Effects of Water Deficit and CO_2 Enrichment on Potato Development

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INTRODUCTION

Potato is a drought sensitive crop. Reductions in growth and development occur at even mild levels of water stress. As with other C3 crops, potato assimilation rates and dry matter production generally increase with CO_2 enrichment. Elevated CO_2 may also play a role in mediating long-term plant responses to drought. Despite the agronomic importance of potato (the United States is the 5th largest potato growing country in the world), however, few studies have evaluated interactions of CO_2 and water stress on its growth and development. Reduced canopy expansion is one of the primary results of long-term drought in potato. Thus, the manner in which potato canopy formation is influenced by the interaction of CO_2 and water stress, and how those dynamics are correlated with whole plant growth, need to be studied. Elucidating these interactions will play an important role in studying agricultural management and production under various global climate change scenarios.

OBJECTIVES

The focus of this study was to determine the interaction of CO_2 and water stress on potato canopy growth and development. Objectives include evaluation of:

(1) Effect of IRR on (i) whole plant length, (ii) leaf appearance and (iii) expansion, (iv) lateral branching patterns, and (v) biomass partitioning, and

(2) Effect of CO_2 enrichment on these factors.

MATERIALS AND METHODS

Figure 1: SPAR chambers, A, B: potato plants at 30 days after emergence, C,D: soilbin compartment.

SPAR Facilities (USDA-ARS Beltsville, MD)

- Soil-plant-atmosphere research (SPAR) chambers are naturally sunlit, controlled growth environments that provide:
  - Control / Monitoring of T, CO_2, RH, PAR.
  - Measurement of whole plant gas exchange.
  - 1 m^2 plant production area and 1 m^3 'soilbin'.
  - Control / Monitoring of irrigation via drippers and TDR probes.

Experiments

- Two 6 SPAR chamber experiments at 370 (ambient) and 740 (elevated) µmol mol^{-1} CO_2
- A 16h 23°C day / 8h 18°C night thermoperiod was used for all chambers.
- A 75% sand / 25% vermiculite mix was used with time release fertilizer.
- *Solanum tuberosum* cv Kennebec seed tubers were planted (12 plants m^{-2}).
- Water stress was imposed by varying daily irrigation (IRR) amount to each chamber.
- The amount of IRR was provided to each SPAR chamber according to 90, 75, 50, 25 and 10% of the daily water uptake measured from the control chamber (100%).

RESULTS

1. Plant Length / Stem Elongation

Summary: Length declined with water stress and was further reduced by elevated CO_2 at lower levels of IRR.

Details:

- Significant IRR x CO_2 interaction present ($p < 0.05$)
- Differences in length for well-watered plants were not significant between CO_2 treatments.
- Shorter stem lengths coincided with smaller stem elongation rates and growth durations.

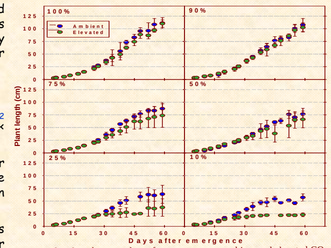

Figure 2: Plant length versus days after emergence at ambient and elevated CO_2 at 6 different levels of IRR (% of control irrigation). Data points are 5 plant averages.

2. Leaf Appearance / Canopy Leaf Formation

Summary: The total number of leaves that formed in the canopy decreased with IRR and elevated CO_2.

Details:

- Leaf appearance rates declined with irrigation.
- The length of time for which leaves continued to appear in the canopy (appearance duration) was reduced by IRR and CO_2.
- Fewer leaves were formed in the canopy at lower irrigation levels and elevated CO_2.

Table 1: Leaf appearance duration, rate, and total number of leaves over the season for potatoes grown at 370 (amb) and 740 (elv) µmol mol^{-1} CO_2 at different irrigation levels (IRR). Values are five plant averages.

