Carbon and Nitrogen Budgets in Spring and Fall Tomato Crops

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Abstract. Carbon and nitrogen budgets were determined for ‘Colonial’ (spring) and ‘Equinox’ (fall) tomato (Lycopersicon esculentum Mill.) plants grown on raised beds with black polyethylene mulch and supplied with preplant-N at 0, 67, 134, 202, or 269 kg·ha⁻¹. For both spring and fall experiments, we quantified the partitioning of dry matter, N, and C, and determined marketable and total yield. In the spring study, the concentration of N in leaves, stems, and in total plants increased linearly with level of N fertilization, whereas a quadratic relationship described the amount of N contained in the fruit (maximum with 202 kg·ha⁻¹). Quadratic relationships occurred between rate of fertilization and leaf weight, stem weight, total plant weight, marketable yield, and total yield in the spring study, with maximum values at 134 or 202 kg·ha⁻¹ rates of N fertilization. In the fall crop, fewer significant relationships occurred between dependent variables and rate of N fertilization, and coefficients of determination tended to be much lower than in the spring study. The fraction of N in leaves, stems, and roots (fall study only) was influenced by N fertilization. Effects of N fertilization on the fraction of C partitioned to any plant part was either nonsignificant or significant at P = 0.05. Total yield was related to N fertilization in a quadratic manner, but marketable yield was significantly affected only in the spring study. In both studies, increasing the rate of N fertilization reduced the C:N linearly for all tissues. In all cases, the quantity of N partitioned to vegetative tissue was at least 65% of that partitioned to the fruit, and the quantity of C in the plant was at least 74% of that in the fruit. In conclusion, although N fertilization above 202 kg·ha⁻¹ generally increased the concentration and total amount of N in vegetative tissues, it did not increase yield. Also, the highest rate of N fertilization (269 kg·ha⁻¹) resulted in a much lower efficiency of applied N [defined as: (N plant + N fruit)/N applied], and a much higher level of residual soil nitrate-N.

Materials and Methods

For the spring study, ‘Colonial’ tomato plants were transplanted 29 Mar. 1996, utilizing a black polyethylene mulch planting system with raised beds 0.91 m wide and 1.83 m apart at the North Florida Research and Education Center (NFREC), Quincy. Prior to transplanting, the raised beds were treated with 98% methyl bromide-2% chloropicrin (trichloromethane) at 225 kg·ha⁻¹. Plant density was 10,760 plants/ha. Tomato transplants were obtained from 3.8 × 3.8 × 6.4 cm deep (pyramidal; 30.8 cm³) volumes of Terra-Lite (Scott-Sierra Horticultural Products Co., Marysville, Ohio) media. Preplant N (ammonium nitrate) was applied at one of five rates (0, 67, 134, 202, or 269 kg·ha⁻¹) in a 1.33-m-wide area that was used as the raised bed just prior to the time of bed formation. Soil type was an Orangeburg loamy fine sand (Typic Paleudult: Siliceous Thermic). All treatments received triple superphosphate (0–46–0) at 224 kg·ha⁻¹ and K₂SO₄ (0–0–50) at 336 kg·ha⁻¹. Plants received drip irrigation with emitters spaced 0.3 m apart. Each single-row plot contained 18 plants spaced 0.51 m row, and only the 12 center plants were harvested for yield. Wooden stakes and twine were used to retain plants in an upright position. Standard insecticide and fungicide applications were employed (Hochmuth and Maynard, 1996). Tomatoes were harvested on 20 June, 26 June, and 8 July, and were graded into medium, large, and extra-large fruit and culls. Total yield included all graded tomatoes including culls, while marketable yield did not include culls.

For the fall study, ‘Equinox’ tomatoes were planted 31 July 1997 at the NFREC–Quincy. The only difference in the culture of ‘Equinox’ in late summer and fall compared with ‘Colonial’ in the spring was that white on black polyethylene mulch was used for ‘Equinox’. Harvest dates were 13, 22, and 30 Oct. 1997. Vegetative plant material was harvested 27
June 1996 and 31 Oct. 1997, respectively, for the spring and fall experiments. Plant weight designations refer to vegetative tissue (leaves, roots, and stems), while total weight refers to plant weight plus fruit weight. The same holds for the weight of C and N. Three plants from each of 20 plots were severed at the ground level, cut into 0.30-m pieces, and placed in paper bags. Root systems were excavated by digging holes 0.45 m wide \( \times \) 0.25 m deep and washing the root system with water. In addition, root weight outside this region was estimated by collecting root segments located in three random soil core cylinders 5.5 cm wide \( \times \) 20 cm deep in each plot. The soil volume in the raised bed under polyethylene mulch to a depth of 0.25 m deep was estimated and root weight outside the original holes was calculated. Total root weight was estimated by adding root weight in the original hole plus that calculated to exist outside the hole. Harvested plant material was dried at 50 °C for 4 to 6 d. Stem, leaf, and fruit dry weights were determined and subsamples of stem, leaf, and root tissue from each plant were dried for an additional 7 to 10 d at 80 °C. Subsamples of tissue were finely ground using a tissue grinder.

