Effects of Nitrogen Fertilization and HPS Supplementary Lighting on Vegetable Transplant Production. II. Yield

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Abstract. Transplants of celery (*Apium graveolens* L.), lettuce (*Lactuca sativa* L.), broccoli (*Brassica oleracea italica* L.), and tomato (*Lycopersicon esculentum* Mill.) grown in multicellular trays under natural light or with supplementary lighting of 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR) in factorial combination with four rates of N fertilization (100, 200, 300, and 400 $\text{mg}\cdot\text{liter}^{-1}$) were tested for productivity under field conditions. Celery was seeded once, lettuce twice, and broccoli and tomato three times. Broccoli and tomato were transplanted at two sites, celery and lettuce at one. Supplementary lighting had no effect on yields of celery, lettuce, and broccoli, but significantly increased yields of early seeded tomato. High rates of N fertilization (300 and 400 $\text{mg}\cdot\text{liter}^{-1}$) applied at the transplant stage improved yields for all the species.

The environmental conditions that vegetable transplants undergo during their early growth play an important role in yield. Canham (1966) stated that the future yield of young tomato plants depends on the first weeks of growth and that it is an appropriate time to plan economically for the crop's development.

Lighting conditions and fertility are two factors that may play a role in early growth of vegetable seedlings. Boivin et al. (1986) demonstrated that the use of supplementary lighting at 50, 100, and 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR) increased marketable yields for the first three harvests of greenhouse-grown tomatoes by 19%, 30%, and 42%, respectively, compared with natural light. Wurr et al. (1986) observed that the use of supplementary lighting on lettuce at the transplant stage modified the growth of the young plants without affecting their productivity.

Pretransplanting nutritional conditioning program plays an important role in the young plants' recovery from planting and in their potential productivity (Dufault, 1986). Increased yields from appropriate fertilization of the transplants were observed for celery (Tremblay et al., 1987), pepper (Knavel, 1977), muskmelon (Dufault, 1986), lettuce (Kratky and Mishima, 1981), and tomato (Weston and Zandstra, 1989).

Supplementary lighting was shown to produce transplants with improved shoot characteristics, root systems, and shoot dry matter percentage (Masson et al., 1991). Levels of 300 to 400 mg N/liter were necessary to obtain maximal shoot or root growth. However, the effect of high N on transplants' ability to survive relatively adverse environmental conditions encountered under field situations is unknown.

Thus, the objectives of this study were to determine the residual effects of supplementary lighting of 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR) and of four rates of N fertilization (100, 200, 300, and 400 mg N/liter) on the productivity of celery, lettuce, broccoli, and tomato transplants under field production. In an attempt to assess the consistency of treatment effect over time and space,

several sowing dates were used (except for celery) and experimentation was conducted at two sites (for broccoli and tomato).

Materials and Methods

Plant material, growing methods, treatments, and date of planting

The detailed description of plant material, growing methods, and treatments are described in Masson et al. (1991). Sites and dates of seeding, planting, and harvest are included in Table 1. Celery transplants were planted in a muck soil field (Sherrington Borohemist) of a commercial grower at Napierville (Montreal region) and were grown according to current commercial practices. The two seedlings of lettuce were planted on a Ste-Clotilde Borohemist at the Ste-Clotilde Agriculture Canada's research substation (Montreal region). Plants from the first seeding of broccoli and tomato were planted at Agriculture Canada's federal research substation at L'Acadie on a St-Blaise clay-loam (Montreal region). Those from the second seeding were planted both at L'Acadie and on the Laval Univ. campus (Quebec region), and the third seedlings were all planted on the Laval Univ. site, a St-Nicolas loam. The tomato and broccoli transplants were planted with the addition of ≈ 500 ml of water with a 10N-22.9P-8.3K transplant fertilizer added at a ratio of 5 g per liter of water. Cultural operations and pesticide treatments applied to the crops were done according to current recommen-

Table 1. Summary of planting sites, seeding period, and planting and harvest date of the four species studied.