	Leaf appearance and duration					
	Leaf appearance duration		Leaf appearance rate		Total leaves	
IRR	Amb	Elv	Amb	Elv	Amb	Elv
	d		leaves $plant^{-1}$ d^{-1}		#	
100%	71.6a†	70.8a	0.91	0.99	65.8a	67.8a
90%	70.2a[1]	55.6b[1]	0.91	0.90	64.8a	53.6a
75%	73.6a[1]	52.8b[1]	0.80	0.93	61.6a	52.8b
50%	67.3a	45.0bc	0.80	0.80	58.5a	38.6c
25%	69a[1]	28.8d[1]	0.75	0.77	58.5a[1]	26.2c[1]
10%	45.2b[1]	36.2cd[1]	0.77	0.53	38.8b[1]	26c[1]
Mean	66.0	48.2	0.82	0.82	58.0	44.2
LSD(0.05)	11.6	12.7	0.1		10.3	13.9
IRR	P < 0.001		P < 0.001		P < 0.001	
[CO_2]	P < 0.001		NS		P < 0.001	
IRRx[CO_2]	P < 0.001		NS		P < 0.001	

†,‡Letters indicate LSD differences between IRR at a given CO_2 treatment. A '1' indicates significant differences between CO_2 treatments at the IRR level.

3. Individual Leaf Area Expansion

Summary: Leaf area of individual leaves declined linearly with IRR. Upper lateral leaf areas were further reduced at lower IRR and elevated CO_2. Differences in final leaf size between CO_2 treatments were due to variations in expansion rate.

Details:

- A IRR x CO_2 interaction was significant for lateral branch individual leaf areas ($p < 0.05$).
- Single leaf final leaf area and leaf expansion rate declined linearly with IRR.
- The duration of single leaf expansion was not influenced by IRR or CO_2.

4. End of Season Branching

Summary: Lateral branch number, length, and 2ndary branching were suppressed at elevated CO_2 and low IRR.

Details:

- The number of lateral branches, average length, and degree of branching were reduced with elevated CO_2.
- A significant CO_2 x IRR interaction was observed for lateral branch number and branching order.
- Length, leaf number, and branching order increased with IRR.

Table 2: Lateral branch number (lat num), length (lat length), leaf number (leaf num), and degree of branching (order) for potatoes grown at 370 (amb) and 740 (elv) µmol mol^{-1} CO_2 at different irrigation levels (IRR). Values are five plant averages.

	Lat Num		Lat Length		Leaf Num		Order	
IRR	Amb	Elv	Amb	Elv	Amb	Elv	Amb	Elv
	#		cm		#		#	
100%	7.5	7.6	144.4a	172.9a	31.1a	35.5a	3.8a	4.0a
90%	7.6	7.3	149.5a	111.2b	29.5a	26.2bc	3.8a	3.6ab
75%	6.2	6.2	123.5ab	87.3bc	29.4a	23.3c	3.4a	3.4ab
50%	8.0[1,†]	5.5[1]	92.3b	67.5cd	23.5ab	19.8cd	3.8a[1]	2.6bc[1]
25%	7.6	6.0	52.4c	38.5d	18.6bc	15.4de	3.2a	2.0cd
10%	9.3[1]	4.0[1]	32.1c[1]	11.1e[1]	12.7c	9.7e	2.4b[1]	1.0d[1]
Mean	7.6	6.0	99.8[1]	83.0[1]	24.3	21.8	3.4[1]	2.8[1]
LSD(0.05)	2.9	2.0	38.5	24.2	7.3	5.3	0.6	1.1
IRR	NS		p < 0.001		p < 0.001		p < 0.001	
[CO_2]	p < 0.01		p < 0.05		p < 0.1		p < 0.001	
IRRx[CO_2]	p < 0.05		p < 0.1		NS		p < 0.05	

†Letters indicate LSD differences between IRR at a given CO_2 treatment. A '1' indicates significant differences between CO_2 treatments at the IRR level.

5. Dry Matter Partitioning

Summary: Differences in total dry matter between CO_2 levels were not significant. Dry weight partitioning to below ground organs increased with elevated CO_2 at lower IRR.

Details:

- Dry mass increased with IRR.
- More dry mass was partitioned below ground at elevated CO_2 as IRR decreased.
- The relative amount of above ground dry mass decreased, and below ground increased, with elevated CO_2 and decreased IRR.
- Leaf dry mass, and lateral stem mass, was a smaller proportion of total canopy mass for elevated CO_2 (not shown).

