Nitrogen Fertilization and HPS Supplementary Lighting Influence Vegetable Transplant Production. I. Transplant Growth

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Abstract. This experiment was initiated to determine the effects of supplementary lighting of 100 µmol·s⁻¹·m⁻² (PAR) in combination with four N rates (100, 200, 300, and 400 mg N/liter) on growth of celery (Apium graveolens L.), lettuce (Lactuca sativa L.), broccoli (Brassica oleracea italica L.), and tomato (Lycopersicon esculentum Mill.) transplants in multicellular trays. Supplementary lighting, as compared with natural light alone, increased shoot dry weight of celery, lettuce, broccoli, and tomato transplants by 22%, 40%, 19%, and 24%, and root dry weight by 97%, 42%, 38%, and 21%, respectively. It also increased the percentage of shoot dry matter of broccoli and tomato, leaf area of lettuce and broccoli, and root : shoot dry weight ratio (RSDWR) of celery and broccoli. Compared with 100 mg N/liter, a N rate of 400 mg liter⁻¹ increased the shoot dry weight of celery, lettuce, broccoli, and tomato transplants by 37%, 38%, 61%, and 38%, respectively. High N fertilization accelerated shoot growth at the expense of root growth, except for tomato where a 16% increase of root dry weight was observed. High N also reduced percentage of shoot dry matter. Supplementary lighting appears to be a promising technique when used in combination with high N rates to improve the production of high quality transplants, particularly those sown early.

According to Tosi and Tesi (1987), transplants with optimal vegetative development can better withstand the stresses caused by the field environment, pests, and diseases following transplanting. Specific characteristics are claimed to be necessary to lessen transplant shock and obtain maximum yield at harvest. For example, stem diameter of celery seedlings (Dufault, 1985) and of tomato transplants (Liptay et al., 1981) is an indication of their vigor and, according to Liptay et al. (1981), the accumulated reserves in tomato transplant stems enhance early fruiting.

High N levels used during celery transplant production have been found beneficial to yield of mature plants (Tremblay et al., 1987). In a subsequent study (Tremblay and Gosselin, 1989), a yield increase was obtained with high N only when 50% of it was provided as urea. However, urea generally did not have much influence on vegetable transplant vegetative characteristics (Tremblay and Senécal, 1990). High N levels are known to favor shoot rather than root growth. However, transplants with well-developed root systems are reported to recover more quickly from transplant shock (Weston and Zandstra, 1986).

The use of supplementary lighting may lessen the undesirable effects of high N on vegetative characteristics. An experiment on this topic conducted in Winter 1988 on lettuce and tomato transplants (Masson et al., 1990) confirmed that high rates of N fertilization increased shoot growth more than root growth. Supplementary lighting promoted a balance between shoot and root development and increased the percentage of shoot dry matter.

The objectives of our experiments were to: a) determine the effects of supplementary lighting and N fertilization on the growth of celery, lettuce, broccoli, and tomato transplants during a normal production period; b) clarify the interactions of the two factors; and c) test the replicability of the treatments effects over time by means of two seeding dates for lettuce, and three for broccoli and tomato.

Material and Methods

Plant material and growing conditions

Plant material used included ‘Florida 683’ celery, ‘Ithaca’ lettuce, ‘Premium Crop’ broccoli, and ‘Springset’ tomato. Seeds were sown in multicell flats (Sutton plug trays #288 for celery and lettuce, and #128 for broccoli and tomato) using a peat-based substrate (Seeding Mix, Les tourbières Premier ltée, Rivière-du-Loup, Quebec). The flats were placed in a polylethene greenhouse, located at Laval Univ. (Quebec City). Tomato flats were placed on a table with heating cables that maintained the substrate at 24°C. The seedlings were thinned to one per cell when emergence was completed, and treatments were initiated at this stage. An early and a late seeding were performed for lettuce while early, midseason, and late seedings of broccoli and tomato were conducted. Celery was sown only once. Table 1 gives the dates for various operations. Overhead fertilization was performed twice daily to partial runoff. Seedlings were watered 1 day-week⁻¹ with tap water to prevent an increase of salinity in the medium (Kratky and Mishima, 1981). Mean air temperature was maintained between 20 and 23°C (day) and 17.0 and 18.0°C (night) for the different species and seedlings during the course of the experiment.

