp. nov. (Figure 1).

Type: India, East Sikkim, Kupup, 3943 m, 12.09.2014, *T. Husain & P. Agnihotri* 257637 (holo. LWG; iso. LWG).

Diagnosis: *A. arunii* is closely allied to *A. spicatum* Stapf, but differs from it in having clawed bracts, hairy linear bracteoles, upwardly directed beak of upper sepal, flattened and conspicuously veined lobes of petal lip and prominent staminal teeth.

Erect herbs, 1 m high, stems much branched, densely strigose towards apex, obscurely angular, hollow. Leaves cauline; petioles up to 8 cm long, sheathing with dilated base, retrorsely strigose; lamina reniform, 1.5–5 × 5–14 cm wide, deeply cordate at base, three-palmatipartite; central lobe narrowly rhomboid, apically 2–3-lobulate; lobules dentate; teeth ovate or triangular, mucronate at apex; lateral lobes obliquely flabellate, unequally parted forming two sub-lobes, all lobes similar, cuneate at base, other sub-lobes 2–3-lobulate, lobules dentate. Racemose panicles 22–26 cm long, retrorsely dense hairy; bracts 1.6–2.2 cm long, tripartite; central lobe 1.4–1.8 cm long, lobed; sub lobes 1–2 lobulate, lobules obovate or acuminate; lateral lobes ca. 8–8.5 mm long, similar to central lobe; densely adpressed hairy above and on veins beneath. Flowers blue; pedicels up to 4 cm long, obscurely angled near base, densely spreading hairy; bracteoles two, opposite, near the middle of lower