Species	Sites	Seeding	Planting date	Harvest date
Broccoli	Quebec region	Early	24 May	19 July
		Late	7 June	30 July
	Montreal region	Early	18 May	14 July
		Late	25 May	20 July
Celery	Montreal region	Midseason	17 May	4 Aug.
Lettuce	Montreal region	Early	17 May	8 July
		Late	30 May	20 July
Tomato	Quebec region	Early	3 June	19 Aug. ^z
		Late	16 June	30 Aug. ^z
	Montreal region	Early	25 May	9 Aug. ^z
		Late	4 June	17 Aug. ^z

^zDate of first harvest.

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dations (C. P.V.Q. 1982, 1983). Celery, lettuce, and broccoli were harvested when the majority of plants in one of the treatments were considered sufficiently developed to be marketable. All the plants from the same seeding were then picked.

Experimental design, characteristics measured, and statistical analysis

Celery was transplanted using a completely randomized design with four replications. Each experimental plot contained 10 plants, with three guard plants at each end. Rows containing experimental plants were separated by one guard row of commercial plants. Plants were spaced with 60 cm between rows and 15 cm between plants. Plants were hand-harvested 79 days after transplanting. Total and marketable weights of four plants per plot were measured. The side shoot weight was calculated by subtracting the marketable weight from the total weight. The analysis of variance (ANOVA) was performed using a 2 x 4 factorial (lighting x N), with four replications, using SAS software (SAS Institute, Cary, N.C.). Bartlett's test was used to check variance homogeneity.

A split-plot design was used for lettuce. It involved four replications with the seeding dates as the main plots and the lighting and N fertilization treatment combinations noted in the subplots. Each experimental unit contained 10 plants, including two guard plants at each end. A border row separated the main plots. The plants were placed 35 cm apart between and within the rows. Harvesting was done 52 and 51 days after transplantation for the first and second seedings, respectively. The marketable weight and circumference of each head were measured for the six plants in the center of each row. The volume of the head was calculated according to the following formula: $V = 1/6 C^3 \pi^{-2}$ (V = volume and C = circumference), assuming a spherical shape. The density of the head was obtained by dividing the marketable weight by the volume. ANOVA was done on a 2 (main plot = seeding date) x 4 x 2 (subplot = N x light combination), comprising four replications. The Bartlett test was used to verify the homogeneity of the variances. The coefficients of variability (cv) of the marketable weight and the circumference of the six plants were calculated and used in the statistical analysis to verify the effect of the treatments on head uniformity at harvest.

The broccoli and tomato transplants were planted at two locations according to the same experiment design (split plot with four replications). The main plots contained the seeding dates and the subplots the lighting and fertilization treatments. Each experimental unit contained 10 plants, with a guard plant at each end. The main plots were separated by a border row. Broccoli were spaced at 75 cm between rows and 45 cm within the row while tomatoes had 150 cm between rows and 30 cm between plants in the row.

Broccoli total and marketable weights and the diameter of the inflorescence were determined for the eight plants in the center row. A severe attack of cabbage maggot, *Delia radicum* L. (*Hylemya brassica*), on the first seeding date planted in the Montreal experiment prevented the plants from being included in the statistical analysis. Therefore, the ANOVA statistical analyses of the broccoli experiment were done on a 2 x 4 plan (light x N) in the Montreal region and a 2 (main plot = seeding date) x 4 x 2 (subplots = N x light combination) in the Quebec region. There were four replications. A second analysis was done to verify the effects of the site and of the interaction of the light and fertilization treatments with the site. This statistical analysis was carried out on transplants from a common seeding using a 2 (main plot = site) x 4 x 2 (subplot = N

x light combination), with four replications. The Bartlett test was also used.

Tomatoes were harvested once a week starting with the dates indicated in Table 1 until 16 Sept. in the Montreal, and 23 Sept. in the Quebec region. The yields of marketable fruits (fruits >6 cm and free from defects) and total yields (marketable fruits + culls) were measured for each harvest. Only the first harvest was associated with early yields. Yields were reported as metric tons of fruit per hectare. ANOVA statistical analyses were done for each site on a 2 x 4 x 2 factorial layout (light x N x seeding), with four replications. As described for broccoli, a second analysis was carried out to verify the effects of the site and the interaction between the light or fertilization treatments with the site.

