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Title
Nitrogen Assimilation Ability of Three Cauliflower Cultivars in Relation to Reduced Post-Transplanting Nitrogen Supply

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Introduction

Cauliflower (*Brassica oleracea* L. *botrytis*), a cool-weather vegetable, contains exceptionally high levels of vitamins and beneficial photochemicals (indole-3-carbinol and sulforaphane) and nitrogen (N) is the main component of these compounds. It is reported that cauliflower plants need an adequate level of N nutrition to produce high quality cauliflower heads (Alt et al., 2000; Rather et al., 2000; Kage et al., 2003; Li et al., 2007).

Nitrogen is the most required nutrient for plant growth and N nutrition determines crop yield and quality (Gastal and Lemaire, 2002; Li et al., 2003; Lea and Azevedo, 2006; Davis, 2009). It is reported that more than 50% of leaf-N is in components associated with plant photosynthesis (Alt et al., 2000). Nitrogen nutrient levels, cultivars, solar radiation and soil water holding capacity can be factors related to N use by cauliflower plants (Rather et al., 2000; Kage et al., 2003; Li et al., 2007). Cauliflower production often calls for large applications of fertilizer N to maximize yields (Rather et al., 2000), and the problem from the grower’s point of view is that reducing N inputs is likely to give lower yields.

There have been equally extensive concerns about high levels of nitrate in crops and also unused of nitrate left at harvest (Lea and Azevedo, 2006). Inadequate N inputs can also lead declining vegetable nutrient composition or nitrate accumulation in the vegetable that may raise human health concerns (Davis, 2009). Knowledge of crop N demand is essential in developing profitable recommendations to meet crop needs (Li et al., 2003). Such recommendations are critical for agronomic, economic and environmental reasons. In northern Atlantic areas, cool climate is suitable for producing cauliflower from early spring through early fall. There is a need for information about *Brassica* plant and N nutrition relations.

Selecting cultivars efficient in use of N could be an option for producing high quality of cauliflower crops. The objectives of this study were to (i) understand the roles of N nutrition in cauliflower development, (ii) assess the ability of whole plant N uptake, fertilizer N recovery, yields and quality cauliflower related to different cultivars and N input rates, and (iii) examine the movement of N nutrients from sources (leaves and stems) to sinks (heads) for producing high quality cauliflower vegetables.

Methods and Materials

Experimental treatments and design

A cauliflower field study was conducted at a flat fallow site (45°7'59" N, 64°38'8" W) in Annapolis Valley, Nova Scotia in 2007. The crop management was a 3-year rotation regime (fallow-cauliflower-wheat). The soil was classified as a moderately well-drained Pelton sandy loam. To maintain soil organic matter level and input beneficial microorganisms, the soil was amended using chicken compost, applied at the rate of 2.2 tons ha⁻¹ before plant transplanting. The chicken compost contained 92% of organic matter, 0.7% N, 1.6% P, 2.2% K, 12.8% Ca, 0.5% Mg, 0.03% B, 0.4% Na, 0.9% Fe, 0.9% Mn, 0.5% Zn and 0.1% Zn on a dry weight basis.

The experimental treatments consisted of three cultivars of cauliflower F₁-hybrids and three rates of N fertilizers. The three cauliflower varieties were ‘Minuteman’, ‘Sevilla’ and ‘Whistler’, all commercial varieties grown in the areas. These varieties were early, hardy, resistant to low temperatures. The three rates of fertilizer N were 0 (control), 45 and 90 kg ha⁻¹ using ammonium nitrate calcium (NH₄NO₃-Ca, 27.5-0-0). The design was a split-block design.
The three cauliflower varieties were seeded using peat-based promix in the greenhouse. The 4-week old seedlings were transplanted on 30 May 2007. The three varieties were transplanted in strip and the N treatments were arranged with four replicates in each variety. The plot size was 6 x 8 m. The planting spacing was 0.91 m between rows and 0.25 m between plants on the row.