Table 1. Effects of rate of N fertilization on concentrations (g·kg–1) of N and C, and C :N ratios in leaves, stems, roots, plants, fruit, and total (plant plus fruit) of tissue were finely ground using a tissue grinder.

| Tissue element | N fertilization (kg·ha–1) | Statistics |
|----------------|--------------------------|------------|
|                | 0  | 67 | 134 | 202 | 269 |         |          |
| **Colonial, 1996** |    |    |    |    |    |         |
| Leaf N         | 12.6 | 17.1 | 21.3 | 23.6 | 25.2 | 13.6 + 0.047x | 0.72 **** |
| C              | 392 | 383 | 385 | 374 | 377 | 385 – 0.036x | 0.22 * |
| C : N ratio    | 30.8 | 22.7 | 18.2 | 16.5 | 15.3 | 28.11 – 0.055x | 0.74 **** |
| Stem N         | 8.70 | 10.9 | 13.0 | 15.3 | 18.6 | 8.40 + 0.036x | 0.80 **** |
| C              | 422 | 413 | 408 | 412 | 416 | 421 – 0.16x + 0.00053x 2 | 0.33 * |
| C : N ratio    | 49.0 | 38.2 | 31.4 | 28.1 | 22.8 | 46.4 – 0.093x | 0.80 **** |
| Root N         | 13.5 | 14.1 | 14.7 | 14.9 | 18.6 | --- --- --- ns |
| C              | 407 | 407 | 412 | 397 | --- | --- --- --- ns |
| C : N ratio    | 30.6 | 29.5 | 27.9 | 27.8 | 25.1 | 30.7 – 0.019x | 0.21 * |
| Plant N        | 10.2 | 12.9 | 16.1 | 17.9 | 20.6 | 10.4 + 0.0387x | 0.79 |
| C              | 411 | 403 | 400 | 400 | 401 | 408 – 0.0354x | 0.29 * |
| C : N ratio    | 40.5 | 31.5 | 24.8 | 23.2 | 19.7 | 38.0 – 0.0745x | 0.80 **** |
| Fruit N        | 16.6 | 18.0 | 18.1 | 22.6 | 23.2 | 16.1 + 0.0263x | 0.60 **** |
| C              | 403 | 385 | 396 | 398 | --- | 401 + 0.0208x + 0.000077x 2 | 0.31 * |
| C : N ratio    | 25.1 | 21.5 | 21.5 | 17.6 | 17.2 | 24.5 – 0.209x | 0.60 **** |
| Total N        | 13.1 | 15.5 | 17.1 | 20.5 | 21.9 | 13.1 + 0.0336x | 0.83 **** |
| C              | 405 | 394 | 393 | 397 | 400 | 406 – 0.173x + 0.00058x 2 | 0.49 * |
| C : N ratio    | 31.5 | 25.5 | 23.1 | 19.5 | 18.3 | 30.5 – 0.0483x | 0.78 **** |
| **Equinox, 1997** |    |    |    |    |    |         |
| Leaf N         | 26.1 | 28.5 | 32.0 | 33.4 | 34.2 | 26.6 + 0.0313x | 0.60 **** |
| C              | 372 | 357 | 379 | 387 | 385 | --- --- --- ns |
| C : N ratio    | 14.4 | 12.6 | 11.9 | 11.6 | 11.3 | 13.8 – 0.0107x | 0.37 * |
| Stem N         | 11.4 | 13.6 | 18.6 | 18.4 | 20.0 | 12.1 + 0.0321x | 0.58 **** |
| C              | 400 | 399 | 390 | 407 | 405 | --- --- --- ns |
| C : N ratio    | 35.2 | 29.6 | 22.5 | 22.6 | 20.6 | 33.3 – 0.0537x | 0.64 **** |
| Root N         | 15.8 | 16.5 | 18.5 | 19.3 | 19.0 | 15.7 + 0.0147x | 0.32 ** |
| C              | 391 | 397 | 399 | 393 | 403 | --- --- --- ns |
| C : N ratio    | 25.1 | 25.6 | 22.0 | 20.4 | 21.5 | 25.4 – 0.0182x | 0.28 * |
| Plant N        | 17.6 | 19.4 | 23.8 | 24.2 | 25.7 | 17.9 + 0.0315x | 0.60 **** |
| C              | 388 | 384 | 391 | 397 | 396 | 385 + 0.0447x | 0.20 **** |
| C : N ratio    | 22.3 | 19.9 | 16.7 | 16.5 | 15.6 | 21.6 – 0.0250x | 0.57 **** |
| Fruit N        | 21.1 | 22.0 | 22.7 | 24.7 | 26.0 | 20.8 + 0.0185x | 0.37 ** |
| C              | 399 | 400 | 396 | 394 | 397 | --- --- --- ns |
| C : N ratio    | 19.4 | 18.3 | 17.4 | 16.3 | 15.5 | 19.1 – 0.0136x | 0.43 ** |
| Total N        | 19.2 | 20.7 | 23.3 | 24.4 | 25.8 | 19.4 + 0.0290x | 0.64 **** |
| C              | 395 | 391 | 393 | 396 | 397 | --- --- --- ns |
| C : N ratio    | 20.7 | 19.0 | 17.0 | 16.4 | 15.4 | 20.3 – 0.0194x | 0.62 **** |