Results and Discussion

Celery. Supplementary light at the transplant stage had no long-term effect on yield of celery. However, increasing the rate of N resulted in a linear increase in total and marketable yield for celery (Table 2), with highest yields obtained at 300 mg N/liter. Compared with N at 100 mg-liter⁻¹, total and marketable yields obtained from celery fertilized with 300 mg-liter⁻¹ were increased by 1670 and 15%, respectively. The side shoot weight was not affected by the treatments (range 366-452 g/plant). Tremblay et al. (1987) also obtained a higher marketable yield when young celery plants were fertilized with 400 mg N/liter, in the form of urea rather than with 200 and 600 mg-liter⁻¹. In another study involving celery, using a nutrient solution similar to the one used in this experiment, Tremblay and Gosselin (1989) obtained a yield increase of 14% when transplants were fertilized at rates of 350 instead of 150 mg N/liter.

Lettuce. Supplementary lighting did not influence lettuce yield or quality. The cv of the marketable weight and the circumference were not affected by the light treatments and are not reported. The earliness of seeding did not affect either the marketable weight or the circumference of the heads of lettuce (data not shown). However, the density of the heads from the late seeding was less than for those from the early seeding (data not shown), which may be attributable to the difference in maturity at the time of harvest. According to Wurr et al. (1986), the use of supplementary light on lettuce transplants does not affect yield at harvest although it may help growers to better schedule their transplant production.

According to Kratky and Mishima (1981), reductions in yields and in the firmness of lettuce heads were linked to very low or very high fertilization rates during the nursery period. However, we obtained an increase of 16% in the marketable weight of lettuce when the transplants were fertilized at a rate of 400 mg N/liter, rather than with 100 mg-liter⁻¹ (Table 3). Head weight and density increased linearly with N rate. The use of high rates

Table 2. Effect of N concentration in the transplants' fertigation solution on yield of celery.

Nitrogen (mg-liter ⁻¹)	Wt (g/plant)	
	Total shoot	Marketable
100	1300	938
200	1450	996
300	1510	1080
400	1480	1050
Significance	L ^{*z}	L ^{**}

^zLinear (L) effect significant at $P = 0.05$ (*) or 0.01 (**).

Table 3. Effect of N concentration in the transplants' fertigation solution on yield of lettuce. Data presented are combined over seeding date and light treatment.

Nitrogen (mg·liter ⁻¹)	Head wt (g/plant)	Circumference (cm)	Head density (g·cm ⁻³)
100	679	47	0.40
200	734	46	0.43
300	776	47	0.44
400	787	47	0.45
Significance	L***	NS	L***

²Linear (L) effect significant at $P = 0.05$ (*), 0.01 (**), 0.001 (***) or nonsignificant (NS).

of N in transplant production not only increased head weight at harvest, but also promoted early maturity (data not shown). Head circumference and uniformity of harvest were not affected by N rate. Yields of early and late seeding were affected similarly by N rate.

Head circumference is the main factor considered by growers when estimating lettuce yield. Nitrogen and light treatments had no effect on this characteristic. Head density, however, is the most important factor in determining the appropriate time for harvesting lettuce. Since increasing N fertilization led to increasing head density, it can be concluded that the major effect of N is on earliness of maturation. Ample N fertilization in the greenhouse would, therefore, shorten production of early and late lettuce crops since there was no interaction of N with seeding time.

Broccoli. When seedlings were planted on both sites, the marketable weight and circumference of the inflorescences of broccoli were higher in the Quebec region (data not shown). This result may be explained by the effect of lower temperatures on plants that were planted early near Quebec. Rate of N fertilization increased the weight of broccoli heads near Quebec for both seedings, but not for the seeding planted in Montreal (data not shown). Marketable weight and diameter of inflorescence increased linearly with increasing rates of N fertilization at both planting sites. Increases of marketable weight of 25% and 58% were measured in the Quebec and Montreal regions, respectively, for transplants fertilized at 400 mg N/liter, rather than with those fertilized at 100 mg·liter⁻¹. In the Quebec region, the plants from the early seeding showed, on average, higher weights of inflorescence than those from the late seeding. The effect of the N fertilization treatments was constant from one seeding to the other. Transplant data from the same seeding date showed that the broccoli transplants reacted similarly to the lighting and fertilization treatments, regardless of the site of production (Table 4). However, we observed a maximal marketable weight under natural light at 200 mg N/liter while under supplementary light, transplants with fertilization at 400 mg N/liter produced the best yields. The interaction of these two factors was, however, significant only at $P = 0.05$. Otherwise, supplementary lighting had no long-term effect on broccoli productivity.