In nutrient management, there was a pre-planting application by broadcast using ammonium phosphate ((NH₄)₃PO₄, 35-7-0), followed by a side-dress application using potassium nitrate (KNO₃, 14-0-10) two weeks after transplanting. At shoot-tip straightened stage (shoot-tip 0.6 cm), the N treatments were then applied by side-dress. This stage was corresponding to 6-7 leaf unfolded vegetative stage, which was three weeks after the first post-transplanting application (Fig. 1A). By counting the N credit values in the chicken compost, the total inputs were 90+0, 90+45 and 90+90 kg ha⁻¹ for N and 23 and 16 kg ha⁻¹ for P and K, respectively. The highest total N rate was still 20% less than the regional nutrient recommendation for cauliflower (225 kg ha⁻¹).

A weather station (Spectrum Tech., Springfield, IL), installed in a nearby field (1 km away), was used for monitoring air/soil temperature, rainfall and soil moisture. Irrigation was done on a rainfall compensate basis using a Rainstar irrigation system. The cauliflower heading stage, it occurred in early August with lack of rainfall but high temperatures of 30ºC. Other crop cares including fungicides were done based on the regional recommendations.

**Plant and soil measurements**

The field measurements included cauliflower plant multispectral reflectance detected using a CropScan MSRSYS5 radiometer (Rochester, MN), soil water content measured using a Spectrum TDR-300 probe (Spectrum Technologies, Plainfield, IL), and leaf/soil temperatures measured using an Extech infrared thermometer (Spectrum Technologies, Plainfield, IL).

Whole plants including roots, stems and leaves were sampled in each plot for determination of plant total N uptake ability. Plant sampling was done five times at five different dates during the growing season. The sampling dates were corresponding to the growth stages as: shoot-tip straightened stage; cauliflower curd initiation; early heading stage: 1-2 cm (or 5% expected size) head diameter reached; late heading stage: 4-8 cm (or 40-60% expected size) head diameter reached; and at maturity stage: head tightly closed and typical size reached.

![Fig. 1. Cauliflower plant shoot-tip straightened stage when the N treatments were applied (A); cauliflower plant multispectral reflectance measurements (B); cauliflower curd initiation (C); Cauliflower heading in the second week after curd initiation (D); and mature cauliflower in the plot at the rate of 45 kg ha⁻¹ (E).](image-url)
Cauliflower plant cover was measured using a camera each time when whole plants were sampled. Biomass of leaves, stems and whole plants, root lengths, and weights, sizes and colors of cauliflower heads were measured. Plant samples were dried at 70°C in the oven. Dry matter was measured then samples were ground into 0.5-mm sizes. Cauliflower plant N concentrations were determined using LECO FP-528 Analyzer. Soil samples were taken for analysis of gravimetric water content, pH and 2N-KCl-extracted NH4 and NO3 concentrations using Kjeldahl stream method (Li et al., 2003). Soil data were not shown in this paper.

The cauliflower yields were hand harvested on 5 August 2007. Three whole plants were hand harvested in each plot. Whole plant biomass and head fresh weights, head color and head diameter size were measured immediately after harvest.

Calculations and data statistics

Whole plant total N uptake was calculated based on plant total N concentration (N%) and whole plant dry matter. Total N in sinks were determined using head N concentration and head dry weights. Total N in sources were estimated by leaf-stem N concentration and its dry weights. Cauliflower N sink-source data at heading stage were not shown in the current paper.

Analysis of variance, descriptive statistics, correlation and regression analysis of plant and soil data were done using PROC GLM, PROC UNIVARIATE and PROC CORR (SAS Institute, 1990). Homogeneity of datasets was verified using the Bartlett test, normality and residual distribution of data sets were confirmed using PROC UNIVARIATE. Means of the treatments was compared using Honestly Significant Difference (HSD) test (SAS Institute, 1990).

Results and discussion

Comparison of cauliflower plant N uptake and heading ability among the varieties

The cauliflower plant development and quality parameters were variable among the three varieties (‘Minuteman’, ‘Sevilla’ and ‘Whistler’) (Table 1). The plant N uptake ability was a function of whole plant biomass at different plant growth stages and maximum whole plant total N uptake occurred at cauliflower curd initiation stage for the three varieties (data not shown).