Treatments

The transplants were under natural light (control) or under supplementary lighting. The latter was provided by 400-W HPS
Table 1. Seeding schedule, treatment initiation, and growth measurement dates of celery, lettuce, broccoli, and tomato transplants grown in multicellular trays under various supplementary lighting and N fertilization regimes.

| Species | Sowing Date | Treatment Initiation | Growth Measure |
|---------|-------------|----------------------|----------------|
| Celery  | Midseason   | 30 Mar.              | 7 Apr.         |
|         |             |                      | 16 May         |
| Lettuce | Early       | 21 Apr.              | 25 Apr.        |
|         |             |                      | 16 May         |
|         | Late        | 6 May                | 10 May         |
|         |             |                      | 29 May         |
| Broccoli| Early       | 18 Apr.              | 22 Apr.        |
|         |             |                      | 16 May         |
|         | Midseason   | 25 Apr.              | 29 Apr.        |
|         |             |                      | 23 May         |
|         | Late        | 11 May               | 16 May         |
|         |             |                      | 6 June         |
| Tomato  | Early       | 21 Apr.              | 30 Apr.        |
|         |             |                      | 24 May         |
|         | Midseason   | 3 May                | 12 May         |
|         |             |                      | 2 June         |
|         | Late        | 16 May               | 24 May         |
|         |             |                      | 15 June        |

The lights (No. 400-SO-SHP-120-Solux Lumiponic, Boisbriand, Quebec) giving a photosynthetic photon flux density (PPFD) of 100 ± s = 10 µmol·s⁻¹·m⁻² photosynthetically active radiation (PAR) (72 measures) at the level of the multicell flats using a LI-COR LI-185 photometer equipped with a LI-COR LI-190SB (LI-COR, Lincoln, Neb.) quantum sensor. The lights were turned on before sunrise and off at sunset so as to have a 16-h photoperiod. The starting time for the lighting was changed once a week in relation to the time of sunset. The lights were lit during the day when natural PPFD was <250 µmol·s⁻¹·m⁻². Table 2 presents available natural and artificial light energy and the number of hours of lighting per day for each species and seeding. Shade from the greenhouse structure caused a 60% loss of transmission. As recommended by Thimijan and Heins (1983), the data were also expressed as total natural and artificial light energy on a 24-h basis.

The fertilization treatments consisted of four nutrient solutions with N concentrations of 100, 200, 300, and 400 mg liter⁻¹. Nitrogen was provided according to a ratio of N-N₀: N-NH₄: N-Urea of 2:1:2. All the nutrient solutions had the same concentrations (mg·liter⁻¹) of P (150), K (250), Ca (50), Mg (20), Fe (2), Mn (0.5), Cu (0.03), B (2.5), Zn (0.05), and Mo (0.02). The pH of the nutrient solution was adjusted to 6.0 using NaOH. The electrical conductivity was 1.89, 2.03, 2.16, and 2.36 mS·cm⁻¹, respectively, for 100, 200, 300, and 400 mg N/liter.

Table 2. Contribution of natural and supplementary lighting to the light integral (PAR) received in the greenhouse by transplants for the various sowings.

