Evaluation of different nitrogen use efficiency indices using field-grown green bell peppers (Capsicum annuum L.)

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Van Eerd, L. L. 2007. Evaluation of different nitrogen use efficiency indices using field-grown green bell peppers (Capsicum annuum L.). Can. J. Plant Sci. 87: 565–569. The effects of increasing nitrogen (N) fertilization on N use efficiency (NUE) and yield of green bell pepper were assessed in five field experiments over 2004 and 2005. These data were used to evaluate and contrast conclusions drawn from among 12 different NUE indices. In two different years (i.e., cool/wet vs. warm/dry), marketable yield response to N application was either positive or no response was observed. Total percent N in the fruit and shoot was lower in non-fertilized plants compared with plants grown in plots that received 70 or 210 kg N ha⁻¹. There were considerable differences among locations in soil mineral N, yield, NUE, and plant N uptake and removal. For all eight fertilizer- and soil-based NUE indices assessed, NUE decreased as N application increased. However, for plant-based NUE indices, there was no difference in NUE values between N treatments. Thus, the interpretation and applicability of NUE depends on the goals of the research and the index used.

Key words: Nutrient use efficiency, green bell peppers, harvest index, nitrogen, fertilizer, vegetable

With increased costs of N fertilizer and the potential environmental damage of excessive N applications, it is becoming increasingly important to improve N use efficiency (NUE) of crops. Although there are many different definitions and methods for determining NUE and other related indices, there are four main differences between NUE calculations (Good et al. 2004): (1) inclusion or exclusion of a zero or low N control, (2) estimates of soil supplied N (i.e., mineralization) compared with N fertilizer applied, (3) total biomass vs. yield biomass and (4) total or yield biomass vs. total or yield N content.

Field experiments were conducted to determine the effects of increasing N fertilization on processing green bell pepper (Capsicum annuum L.) yield and NUE. There have been many studies evaluating NUE in various crops (Craswell and Godwin 1984; Raun and Johnson 1999; Zebarth et al. 1995; Zvomuya and Rosen 2002), but there is no standard method for calculating NUE. The objective of this study was to compare several different NUE indices using green bell peppers as a model crop.

MATERIALS AND METHODS

In 2004 and 2005, field experiments on green bell pepper were conducted at the University of Guelph Ridgetown Campus and at grower sites in southwestern Ontario for a total of five sites (Table 1). Pest management, fertilization for all nutrients other than N, and other field management were according to typical production practices in Ontario.

Preplant ammonium nitrate was broadcast at 0, 35, 70, 140, and 210 kg N ha⁻¹ in a randomized complete block design with four replications of three twin rows of peppers.
within 6 m by 8 m plots. The center 6 m of the center twin row (ca. 26 plants/plot) was harvested four times between mid-August and early October. At each harvest total and marketable yields were determined. After the final harvest, five representative plants per experimental unit were harvested at ground level. Representative fruit and shoot samples were dried at 65–70°C to determine dry-matter content (%). A composite shoot sample and a weighted composite fruit sample were ground to determine N content for the following N application doses: 0, 70, and 210 kg N ha–1. These N doses were selected for NUE analysis because they encompass the range of doses tested and 70 kg N ha–1 is the Ontario recommended N rate for peppers. It was assumed that NUE for the remaining doses tested would be intermediate.

For determination of soil inorganic N concentration (NO₃-N and NH₄-N), one composite soil sample from six cores was obtained from each block prior to transplanting and each plot at harvest at depths of 0–15, 15–30, 30–60, 60–90 cm in 2004 and 0–30, 30–60, and 60–75 cm in 2005. For selected treatments, plant and soil N analyses were conducted by A&L Laboratories Inc. (London, ON) and Agri-Food Laboratories Ltd. (Guelph, ON), respectively, using the Ontario certified procedures as described by Maynard and Kalra (1993).

Nitrogen use efficiency indices were calculated using dry-matter of plant (i.e., above-ground shoot and fruit; Pw) and fruit (Yw) in kg ha⁻¹. Nitrogen content in the plant (Pn) and fruit (Yn), in kg N ha⁻¹, was determined by multiplying N content by dry-matter content. Soil mineral N content (Sn) was calculated from fertilizer applied plus soil mineral N content based on preplant and harvest soil cores to the 75- or 90-cm depth and converted to kg N ha⁻¹ based on bulk density. Indices were categorized into three types based on parameters used (Table 2); fertilizer-based NUE indices with the quantity of fertilizer applied as denominator (Eqs. 1–4), soil-based NUE indices with soil available N as denominator (Eqs. 5–8), and plant-based NUE indices where only plant parameters were used (Eqs. 9–12).

Yield data and NUE parameters were subjected to linear and quadratic regression and NUE data were analyzed using PROC MIXED model (SAS version 8.2; SAS Institute, Inc., Cary NC), with location and replicate as random effects and N application and year as fixed effects. Mean separation was determined using Tukey-Kramer multiple comparison procedure (α = 0.05).