Table 3: End of season total, above, and below ground biomass for potatoes grown at 370 (amb) and 740 (elv) µmol mol^{-1} CO_2 at different irrigation levels (IRR). Values are averages of 12 plants.

	Total		Above Ground		Below Ground	
IRR	370	740	370	740	370	740
	g dry mass $plant^{-1}$					
100%	292	346	217a†	239a	75ab	107ab
90%	306	249	218b[1]	152b[1]	88ab	98b
75%	282	271	178c[1]	125bc[1]	111a	146a
50%	198	238	147c	110c	51b	128ab
25%	140	172	69de	59d	71ab	113ab
10%	100	73	41e[1]	26e[1]	59b	47c
Mean	219	225	144	118	76	107
LSD(0.05)	68	59	33	31	50	44
IRR	p < 0.001		p < 0.001		p < 0.05	
[CO_2]	NS		p < 0.001		p < 0.05	
IRRx[CO_2]	NS		p < 0.05		NS	

†Letters indicate LSD differences between IRR at a given CO_2 treatment. A '1' indicates significant differences between CO_2 treatments at the IRR level.

DISCUSSION

The reduction in plant length, leaf appearance, leaf expansion, and dry matter production with decreasing IRR was consistent with other reports on potato response to water stress. Total dry matter was statistically similar between CO_2 treatments at a given IRR level. Elevated CO_2 further suppressed canopy growth and development as IRR levels dropped below 75% of the control as compared with ambient CO_2 treatments. This suppression was accompanied by a shift in dry matter partitioning from above to below ground organs.

These results indicated that CO_2 interacted with water stress in a way that increased yield without an equivalent increase in canopy formation at the lower IRR. Some considerations:

- Photosynthetic rates per unit leaf mass were likely higher for elevated CO_2 plants (differences among end of season leaf area were not detected):
  1. Leaf dry mass was smaller for elevated CO_2 plants at several IRR levels, but significant differences in total dry mass were not measured.
  2. Increases in canopy photosynthetic rate and radiation use efficiency of water stressed elevated CO_2 plants were observed (data not shown).
- Source-sink relationships can play a large role in mediating plant response to drought (e.g. perennials and some agronomic crops); elevated CO_2 positively influenced source-sink relationships in water-stressed potato:
  1. CO_2 enrichment increases sink capacity for storage organs which may help delay effects of severe water shortage on growth. The start of IRR treatments coincided with tuber initiation, when tubers are the largest sink. A large tuber sink may positively modify photosynthetic responses of water stressed plants by maximizing sucrose assimilation and transport from leaves (alleviates drought-induced feedback inhibition of photosynthesis).
  2. A larger tuber sink in water stressed potato grown under elevated CO_2 diverted dry matter away from the canopy, and as a result of increased assimilate production in response to CO_2 enrichment, continued to grow in strength during the course of the season. The result was the observed partitioning shift between above and below ground organs.

CONCLUSIONS

Potato productivity declines with water stress, primarily due to reduced canopy expansion. Canopy growth and development was reduced in potatoes grown at 370 and 740 µmol mol^{-1} CO_2 in response to decreasing irrigation. General responses included decreased plant length, leaf appearance and expansion rates, duration of canopy formation, and lateral branch production. Total dry mass increased with irrigation. Total dry mass was also similar for elevated versus ambient CO_2 plants despite a decrease in partitioning of dry mass to the canopy in the elevated CO_2 treatments as irrigation decreased. We speculated that the presence of a larger tuber sink in the elevated CO_2 plants helped mitigate water stress effects by minimizing potential drought induced substrate feedback inhibition of photosynthesis and shifting carbohydrate partitioning away from new canopy development and into the storage organs. These results suggest that sink demand for assimilate supply plays a large role in mediation of water stress under enriched CO_2. Thus, potential water deficiencies predicted by some global climate change models may be reduced to a certain extent due to CO_2 enrichment. Results can support models and simulations involved in identifying alternative management strategies and production scenarios for potato grown under various global climate change scenarios.

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