| Sowing    | Lighting level | Lamp use (h·day⁻¹) | Natural light integral (PAR) (W·m⁻²·day⁻¹) | Supplemental light integral (PAR) (W·m⁻²·day⁻¹) | Total light integral (PAR) (W·m⁻²·day⁻¹) | Mean light integral (24-h basis) (W·m⁻²·h⁻¹) | Increase attributed to suppl. lighting (%) |
|-----------|----------------|--------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------|---------------------------------------------|-------------------------------------------|
| Midseason | Natural        | 0                  | 1094                                        | 0                                            | 1094                                    | 45.6                                        | ---                                       |
|           | Supplemented   | 12.5               | 1094                                        | 250                                          | 1344                                    | 56.0                                        | 22.8                                      |
| Early     | Natural        | 0                  | 1313                                        | 0                                            | 1313                                    | 54.7                                        | ---                                       |
| Late      | Natural        | 0                  | 1365                                        | 0                                            | 1365                                    | 56.9                                        | ---                                       |
| Early     | Supplemented   | 11.6               | 1313                                        | 232                                          | 1545                                    | 64.4                                        | 17.7                                      |
| Late      | Supplemented   | 11.3               | 1365                                        | 226                                          | 1591                                    | 66.3                                        | 16.6                                      |
| Early     | Natural        | 0                  | 1208                                        | 0                                            | 1208                                    | 50.3                                        | ---                                       |
| Midseason | Natural        | 0                  | 1400                                        | 0                                            | 1400                                    | 58.3                                        | ---                                       |
| Late      | Natural        | 0                  | 1433                                        | 0                                            | 1433                                    | 59.7                                        | ---                                       |
| Early     | Supplemented   | 11.8               | 1208                                        | 236                                          | 1444                                    | 60.2                                        | 19.5                                      |
| Midseason | Supplemented   | 10.5               | 1400                                        | 210                                          | 1610                                    | 67.1                                        | 15.0                                      |
| Late      | Supplemented   | 9.6                | 1433                                        | 192                                          | 1625                                    | 67.7                                        | 13.4                                      |
| Early     | Natural        | 0                  | 1337                                        | 0                                            | 1337                                    | 55.7                                        | ---                                       |
| Midseason | Natural        | 0                  | 1412                                        | 0                                            | 1412                                    | 58.8                                        | ---                                       |
| Late      | Natural        | 0                  | 1428                                        | 0                                            | 1428                                    | 59.5                                        | ---                                       |
| Early     | Supplemented   | 11.5               | 1337                                        | 230                                          | 1567                                    | 65.3                                        | 17.2                                      |
| Midseason | Supplemented   | 9.9                | 1412                                        | 198                                          | 1610                                    | 67.1                                        | 14.0                                      |
| Late      | Supplemented   | 9.7                | 1428                                        | 194                                          | 1622                                    | 67.6                                        | 13.6                                      |
Results and Discussion

Shoot dry weight. Supplementary lighting significantly increased shoot dry weight of celery, lettuce, broccoli, and tomato by 22%, 40%, 19%, and 24%, respectively (Tables 3, 4, 5, and 6). Dry weight accumulated in celery stalks but not in the leaf blade; for broccoli and tomato, both variables increased. According to Liptay et al. (1981), the reserves accumulated in tomato transplant stems promote earliness. Stem dry weight can be considered a good indicator of the radial growth of the transplants' base, which is evidence of the young plant's vigor (Dufault, 1985; Liptay et al., 1981).

High rates of N fertilization also increased shoot dry weight for all species (Tables 3, 4, 5, and 6). Nitrogen at 400 mg liter⁻¹ increased celery, lettuce, broccoli, and tomato shoot dry weight by 37%, 38%, 61%, and 38%, respectively, compared with N at 100 mg liter⁻¹. For celery and broccoli, shoot dry weight increased curvilinearly in relation to N, whereas a linear response was obtained for tomato. Similar results for tomato were reported by Weston and Zandstra (1989). With celery, the increase in shoot dry weight with N rates was linear under natural light, but a plateau was reached under supplementary lighting.

Response of lettuce shoot dry weight to N rates was complex but, under supplementary lighting, the highest shoot dry weight was obtained with 400 mg N/liter.