The most economical rate of N (MERN) values were calculated using the following equation (Rashid and Voroney 2005):

\[
\text{MERN} = \frac{b - \frac{F}{P}}{2c}
\]

where \(F\) is fertilizer cost at $1.10 kg⁻¹, \(P\) is peppers’ selling price at $295 t⁻¹, and \(b\) and \(c\) are the linear and quadratic coefficients from the quadratic N dose–yield response curve for each site. For NUE calculations at the MERN, parameters were estimated using linear and quadratic regression equations of individual NUE parameters (i.e., \(Pw, Yw, Pn, Yn, \text{and } Sn\)) to N fertilizer applied for the responsive RC2004 site only; Howard 2004 was not included because the MERN was significantly beyond the range of N fertilizer tested.

**RESULTS AND DISCUSSION**

Significant positive quadratic yield responses to fertilizer N were observed in 2004 (Fig. 1). MERN values were 121 and >>210 kg N ha⁻¹, depending on site and based on fertilizer costs of $1.10 kg⁻¹ and peppers sold at $295 t⁻¹. The large discrepancy in MERN values suggests that any new N recommendations for peppers grown in Ontario should not be based on a single N dose. The lack of yield response to N observed in 2005 (Fig. 1) may be partially explained by the warm and dry weather conditions (data not shown), where moisture, rather than N, was the more limiting growth factor and soil texture, sandy loam vs. loam in 2004 vs. 2005. Yields from all trials were at or above the average provincial yield (Mailvaganam 2006).

Regardless of yield response to N fertilization, at the final harvest there was no difference in shoot weight between N treatments (data not shown). Compared with the non-fertilized control, applied N increased total N content in shoot and fruit, with a significant linear response observed for shoot total N (Fig. 2). Pepper plants were luxury consumers of N because with increased N fertilization there was an increase in shoot N without a consistent corresponding increase in plant shoot weight or fruit yield.

There were considerable differences between field locations in yield, yield response to N (Fig. 1) and NUE. For example, in 2004 depending on the field, fertilizer N uptake efficiency (Eq. 1 in Table 2) ranged from 49% to 105%.
Fig. 1. Field-grown green bell pepper yield response to ammonium nitrate applied preplant broadcast. Symbols are sample means of four replicates, with standard error lines. Howard 2004: $Y = 62.8 + 0.08N - 0.00007N^2$ ($r = 0.5$) and RC 2004: $Y = 56.9 + 0.21N - 0.00086N^2$ ($r = 0.47$).

Fig. 2. Response of total N content of field-grown green bell pepper fruit and shoot to ammonium nitrate applied preplant broadcast. Different letters indicate statistical differences between treatment means based on Tukey-Kramer test ($P < 0.05$). Shoot: $y = 2.77 + 0.005x$ ($r = 0.50$).
when 70 kg N ha⁻¹ was applied (individual data not shown); a NUE index value larger than 100% indicates that plant N uptake was more than N applied. Overall, for all indices assessed, values in 2005 were no different or consistently lower than 2004 values, which was likely due to contrasting weather; warm and dry vs. cool and wet, respectively, which resulted in a yield response in 2004 only.

For all fertilizer-based NUE indices (Eq. 1–4), there were differences in NUE between years. In 2005, there was no difference among N treatments (70–210 kg N ha⁻¹) for all fertilizer-based NUE indices values, but in 2004, increasing N fertilizer from 70 to 210 kg N ha⁻¹ decreased NUE (Eq. 1–4). This result was similar to the outcome of other research (Olsen et al. 1993; Tei et al. 1999) where increasing N fertilization decreased NUE. The same conclusions would result (i.e., increased N application decreased NUE) regardless of which fertilizer-based NUE index was used.

