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Supplemental Carbon Dioxide and Light Improved Tomato and Pepper Seedling Growth and Yield

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Abstract. **The experiment was conducted to determine the effects of CO, enrichment (900 µl·liter^{1}, 8 hours/day) in combination with supplementary lighting of 100 µmol·s^{1}·m^{2} (16-h photoperiod) on tomato *(Lycopersicon esculentum* Mill.) and sweet pepper *(Capsicum annuum* L.) seedling growth in the greenhouse and subsequent yield in the field. Enrichment with CO_2 and supplementary lighting for ≈ 3 weeks before transplanting increased accumulation of dry matter in shoots by ≈ 50% compared with the control, while root dry weight increased 49% for tomato and 6270 for pepper. Early yields increased by =1570 and 11% for tomato and pepper, respectively.**

Among the most important factors affecting seedling growth and development that can be optimized in a greenhouse are ambient CO_2 concentration and light energy. Seedlings grow more quickly at high CO_2 concentrations, and a value of 1000 µl·liter^{1} seems to be optimal (Madsen, 1973; Porter and Grodzinksi, 1985). Morgan (1971) concluded that for tomato seedlings, early yields depended on rapid accumulation of dry matter.

In northern regions, the production of transplants in the spring is limited by poor light conditions. Seedlings grown under low light reveal photosynthetic characteristics common to shade plants and are unable to use the relatively intense light that prevails in the field efficiently (Bjorkman, 1981). There is an interaction between supplementary lighting and CO_2 enrichment. According to Mortensen and Moe (1983), the largest increase in growth rate achieved with CO_2 enrichment is obtained with the highest photosynthetic photon flux density (PPFD). They further suggest that a high CO_2 concentration may partially compensate for an insufficient PPFD.

Differences in seedling growth obtained up to the transplanting stage with CO_2 and light treatments may influence yields. When applied separately, CO_2 enrichment and supplementary lighting at the seedling stage can increase early yields of greenhouse tomatoes (Boivin et al., 1986; Morgan, 1986).

The objective of this study was to determine the effects of combined CO_2 and supplementary lighting on the growth and subsequent fruit yields of tomato and pepper seedlings grown in the field.

Materials and Methods

Plant material and cultivation

'Springset' tomato and 'Bell Boy' pepper were sown on 25 Apr. and 19 May 1989, respectively, in multicellular polystyrene trays (#50 Sutton plug trays; Kord Products, Bramalea, Ont.) (365 seedlings/m^{2}) filled with a peat-based seedling mixture (Pro-Mix; Tourbières Premier Ltée, Riviere-du-Loup, Que.). Seeds were covered with a thin layer of vermiculite, and the trays were placed on tables in four identical greenhouse compartments (24 m^{2}) at Laval Univ., Quebec City. Germination in the compartments was at 27 ± 2C. During subsequent growth, the ventilation set point was 18C.

Carbon dioxide and light were supplemented from the time the cotyledons completely unfolded. The seedlings then were fertigated every morning and evening until partial drainage occurred. They were irrigated with tap water at noon, if necessary. The nutrient solution concentration was increased as the seedlings developed. During the first week, it included (in ppm) 100 N, 50 P, 100 K, 22 Ca, 6 Mg, 0.4 Fe, 0.3 Mn, 0.2 CU, 0.2 B, 0.1 Zn, and 0.06 Mo. The mineral concentrations were doubled and tripled in the second and third week, respectively. The respective nutrient solution pH was 6.4, 6.5, and 6.2; the respective electrical conductivity was 1.0, 1.51, and 2.26 mS·cm^{1}.

Tomato and pepper plants were transferred to the field 29 and 32 days and 37 and 40 days after sowing, respectively. The experimental plots were located at Laval Univ., where the soil is a St. Nicolas schist loam. Transplanting was done manually and seedlings were watered immediately with a 10N–52P–10K (500 ppm N) transplanting solution. The plots were sprinkler-irrigated as indicated by tensiometers with a 30-kPa threshold. Cultivation was conducted according to commercial practices (Conseil des Productions Végétales du Québec, 1982).