Percentage of shoot dry matter. Supplementary lighting improved the percentage of shoot dry matter for broccoli, tomato (Tables 5 and 6), and lettuce (data not shown) but not for celery (Table 3). Tesi and Tallarico (1984) reported that an increase in percentage of shoot dry matter improves cold resistance and that a good tomato transplant should have > 10% dry matter. Increasing the N rate decreased the percentage of shoot dry matter in all species (Tables 3, 4, 5, and 6), with the lowest percentages obtained at highest level of N fertilization. A similar response was previously reported for celery, lettuce, broccoli, and pepper (Tremblay and Senécal, 1988; Tremblay et al., 1987). Transplants overfertilized with N show an increase in succulence and are easily broken when transplanted (Kratky and Mishima, 1981).

Leaf area, SLA, and LAR. Leaf area for lettuce and broccoli increased under supplementary lighting (Tables 4 and 5), but no effect was detected for celery and tomato (Tables 3 and 6). Supplementary lighting enhanced leaf area development for early tomato seeding only (data not shown). According to Boivin et al. (1986), leaf area is a poor indicator of the effect of light treatments on growth of tomato transplants. Supplementary lighting lowered the SLA of celery, broccoli, and tomato (Tables 3, 5, and 6), but not that of lettuce (Table 4). A low SLA is desirable since it is associated with greater leaf thickness. Leaf anatomy is changed by an increase in light energy (Salisbury and Ross, 1985), as is the case for the amount of chlorophyll and the chloroplasts (Björkman, 1981). Leaves adapt to high amounts of radiation, and one can generally observe an elongation of the palisade layer or the addition of a second layer of cells. Under high PPFD, the palisade layer cells generally elongate so that the leaves are thicker and a decrease in SLA is observed. A low SLA may make transplants more resistant to transplant shock. The increase in natural light energy associated with later seeding seemed to lessen the effect of supplementary lighting on the SLA of broccoli (data not shown) but not that of tomato.

The increase in leaf area with N fertilization (Tables 3, 4, 5, and 6) is in agreement with several studies (Dufault, 1985, 1986; Tremblay and Senécal, 1988; Weston and Zandstra, 1989). Lettuce, broccoli, and tomato SLA increased with N rate in a curvilinear manner (Tables 4, 5, and 6), but celery was not

Table 3. Effect of supplementary lighting (100 µmol·s⁻¹·m⁻²; PAR) and four N levels on celery transplant growth.

| Treatments | N (mg·liter⁻¹) | Shoot dry wt (g/plant) | Shoot dry matter (%) | Leaf area (cm²/plant) | SLA (cm²·mg⁻¹) | LAR (cm²·g⁻¹) | RSDWR |
|------------|----------------|------------------------|---------------------|----------------------|----------------|----------------|-------|
| Light      | Natural        | 100                    | 123                 | 52                   | 71             | 12             | 8.5   | 31.4 | 0.44 | 0.25 | 0.10 |
|            |                | 200                    | 134                 | 58                   | 76             | 8              | 8.0   | 33.5 | 0.44 | 0.25 | 0.06 |
|            |                | 300                    | 133                 | 58                   | 75             | 7              | 7.7   | 32.8 | 0.44 | 0.25 | 0.05 |
|            |                | 400                    | 146                 | 65                   | 81             | 9              | 7.7   | 35.7 | 0.44 | 0.24 | 0.06 |
|            | Supplementary  | 100                    | 116                 | 47                   | 69             | 27             | 8.8   | 27.2 | 0.40 | 0.24 | 0.23 |
|            |                | 200                    | 171                 | 74                   | 97             | 18             | 9.5   | 36.4 | 0.37 | 0.21 | 0.11 |
|            |                | 300                    | 183                 | 81                   | 102            | 14             | 8.0   | 41.6 | 0.41 | 0.23 | 0.08 |
|            |                | 400                    | 182                 | 80                   | 102            | 12             | 8.1   | 41.0 | 0.40 | 0.22 | 0.06 |
| Significance* | Nitrogen | *                      | L***,Q*             | L***,Q*              | L***           | L**           | L***  | NS   | NS   | L***,Q*** |
| Light      | *              | *                      | NS                  | *                   | NS             | **            | **    | NS   | NS   | * *
| Nitrogen × light | *     | L**                   | L*,Q*               | L*,Q*              | L**           | L**           | NS    | NS   | L**   |