### Table 2. Comparison of N use efficiency indices calculated for field-grown green bell peppers

<table>
<thead>
<tr>
<th>Eqn.</th>
<th>NUE term</th>
<th>Formula</th>
<th>N rate</th>
<th>2004</th>
<th>2005</th>
<th>Explanation of indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fertilizer N uptake efficiency</td>
<td>( \frac{P_{nf} - P_{nc}}{F - F_e} \times 100 )</td>
<td>70 125a</td>
<td>30c</td>
<td>• Increases in plant N derived from added fertilizer N compared with non-treated control</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Apparent fertilizer N recovery</td>
<td>( \frac{Y_{nf} - Y_{nc}}{F - F_e} \times 100 )</td>
<td>70 85a</td>
<td>49c</td>
<td>• Proportion of fertilizer N converted to yield N compared with non-treated control</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Fertilizer N use efficiency</td>
<td>( \frac{P_{nf} - P_{nc}}{F} \times 100 )</td>
<td>70 36a</td>
<td>56c</td>
<td>• Increases in plant biomass per unit N applied compared with non-treated control</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Agronomic fertilizer efficiency</td>
<td>( \frac{Y_{nf} - Y_{nc}}{F} \times 100 )</td>
<td>70 12a</td>
<td>65c</td>
<td>• Increased yield per unit N applied compared with non-treated control</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>N uptake efficiency (NUpE)</td>
<td>( \frac{P_n}{S_n} \times 100 )</td>
<td>0 110a</td>
<td>77b</td>
<td>• Relative to available N, how much N is taken into the plant</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Soil N use efficiency</td>
<td>( \frac{P_w}{S_n} \times 100 )</td>
<td>70 42a</td>
<td>31b</td>
<td>• Biomass production relative to available N</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Apparent N recovery</td>
<td>( \frac{Y_n}{F} \times 100 )</td>
<td>0 71a</td>
<td>15c</td>
<td>• Quantity of crop N removed from field as yield based on available N</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Soil yield N use efficiency = NUtE × NUpE</td>
<td>( \frac{Y_w}{S_n} \times 100 )</td>
<td>70 29a</td>
<td>21b</td>
<td>• Yield potential based on available N</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>N utilization efficiency (NUtE)</td>
<td>( \frac{Y_{nf} - Y_{nc}}{P_{nf} - P_{nc}} \times 100 )</td>
<td>70 23a</td>
<td>33a</td>
<td>• Fraction of total plant N converted to yield compared with non-treated control</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>N harvest index</td>
<td>( \frac{Y_n}{P_n} \times 100 )</td>
<td>70 64a</td>
<td>61a</td>
<td>• Partitioning of plant N between fruit and vegetative shoots</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Harvest index</td>
<td>( \frac{Y_w}{P_w} \times 100 )</td>
<td>70 62a</td>
<td>51b</td>
<td>• Partitioning of biomass between fruit and vegetative shoots</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Standardized N removal</td>
<td>( \frac{Y_n}{Y_w} \times 100 )</td>
<td>70 25c</td>
<td>23c</td>
<td>• Percent of N within the fruit</td>
<td></td>
</tr>
</tbody>
</table>

*a–d, z–y Different letters for each index indicate a statistically significant difference (P < 0.05) based on Tukey-Kramer means separation.

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a Formula symbols are as follows: plant (P), yield (Y), soil (S), weight (w), nitrogen content (n), fertilizer N treatment (f), and nonfertilized control or lowest N application (c). Units were kg ha⁻¹ for weight and kg N ha⁻¹ for nitrogen content in fertilizer, plant, and soil. For NUE analysis, soil nitrogen (Sn) consisted of preplant and harvest mineral N content to 75 or 90 cm depth plus fertilizer applied.

b Most economical rate of N (MERN) was 121 kg N ha⁻¹ for RC2004.

c–d, z–y Different letters for each index indicate a statistically significant difference (P < 0.05) based on Tukey-Kramer means separation.
Likewise, for all four soil-based NUE indices, increasing N fertilization decreased NUE. There was no difference between years for soil-based indices except apparent N recovery (Eq. 7), where 2005 NUE values were lower than 2004. Therefore, regardless of the soil-based index used, NUE decreased with increasing N fertilization.

When considering plant-based NUE indices (Eqs. 9–12) there were no differences in NUE index values between N treatments. For instance, 51–66% of total plant N was in the fruit (Eq. 10). Similarly, Olsen et al. observed no differences in N uptake efficiency (Eq. 9) between years and with increasing N rates. Thus, the partitioning of plant biomass and plant N between shoots and fruit varied from year to year, but was independent of the quantity of N available from fertilizer and/or soil. This suggests that biomass and N partitioning is a characteristic of crop and year, rather than N fertilization. Consequently, the same conclusions would be generated (i.e., N application did not impact NUE) if any of the four plant-based indices were used.

For fertilizer- and soil-based indices where there was a difference in NUE values between N treatments, the NUE values at the MERN were intermediary, which corresponds to the intermediary rate of 121 kg N ha⁻¹. For plant-based values at the MERN were intermediary, which corresponds to the intermediary rate of 121 kg N ha⁻¹. For plant-based indices within the plant is independent of N rate (Eqs. 9–12) and Pn is more relevant than Yn because the partitioning of biomass and N within the plant is independent of N rate (Eqs. 9–12) and Pn is immobilized and not immediately susceptible to environmental losses. Based on the four aforementioned indices, one would conclude that there was no difference in NUE between treatments if Eq. 12 was used; if Eqs. 1, 4, or 7 were used, then one would conclude that increasing N fertilization would decrease NUE.

Thus, a conclusion drawn from NUE depends on the index used. The selection of a NUE index must be based on the crop, the harvested portion, and the goals of the research (i.e., soil vs. crop focus). One should be aware that different conclusions may result if a different index were selected. Overall, Eq. 1 is the suggested standard NUE index from an agronomic, economic and environmental perspective.

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