*All variables reported on the basis of dry weight.

**Note:** Nonsignificant or significant at \( P < 0.05, 0.01, \) or 0.001, respectively.
not statistically significant. The concentrations of root N and root C were not affected by N fertilization in the spring, although root N increased in the fall with increasing rate of N fertilization. The concentration of fruit N increased with the rate of N fertilization in both spring and fall experiments. The concentration of plant and total N increased up to 2-fold with N fertilization, although C was much less affected. The C : N ratios of leaves, stems, roots, and fruit decreased linearly with increasing rate of N fertilization in both spring and fall plantings, because of increases in N. Seventy-eight percent of the variation in plant C : N and total C : N ratio in the spring was explained by rates of N fertilization.

**Tissue weight and yield of fruit.**

In the spring study, weights of leaves, stems, and total plant, marketable yield, and total yield were related to N fertilization in a quadratic manner, with maximum values of all variables observed at 134 or 202 kg ha⁻¹ (Table 2). Root weight was not affected by rate of N fertilization. In the fall study, leaf and plant weight, and total yield were the only dependent variables influenced by the rate of N fertilization. Maximum marketable and total yields in the spring study (54 and 75 t ha⁻¹, respectively) were obtained at a N rate of 202 kg ha⁻¹. Marketable and total yield in the fall study varied from 54 to 59 t ha⁻¹ and 65 to 70 t ha⁻¹, respectively, with the application of 67 to 269 kg ha⁻¹ (Table 2). These results are consistent with those of Rhoads et al. (1996), who reported maximum yield for a spring crop of tomatoes at 202 kg ha⁻¹ N, while the fall crop did not respond to N fertilization rates above 67 kg ha⁻¹. There were quadratic relationships for the ratios of marketable yield to plant weight and total yield divided by plant weight (indications of partitioning to reproductive vs. vegetative tissue) for the spring study, with maximum values at 202 kg ha⁻¹ N; in the fall study, these values did not vary significantly with rate of N fertilization. After factoring in a 4.9% dry-weight to fresh-weight ratio for fruit, the ratio of total reproductive to vegetative growth ranged from 0.83 to 1.30 in the spring, and from 1.06 to 1.27 in the fall.

**Partitioning of N and C.** In the spring experiment, the quantity of N partitioned to leaves increased almost 5-fold as the amount of N applied increased from 0 to 269 kg ha⁻¹, yet stem, plant, and total N increased only 3-fold (Table 3). The N partitioned on the fruit was related to N fertilization in a curvilinear manner, whereas that partitioned to other plant parts (except root N during the spring) was linearly related to rate of N fertilization. Although total-N was highest for the 269 kg ha⁻¹ treatment, the quantity of N partitioned to the fruit was greatest for the 202 kg ha⁻¹ treatment. In the fall study, the quantity of N in leaves and fruit was correlated with the rate of N fertilization in a linear manner, whereas a quadratic relationship best explained stem and plant N. Total N was linearly related to N fertilization in both studies. These data support the data of Terman and Brown (1968), who reported that total N uptake was essentially linear over a broad range of applied N. Data from the spring experiment also appear to support the results of Stark et al. (1983), who found that applying more N to the soil increased the amount of N taken up by the plant, although it did not necessarily increase the amount of N partitioned to the fruit.