Notes:
- Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or 0.001 (***); or nonsignificant (NS)
Table 4. Effect of supplementary lighting (100 µmol·s⁻¹·m⁻²; PAR) and four N levels on lettuce transplant growth (averages of two seeding dates).

| Treatments   | N (mg-liter⁻¹) | Dry wt (mg/plant) | Shoot dry matter (%) | Leaf area (cm²/plant) | SLA (cm²·mg⁻¹) | RSDWR  |
|--------------|---------------|-------------------|----------------------|-----------------------|---------------|--------|
| Light        | Shoot Root    |                   |                      |                       |               |        |
| Natural      | 100  85  9   | 5.0  34.2  0.41  0.11 |                      |                       |               |        |
|              | 200  91  7   | 5.4  38.9  0.43  0.08 |                      |                       |               |        |
|              | 300  99  8   | 5.2  43.9  0.45  0.08 |                      |                       |               |        |
|              | 400  97  6   | 5.0  43.3  0.45  0.08 |                      |                       |               |        |
| Supplementary| 100  97  13  | 6.5  35.7  0.37  0.13 |                      |                       |               |        |
|              | 200  135  11 | 5.5  54.3  0.41  0.08 |                      |                       |               |        |
|              | 300  136  11 | 5.1  58.0  0.43  0.08 |                      |                       |               |        |
|              | 400  153  7  | 5.2  63.4  0.42  0.05 |                      |                       |               |        |

Significance:
- \(^*\) Linear (L), quadratic (Q) or cubic (C) effects significant at \(P = 0.05\) (*), 0.01 (**), or 0.001 (***); or nonsignificant (NS).

Table 5. Effect of supplementary lighting (100 µmol·s⁻¹·m⁻²; PAR) and four N levels on broccoli transplant growth (averages of three seeding dates).

| Treatments   | N (mg-liter⁻¹) | Dry wt (mg/plant) | Shoot dry matter (%) | Leaf area (cm²/plant) | SLA (cm²·mg⁻¹) | RSDWR  |
|--------------|---------------|-------------------|----------------------|-----------------------|---------------|--------|
| Light        | Shoot Stem Leaf Root |                   |                      |                       |               |        |
| Natural      | 100 179 65 114 40 | 11.4 32.1 0.28 0.18 |                      |                       |               |        |
|              | 200 224 84 159 35 | 9.4 45.4 0.33 0.20 |                      |                       |               |        |
|              | 300 269 99 170 33 | 8.9 56.0 0.33 0.21 |                      |                       |               |        |
|              | 400 282 103 179 31 | 8.8 58.1 0.33 0.21 |                      |                       |               |        |
| Supplementary| 100 209 73 136 53 | 12.6 32.1 0.24 0.15 |                      |                       |               |        |
|              | 200 280 103 177 50 | 10.1 50.2 0.28 0.18 |                      |                       |               |        |
|              | 300 302 112 190 46 | 9.4 57.5 0.30 0.19 |                      |                       |               |        |
|              | 400 344 125 219 43 | 9.3 66.3 0.30 0.19 |                      |                       |               |        |

Significance:
- \(^*\) Linear (L), quadratic (Q) or cubic (C) effects significant at \(P = 0.05\) (*), 0.01 (**), or 0.001 (***); or nonsignificant (NS).

Table 6. Effect of supplementary lighting (100 µmol·s⁻¹·m⁻²; PAR) and four N levels on tomato transplant growth (averages of three seeding dates).