Treatments

The light treatments were as follows: 1) natural light only and 2) natural light supplemented with 100 µmol·s^{1}·m^{2} photosynthetically active radiation (PAR). The supplementary lighting was provided by 400-W high-pressure sodium lamps (HPS Solux Lumiponic, no. 400-SO-SHP-120; Lumiponic, Saint-Laurent, Que.), and the PPFD was measured with an LI- 185 photometer equipped with an LI-190SB quantum sensor (LI-COR, Lincoln, Neb.). The lamps operated between 0200 and 1000 HR, to extend the photoperiod to 16 h.

The CO, treatments consisted of 1) ambient in the greenhouse and 2) 900 ± 100 µl·liter^{-1} from 0200 to 1000 HR. This period was chosen because the lower temperatures limited ventilation requirements and kept CO_2 concentrations at the desired levels. Compressed CO, (Liquid Air Canada, Montréal, Que.) was used. Carbon dioxide concentration was maintained with an infrared analyzer (no. APBA 251 E CO_2 monitor; Priva Computers, De Lier, Netherlands) and recorded by a computerized datalogging system.

Design of experiment and growth variables

The four greenhouse compartments formed two experimental blocks. Each block consisted of two main plots corresponding to the CO_2 treatments. Within each main plot were the light treatments, distributed randomly in subplots and repeated four times for a total of 32 subplots. The subplots were separated by white polyethylene opaque curtains that were opened between 1000 and 1800 HR. In each subplot, there were four multicellular trays, one per species and per sowing, containing 50 seedlings each (experimental unit). The design in the greenhouse was a split-plot with CO_2 concentration in the main plots and lighting treatments in the subplots. The two sowings were considered repeated measurements (Little and Hills, 1978). Statistical analysis was performed using SAS software (SAS Institute, Cary, N.C.). On the eve of the transplant day, eight sample plants were picked randomly from the center of each multicellular tray to measure root and shoot dry weights (48 h at 70C).

In the field, the split-plot design included eight replications. Planting dates were main plots, and the subplots contained the CO_2 and light treatments applied previously in the greenhouse. The experimental unit consisted of a row of eight plants with a guard plant at each end. A guard row was between each main plot. The tomato and pepper plants were planted 0.30 m apart within rows, with 1.5 and 1 m between rows, respectively. The plots were harvested by hand once each week. Early yields consisted of the first two tomato harvests, but only the first pepper harvest. At each

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harvest, marketable and "all categories" (marketable fruits + culls) yields were measured. Defect-free tomato fruit were considered marketable. Pepper fruit > 5 and 7 cm in diameter were considered marketable.

Homogeneity of variance among treatments was verified for all variables using the Bartlett test with $P \leq 0.01$.

Results and Discussion

Seedling growth

Carbon dioxide enrichment increased shoot dry weight of both species for both planting dates, but only root dry weight for the second sowing, with a 12% increase for tomato and 11% for pepper (Table 1). A more abundant root system would likely encourage rapid reestablishment after transplanting (Weston and Zandstra, 1986), as these young plants would have better access to soil water and nutrients. The second sowing showed a greater response to CO_2 enrichment than the first, possibly because treatments were applied for three more days on the second sowing, which also benefited from better natural light conditions. Under our experimental conditions, the effect of CO_2 enrichment was less than previously experienced (Porter and Grodzinski, 1985). There are two probable reasons for the mitigated CO_2 effect: 1) CO_2 enrichment was applied only during half of the photoperiod and 2) the ventilation set point was 18C, resulting in frequent ventilation and drops in CO_2 concentration, even though CO_2 injection was maintained during ventilation.

Supplementary lighting increased shoot dry weight 44% in peppers and 32% in tomatoes (Table 1). Shoot dry weight of tomato seedlings with CO, and supplementary lighting increased by 33% and 66% in the first and second sowings, respectively, compared with control plants. This increase was 42% for the first pepper seedling sowing and 67% for the second. Mortensen and Moe (1983) obtained maximum growth of young chrysanthemum *[Dendranthema × grandiflorum* (Ramat.) Kitamura] seedlings with a CO_2-enriched atmosphere and high PPFD. Tomato and pepper seedlings accumulated 37% and 49% more dry matter, respectively, in their roots under supplementary lighting (average of two sowings) (Table 1). The results are similar for lettuce *(Lactuca sativa* L.), broccoli *(Brassica oleracea* L. Botrytis Group), and tomato seedlings given supplementary lighting (Masson et al., 1991a).