When all data were analyzed collectively, the quantity of N and C in the fruit paralleled that contained in the plant (Table 3). For example, for all treatments the N in the plant was 65% to 102% of that contained in the fruit. Similarly, C in the plant varied from 74% to 122% of that contained in the fruit. The ratios of marketable yield/plant weight and total yield/plant weight were higher in the fall than in the spring. In the spring, the highest ratio of reproductive to vegetative growth occurred at 202 kg ha⁻¹ N; in the fall study, neither marketable yield/plant weight or total yield/plant weight were affected by the rate of N fertilization. The ratio of total yield to plant weight was fairly constant (Table 2). For example, total plant weight varied from 216 to 286 for both experiments, with the exception of the 0 kg ha⁻¹ treatment in the spring study. Given the close correlation of plant N and crop N, and that of plant C and crop C for all treatments in both years, the amount of N and C in a tomato crop appears to be influenced or regulated by the quantities of N and C in the plant within roughly defined limits.

**Soil nitrate-N.** In the fall, but not the spring experiment, residual soil nitrate-N increased significantly as a function of rate of N fertilization. The amount of residual soil nitrate-N (just after final harvest) varied from 7 to 17 kg ha⁻¹ in the spring study and 9 to 51 kg ha⁻¹

### Table 2. Effects of rate of N fertilization on leaf, stem, root, and plant dry weight, marketable yield (kg ha⁻¹), total yield, and the ratio of these variables divided by plant weight for two cultivars of tomato planted 29 Mar. 1996 and 31 July 1997.

| Variable | N fertilization (kg·ha⁻¹) | Weight of: | Ratio of: | Statistics |
|----------|-------------------|-------------|------------|------------|
|          | 0 | 67 | 134 | 202 | 269 | y = | $R^2$ | $P$ |
| **Colonial, 1996** | | | | | | | | | |
| Leaf | 422 | 787 | 1,117 | 979 | 1,098 | 434 + 6.40x – 0.0153x² | 0.70 | **** |
| Stem | 1,130 | 1,728 | 1,850 | 1,830 | 1,809 | 1180 + 8.06x – 0.0219x² | 0.70 | **** |
| Root | 203 | 190 | 257 | 233 | 245 | --- | --- | --- |
| Plant | 1,753 | 2,704 | 3,224 | 3,047 | 3,153 | --- | --- | --- |
| Marketable yield | 18,888 | 41,993 | 51,009 | 54,238 | 39,588 | 18,789 + 427x – 1.29x² | 0.81 | **** |
| Total yield | 29,798 | 56,429 | 65,394 | 74,888 | 63,061 | 29,221 + 484x – 1.30x² | 0.74 | **** |
| **Equinox, 1997** | | | | | | | | | |
| Leaf | 799 | 1,039 | 1,218 | 1,202 | 1,182 | 10.9 + 0.087x – 0.00029x² | 0.56 | **** |
| Stem | 1,051 | 1,475 | 1,519 | 1,447 | 1,373 | 16.6 + 0.078x – 0.00027x² | 0.31 | * |
| Root | 285 | 297 | 350 | 478 | 298 | --- | --- | --- |
| Plant | 2,135 | 2,811 | 3,087 | 3,127 | 2,853 | 2147 + 11.7x – 0.0378x² | 0.36 | * |
| Marketable yield (kg ha⁻¹) | 49,306 | 56,028 | 58,767 | 54,151 | 55,667 | --- | --- | --- |
| Total yield (kg·ha⁻¹) | 57,012 | 65,072 | 69,388 | 69,880 | 67,575 | 58039 + 111x – 0.302x² | 0.35 | * |

**Note:** All variables of plant weight with the exception of marketable and total yield are reported as dry weight; marketable and total yield are fresh weight. To calculate dry weight of marketable and total yield, multiply by 0.049.

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**NS**, "**, ****" Nonsignificant or significant at $P < 0.05$, 0.01, 0.001, or 0.0001, respectively.

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in the fall study. Soil nitrate-N was substantially higher in the 269 kg·ha⁻¹ treatment, which suggests an increased level of nitrate leaching at this high level of N fertilization.

Crop residues are also a significant source of N and may contribute greatly to soil nitrate-N. For example, foliage of sugar beets contains 50 to 150 kg·ha⁻¹ N (Neeteson and Ehler, 1989; Wehrmann and Scharpf, 1989). The quantity of N in tomato plants after final harvest varied between 52 and 77 kg·ha⁻¹ for the preplant N rates of 134 to 269 kg·ha⁻¹. As might be expected, the quantity of C contained in the various plant fractions increased linearly with an increasing rate of N fertilization, with most variables approaching a maximum at the high level of N fertilization.