| Treatments   | N (mg-liter⁻¹) | Dry wt (mg/plant) | Shoot dry matter (%) | Leaf area (cm²/plant) | SLA (cm²·mg⁻¹) | RSDWR  |
|--------------|---------------|-------------------|----------------------|-----------------------|---------------|--------|
| Light        | Shoot Stem Leaf Root |                   |                      |                       |               |        |
| Natural      | 100 233 100 133 35 | 8.2 45.8 0.34 0.20 |                      |                       |               |        |
|              | 200 273 130 144 39 | 6.6 65.5 0.45 0.24 |                      |                       |               |        |
|              | 300 303 141 162 36 | 6.3 77.6 0.48 0.26 |                      |                       |               |        |
|              | 400 336 149 187 41 | 6.5 84.3 0.45 0.25 |                      |                       |               |        |
| Supplementary| 100 294 124 170 40 | 9.8 45.0 0.27 0.16 |                      |                       |               |        |
|              | 200 363 162 201 48 | 7.7 74.1 0.37 0.20 |                      |                       |               |        |
|              | 300 373 171 202 48 | 7.1 83.8 0.42 0.23 |                      |                       |               |        |
|              | 400 393 177 216 46 | 7.1 90.8 0.42 0.23 |                      |                       |               |        |

Significance:
- \(^*\) Linear (L), quadratic (Q) or cubic (C) effects significant at \(P = 0.05\) (*), 0.01 (**), or 0.001 (***); or nonsignificant (NS).

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affected (Table 3). For broccoli, the effects of N and supplementary lighting on the SLA were greater with early seedings (data not shown). For tomato, the increase in SLA with N fertilization was more pronounced under supplementary lighting.

Supplementary lighting reduced LAR in celery, broccoli, and tomato (Tables 3, 5, and 6). For broccoli, the effect of supplementary lighting on LAR was less in the late seedings, contrary to the observations for tomato (data not shown). Boivin et al. (1986) observed a lowering of LAR in greenhouse tomato transplants placed under increasing PPFD.

LAR of broccoli and tomato increased curvilinearly with N rate. Tremblay and Senécal (1988) reported increased LAR for broccoli and green pepper when plants were grown with 350 instead of 150 mg N/liter. With broccoli, the response of LAR to N rate was greater without supplementary lighting (Table 5). The LAR and SLA of broccoli and tomato changed in a very similar way according to the lighting and fertilization treatments, thus indicating a similar response of leaves and stems. The effect of supplementary lighting and N on the LAR of tomato plants increased the later they were sown (data not shown). Boivin et al. (1986) reported a decrease in root weights of celery, lettuce, and broccoli, and tomato, respectively. According to Weston and Zandstra (1986), transplants with a well-developed root system recover better in the field.

Increasing N fertilization decreased celery, lettuce, and broccoli root dry weight (Tables 3, 4, and 5). Tomato plants, however, showed a linear increase (Table 6), as noted by Weston and Zandstra (1989). Tomato root dry weight was 16% higher with 400 than with 100 mg N/liter. Tremblay and Senécal (1988) reported a decrease in root weights of celery, lettuce, and broccoli caused by high rates of N fertilization.

The RSDWR of celery and broccoli was increased by supplementary lighting (Tables 3 and 5). However, lighting did not affect this relation for lettuce and tomato (Tables 4 and 6). RSDWR decreased curvilinearly in relation to N rate in celery, lettuce, and broccoli but linearly for tomato (Tables 3-6). Decreases in RSDWR caused by high N rates have been reported for several species (Dufault, 1985; Tremblay and Senécal, 1988; Tremblay et al., 1987; Weston and Zandstra, 1989). For celery and lettuce, this decrease was more evident under supplementary lighting.

In summary, the use of supplementary lighting (HPS) of 100 μmol·s⁻¹·m⁻² (PAR) on seedlings during transplant production promoted balanced growth. Supplementary lighting also improved shoot and root dry weights of all species and it can be used in combination with high N fertilization for most of the species tested to obtain vigorous transplants, with acceptable levels of dry matter percentage. Supplementary lighting can be considered a promising technique to hasten production of good quality transplants in northern latitudes, particularly for early seeding dates. Nitrogen at 100 mg·liter⁻¹ limited growth of all the species. Rates of 300 to 400 mg N/liter optimized growth of the transplants under natural light, while 400 mg N/liter was generally optimal under supplementary lighting or when sowing was late. Since such high N levels may be detrimental to transplant survival under field conditions, it is therefore necessary to verify the consequences of this treatment in the field.

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