Thus, for broccoli, increasing N fertilization for transplants improved marketable yield and head diameter irrespective of site or seeding time. The use of supplementary lighting, however, may occasionally alter the influence of N fertilization on marketable yield.

Tomato. Early yields of marketable fruits and total yields for tomato in the Quebec region were higher when transplants were seeded earlier in the greenhouse (Table 5). In the Montreal

Table 4. Effect of supplementary HPS lighting [100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR)] and N concentration in the transplants' fertigation solution on yield of broccoli. Data presented are combined over locations.

Light	Nitrogen (mg·liter ⁻¹)	Shoot wt (g/plant)	Marketable yield (g/plant)	Head diameter (cm)
Natural	100	1520	367	12.8
	200	1710	489	15.3
	300	1600	444	14.1
	400	1580	449	14.4
Supplementary	100	1620	369	13.1
	200	1580	426	13.9
	300	1540	463	14.8
	400	1780	552	16.5
Light		NS ²	NS	NS
Nitrogen		NS	L***	L**
Light × nitrogen		Q*	L*	NS

²Linear (L) or quadratic (Q) effects significant at $P = 0.05$ (*), 0.01 (**), 0.001 (***), or nonsignificant (NS).

Table 5. Effect of seeding time, HPS supplementary lighting [100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR)] and of N concentration in the transplants' fertigation solution on yield of tomato in the Quebec region.

	Nitrogen	Early yield (t·ha ⁻¹)		Total yield (t·ha ⁻¹)	
Light	(mg·liter ⁻¹)	Marketable	Total	Marketable	Total
<i>Early seeding</i>					
Natural	100	0.75	2.08	67.05	89.42
	200	2.18	3.82	58.36	83.12
	300	4.33	5.53	53.68	81.04
	400	3.88	5.75	63.57	88.38
Supplementary	100	2.12	2.97	59.09	83.55
	200	4.12	6.91	58.34	85.07
	300	5.02	6.35	65.28	88.48
	400	5.93	6.47	54.37	74.40
<i>Late seeding</i>					
Natural	100	0.28	0.84	48.13	74.22
	200	0.86	2.13	42.26	70.66
	300	0.79	1.92	47.46	76.06
	400	0.56	2.34	40.28	69.87
Supplementary	100	1.30	2.71	44.14	71.45
	200	1.55	3.08	50.14	74.78
	300	1.53	2.16	51.05	73.97
	400	0.58	1.49	49.56	73.97
Seeding		***	**	*	NS
Light		**	*	NS	NS
Nitrogen		L***z	L**,Q*	NS	NS
Light × seeding		NS	NS	*	NS
Nitrogen × seeding		L***	L**	NS	NS
Nitrogen × light		NS	NS	Q**	Q*
Nitrogen × light × seeding		NS	NS	**	*

²Linear (L) or quadratic (Q) effects significant at $P = 0.05$ (*), 0.01 (**), 0.001 (***), or nonsignificant (NS).

region, seeding time did not affect early yields (Table 6). This difference between the two sites is attributable to the shorter growing seasons in Quebec than in Montreal. Cumulative harvests and early yields of fruits of all grades were not influenced by planting site (data not shown).

Early yields of tomato transplants treated with supplementary lighting were higher on average than for transplants produced under natural light alone (Tables 5 and 6). In Quebec, early yields of marketable fruits were increased by 55% and 100% for the early and late seedings, respectively; increases of 36%

Table 6. Effect of seeding time, HPS supplementary lighting [$100 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR)] and of N concentration in the transplants' fertigation solution on yield of tomato transplants planted in the Montreal region.