Carbon dioxide enrichment and supplementary lighting interacted positively on seedling root dry weight, with 49% and 62% increases for tomato and pepper, respectively. Desjardins et al. (1990) reported a positive CO_2 enrichment × supplementary lighting interaction on shoot and root dry weights of asparagus *(Asparagus officinalis L.)* transplants.

Yield

Tomato. Higher early and cumulative yields were observed for all-categories fruit when seedlings were enriched with CO_2 (Table 2). According to Morgan (1986), the increase in early yields of tomato seedlings enriched with CO_2 is due in part to accelerated anthesis and fruit maturation. Carbon dioxide enrichment increased the cumulative yields of marketable fruit by 7% for the second planting. The percentage of marketable fruit was not affected by CO, treatments.

The effect of supplementary lighting lasted through the first two harvests. Early yields in all-categories fruit increased by ≈10% for both first and second plantings (Table 2). Under similar conditions, Masson et al. (199 lb) obtained greater effects of lighting than those reported here, although the differences obtained in accumulated dry weight at the time of transplanting were similar. The cumulative yields were not changed by adding artificial light, which agrees with Masson et al.'s (1991b) results.

When comparing control seedlings planted first with those that received simultaneous CO, and light treatments, early yields increased 15% and 22% for marketable fruit and total fruit, respectively (Table 2). These increases were 12% and 10% for the second planting. The CO_2 × lighting interaction did not affect the cumulative yields of either of the two plantings. All yield increases measured were due to a greater number of fruit.

Pepper. Based on the analysis of variance, there was no significant difference between treatments. However, CO^2 enrichment tended to improve early yields of marketable fruit and all-categories yields (7%) for the first planting (Table 3). As observed for tomato seedlings, supplementary lighting interacted with CO_2 enrichment to increase early yields by 1190 over control. The second planting was unproductive after a heavy flower drop and almost no fruit set because of extremely high temperatures and water stress.

In summary, combined CO, enrichment

Table 1. Effects of CO_2 enrichment and 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ photosynthetically active radiation supplementary lighting during plant growth on shoot and root dry weight of tomato and pepper transplants for two sowings.

CO_2 ($\mu l \cdot liter^{-1}$)	Supplementary lighting	Tomato dry wt (mg/plant)		Pepper dry wt (mg/plant)	
		Shoot	Root	Shoot	Root
	First planting				
900	+	544	46	486	33
	–	411	32	349	24
350	+	500	44	473	34
	–	410	32	342	23
	Second planting				
900	+	635	56	674	71
	–	455	40	463	48
350	+	505	50	613	65
	–	383	36	404	42
Significance					
Lighting		***	***	***	***
Lighting × planting		NS	NS	**	**
CO_2[z]		17	3	21	2

[z] Standard error of the means, because the $C0_2$ treatment could be run only twice.

NS,**,***Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

Table 2. Effects of CO_2 enrichment and 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ photosynthetically active radiation supplementary lighting during plant growth *on* yield of tomatoes transplanted to the field for two plantings.

CO_2 ($\mu l \cdot liter^{-1}$)	Supplementary lighting	Early yield ($t \cdot ha^{-1}$)[z]		Cumulative yield ($t \cdot ha^{-1}$)[y]	
		Marketable	All[x]	Marketable	All
	First planting				
900	+	10.6	27.5	21.8	72.8
	–	9.2	23.0	24.1	73.3
350	+	9.0	22.7	26.7	74.7
	–	9.2	22.5	23.5	68.4
	Second planting				
900	+	21.0	36.2	44.8	77.1
	–	18.6	32.7	43.0	74.6
350	+	19.4	35.2	39.7	70.8
	–	18.7	32.8	42.3	72.6
Significance					
Lighting (L)		NS	*	NS	NS
CO_2		NS	*	NS	*
Planting (P)		***	***	***	NS
CO_2 × P		NS	NS	*	NS
L × CO_2 × P		NS	NS	*	NS

[z] First two harvests.