In conclusion, in both spring (‘Colonial’) and fall (‘Equinox’) experiments, the concentration of N and the total N taken up by the tomato crop appears to be largely independent of the amount applied, as Stark et al. (1983) showed that an increase in N application rate from 120 to 585 kg·ha⁻¹ only slightly increased (by 40 kg·ha⁻¹) the amount of N harvested in the crop. However, our study supports the observations of Stark et al. (1983), in that increasing N fertilization increased the amount of N partitioned to vegetative portions of the plant.

Table 3. Effects of N fertilization rate on the quantity of N and C partitioned to leaves, stems, roots, plants, fruit, and total (plant + fruit) and on residual nitrate-N in soil after final harvest and N efficiency ([plant N + fruit N]/kg N applied) of two cultivars of tomato planted 29 Mar. 1996 and 31 July 1997. All values in kg·ha⁻¹.

| Variable  | 0      | 67     | 134    | 202    | 269    |
|-----------|--------|--------|--------|--------|--------|
| N in:     |        |        |        |        |        |
| Leaf      | 5.35   | 13.3   | 23.8   | 23.0   | 29.1   |
| Stem      | 9.95   | 19.2   | 24.8   | 27.7   | 33.7   |
| Root      | 2.77   | 2.78   | 3.84   | 3.44   | 3.89   |
| Plant     | 18.1   | 35.3   | 52.4   | 54.1   | 66.6   |
| Fruit     | 25.2   | 49.7   | 57.6   | 89.1   | 71.4   |
| Total     | 43.3   | 85.0   | 110.0  | 143.2  | 138.0  |
| C in:     |        |        |        |        |        |
| Leaf      | 164    | 301    | 430    | 366    | 449    |
| Stem      | 473    | 696    | 750    | 754    | 752    |
| Root      | 82.4   | 76.4   | 104    | 95.8   | 97.7   |
| Plant     | 720    | 1074   | 1284   | 1216   | 1299   |
| Fruit     | 589    | 1065   | 1235   | 1558   | 1230   |
| Total     | 1309   | 2141   | 2519   | 2670   | 2529   |
| Residual soil nitrate-N (kg·ha⁻¹) | 6.86 | 8.76 | 7.62 | 9.14 | 7.17 |
| N efficiency | 1.42 – 0.00353x | 0.82 |

*All plant variables are reported on the basis of dry weight.

**Nonsignificant or significant at P < 0.05, 0.01, 0.001, or 0.0001, respectively.

\[ R^2 \] and \[ P \] statistics of the regression equations (Table 3).

\[ y = 7.51 + 0.0847x \] 0.80 ****
\[ 11.9 + 0.0831x \] 0.67 ****
\[ 23.6 + 0.455x - 0.00096x^2 \] 0.71 ****
\[ 54.5 + 0.368x \] 0.79 ****
\[ 172 + 2.23x - 0.00478x^2 \] 0.76 ****
\[ 491 + 3.04x - 0.00789x^2 \] 0.47 **
\[ 742 + 5.4x - 0.0130x^2 \] 0.69 ****
\[ 573 + 8.84x - 0.0231x^2 \] 0.73 ****
\[ 1315 + 14.3x - 0.0363x^2 \] 0.78 ****
\[ 24.3 + 0.0742x \] 0.35 **
\[ 11.74 + 0.172x - 0.00434x^2 \] 0.49 **
\[ 36.2 + 0.394x - 0.00095x^2 \] 0.48 **
\[ 61.8 + 0.0972x \] 0.45 ***
\[ 108 + 0.224x \] 0.45 ***
\[ 327 + 0.614x \] 0.28 *
\[ 435.3 + 2.72x - 0.0069x^2 \] 0.30 *
\[ 826 + 4.60x - 0.0128x^2 \] 0.39 *
\[ 1991 + 6.30x - 0.0174x^2 \] 0.39 *
\[ 3.63 + 0.141x \] 0.51 ***
\[ 2.13 - 0.00620x \] 0.81 ****
result of the strong influence of fertilization on N concentration. Considering all treatments for both spring (‘Colonial’) and fall (‘Equinox’) crops, the quantity of N and C partitioned among vegetative and fruit tissues was closely related, suggesting that the amount of N and C in the crop is dependent on the pool of N and C in the plant. The highest rate of N fertilization (269 kg·ha$^{-1}$) resulted in the lowest N efficiency and the highest amount of residual soil nitrate-N.

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