Light	Nitrogen (mg·liter ⁻¹)	Early yield (t·ha ⁻¹)		Total yield (t·ha ⁻¹)	
		Marketable	Total	Marketable	Total
<i>Early seeding</i>					
Natural	100	3.41	5.02	46.89	86.18
	200	6.23	7.42	51.65	88.68
	300	7.30	8.94	48.95	89.07
	400	6.38	7.97	53.78	90.53
Supplementary	100	4.90	5.86	49.47	87.75
	200	8.37	10.02	51.41	86.08
	300	8.82	10.65	49.18	86.67
	400	9.67	11.50	55.18	90.35
<i>Late seeding</i>					
Natural	100	4.03	4.44	56.18	88.01
	200	3.92	4.37	46.10	84.31
	300	6.24	7.50	49.95	85.51
	400	8.89	10.99	45.61	81.43
Supplementary	100	6.07	6.77	52.14	84.31
	200	8.29	10.03	51.64	85.17
	300	10.20	12.37	49.01	78.84
	400	9.40	11.31	44.67	75.06
Seeding		NS	NS	NS	NS
Light		***	***	NS	NS
Nitrogen		L***z	L***	NS	NS
Light × seeding		NS	NS	NS	NS
Nitrogen × seeding		NS	NS	L*	L*
Nitrogen × light		NS	NS	NS	NS
Nitrogen × light × seeding		NS	NS	NS	NS

Linear (L) effect significant at $P = 0.05$, () or 0.001 (***) or non-significant (NS).

and 47% were obtained in Montreal. Early yields of fruits of both grades were increased by supplementary lighting. Cumulative yields were not affected by lighting. Boivin et al. (1986) obtained an increase of 31% in the weight of marketable fruits in the first 3 weeks of harvest from greenhouse tomato transplants that had received supplementary light energy of $100 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (PAR).

High rates of N fertilization increased early tomato yields in both regions (Tables 5 and 6). Linear relations were observed as an increase in rate of N fertilization and resulted in an increase of marketable weight of early fruits for both sites. However, the optimal N rate varied according to treatments. For early seedings in Quebec and Montreal, fertilization with 300 mg N/liter and 400 mg N/liter gave the best early yields of marketable fruits under natural light and supplementary lighting, respectively. For the late seeding, in Quebec, 200 mg N/liter was optimal, with or without supplementary lighting. Rates of 400 mg N/liter under natural light and 300 mg N/liter under supplementary lighting were optimal for the late seeding planted in Montreal. However, no significant interaction between N and lighting and between lighting and seeding date was observed for early yields. The effects of the light and fertilization treatments on the productivity of tomato plants from the same seeding were similar at the two sites (data not shown). The effect of N fertilization observed in our experiments is in agreement with the observations of Weston and Zandstra (1989) on tomato, and of Knavel (1977) on pepper.

In general, total tomato yields were negligibly affected by

the treatments. Nitrogen rate and supplementary lighting did not modify yields at either site (Tables 5 and 6). High N rates decreased total yields for transplants of the same seeding (data not shown); Weston and Zandstra (1989) obtained no effect on total yields from N and phosphorus fertilization. In Quebec, some interactions of N, lighting, and seeding date were observed. These interactions were not significant in Montreal.

In summary, yields of celery, lettuce, and broccoli transplants were generally not affected by supplementary lighting during the nursery stage. However, high N fertilization, applied at the nursery stage increased yield. The rate of 300 mg N/liter increased the marketable weight of celery by 15%. The rate of 400 mg N/liter increased marketable lettuce head weight by 16% and promoted maturation. Increases of marketable yields of broccoli of 25% and 58% were measured in the Quebec and Montreal regions, respectively, with N at 400 mg·liter⁻¹. For tomato, N at 300 and 400 mg·liter⁻¹ increased early yield but did not substantially affect total yield. The use of supplementary lighting (high pressure sodium) during the nursery stage increased the early yield of tomato but had no effect on total yield. Early yields of marketable fruit were increased by 55% and 100%, respectively, for the early and late seedings done in the Quebec region. Increases of 36% and 47% were obtained in the Montreal region for the same seedings.

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