[y] Sum of six harvests.

[x] All categories confounded.

NS, *, ***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Table 3. Effects of CO_2 enrichment and 100 µmol·s^{-1}·m^{-2} photosynthetically active radiation supplementary lighting during plant growth on yield of peppers transplanted to the field. Means of eight replications ± standard error.

CO_2	Supplementary	Early yield (t•ha^{-1})[z]		Cumulative yield (t•ha^{-1})[y]	
(µl•liter^{-1})	lighting	Marketable	All[x]	Marketable	All
900	+	4.7 ± 0.9	4.9 ± 1.0	17.7 ± 1.1	18.8 ± 1.3
	–	4.3 ± 0.3	4.4 ± 0.3	16.5 ± 1.1	17.2 ± 1.0
350	+	4.2 ± 0.5	4.3 ± 0.5	17.4 ± 1.1	18.8 ± 1.3
	–	4.2 ± 0.5	4.4 ± 0.5	16.4 ± 1.1	17.5 ± 1.2

[z] First harvest.

[y] Sum of five harvests.

[x] All categories confounded.

and supplementary lighting in the greenhouse increased seedling shoot and root dry weights. Early fruit yields were generally improved, although not significantly in all cases.

Literature Cited

Bjorkman, O. 1981. Responses to different quantum flux densities, p. 57-107. In: O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Ziegler (eds.). Physiology of plant ecology I. Encyclopedia of plant physiology. New series, vol. 12A. Springer-Verlag, Berlin.

Boivin, C., M.J. Trudel, and A. Gosselin. 1986. Influence duniveau d'irradianced'appoint (HPS) en pépinière sur la croissance et la productivité d'une culture de tomate de serre. Can. J. Plant Sci. 66(4):961-970.

Conseil des Productions Végétales du Quebec. 1982. Légumes: Culture. Production Guide, Conseil des Productions Végéales du Québec. Agdex 250/20. Ministère de L'Agriculture, des Dêheries et de L' Alimentation, Quebec,

Desjardins, Y., A. Gosselin, and M, Lamnarre. 1990. Growth of transplants and in vitro-cultured clones of asparagus in response to CO_2 enrichment and supplemental lighting. J. Amer. Soc. Hort. Sci. 115:364-368.

Little, T.M, and F.J. Hills. 1978. Agricultural experimentation: Design and analysis. Wiley, New York.

Madsen, E. 1973. The effect of CO_2 concentration on development and dry matter production in young tomato plants. Acts Agr. Stand. 23(4):235-240.

Masson, J., N. Tremblay, and A. Gosselin. 1991a. Nitrogen fertilization and HPS supplementary lighting influence vegetable transplant production. I. Transplant growth. J. Amer. Soc. Hort. Sci. 116:594-598,

Masson, J., N. Tremblay, and A. Gosselin. 1991b. Effects of nitrogen fertilization and HPS supplementary lighting on vegetable transplant production. H. Yield. J. Amer. Sot. Horc. Sci. 116:599-602.

Morgan, J.V. 1971. The influence of supplementary illumination and CO_2 enrichment on the growth, flowering and fruiting of the tomato. Acta Hort. 22:187-199.

Morgan, J.V. 1986. Chemical and environmental control of growth during propagation of tomato plants for transplanting. Acta Hort. 190523-530.

Mortensen, L.M. and R. Moe. 1983. Growth responses of some greenhouse plants to environment. VI. Effect of CO_2 and artificial light on growth of *Chrysanthemum morfolium* Ramat. Scientia Hort. 19(1/2):141–147.

Porter, MA. and B. Grodzinski. 1985. CO_2 enrichment of protected crops. Hort. Rev. 7:345–398.

Weston, L.A. and B.H. Zandstra. 1986. Effect of root container size and location of production on growth and yield of tomato transplants. J. Amer. Soc. Hort. Sci. 111:498–501.