Table 1. Descriptive statistics of cauliflower whole plant biomass, dry matter, head yield, leaf-stem N concentrations and total N uptake of three varieties (n = 36).

<table>
<thead>
<tr>
<th></th>
<th>Whole plant biomass</th>
<th>Whole plant dry matter</th>
<th>Head yield</th>
<th>Head dry matter</th>
<th>Head dry matter %</th>
<th>Head size</th>
<th>Leaf-stem N%</th>
<th>Total N uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2313</td>
<td>219</td>
<td>710</td>
<td>68</td>
<td>9.8</td>
<td>15.8</td>
<td>4.1</td>
<td>8.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>587</td>
<td>41</td>
<td>277</td>
<td>25</td>
<td>1.2</td>
<td>2.7</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.6</td>
<td>-0.6</td>
<td>0.1</td>
<td>0.0</td>
<td>-0.6</td>
<td>-0.6</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.3</td>
<td>-0.1</td>
<td>-0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Min</td>
<td>1250</td>
<td>142</td>
<td>296</td>
<td>33</td>
<td>8.0</td>
<td>11</td>
<td>3.3</td>
<td>6.6</td>
</tr>
<tr>
<td>Max</td>
<td>3520</td>
<td>300</td>
<td>1400</td>
<td>132</td>
<td>13</td>
<td>21</td>
<td>4.7</td>
<td>12.5</td>
</tr>
</tbody>
</table>

† Data units are g plant⁻¹. Head size is in cm.
The N concentration in cauliflower plant leaf-stems varied between 4.1±0.4% at head maturity, and the whole plant total N uptake varied between 8.6±1.3 g plant\(^{-1}\) for the three varieties (Table 1). The range was 1.4% for the leaf-stem N concentration and 5.9 g plant\(^{-1}\) for the whole plant total N uptake. The datasets were not skewed (kurosis < 3) (Table 1).

Cauliflower heading started at the picks of total N uptake for the three varieties and its heading ability reached the maximum within a week of time. Nitrogen movement from sources (leaf-stems) to the sinks (heads) was as a function of head size (data not shown). The cauliflower head yield varied between 709±277 g plant\(^{-1}\) among the three varieties (Table 1).

The ability of N uptake and head development of cauliflower plants were significantly different among the three cauliflower varieties (Fig. 2). Total N uptake was similar between ‘Minuteman’ and ‘Sevilla’ but total N uptake was significantly lower in ‘Whistler’ compared to the other two varieties. Cauliflower head yield showed the similar trends for the three varieties (Fig. 2B). This result suggested that the difference in plant N uptake could be the factor causing differences in cauliflower head yield.

**Fig. 2.** Comparison of cauliflower plant ability of total N uptake (A) and cauliflower head yield (B) among three varieties ‘Minuteman’, ‘Sevilla’ and ‘Whistler’.

**Trends of cauliflower plant responses to post-transplanting N treatments**

The comparison of cauliflower leaf-stem N concentrations and cauliflower head yield related to the post-transplanting N input rates showed that the leaf-stem N concentrated peaked at the post-transplanting N rate of 45 kg ha\(^{-1}\) for all the three varieties (Fig. 3A).

**Fig. 3.** Leaf-stem N concentrations in cauliflower plants (A) and cauliflower head yield (B) in relation to the post-transplanting N inputs among three varieties.
The cultivar ‘Sevilla’ had the highest N concentration in leaves and stems among these three varieties. The difference in leaf-stem N concentrations was significant between ‘Sevilla’ and ‘Whistler’ only (Fig. 3A). The responses of cauliflower plants to the post-transplanting N inputs showed also that changes in head yield appeared the similar trends as in leaf-stem N concentrations. The head yields increased linearly up to the rate of 45 kg ha\(^{-1}\) then decreased at the higher N rate (90 kg ha\(^{-1}\)) for all three varieties (Fig. 3B). This result suggests that post-transplanting input rate higher than 45 kg ha\(^{-1}\) might not be necessary but more studies should be done to test if moderate inputs (between 45 and 90 kg ha\(^{-1}\)) could differ significantly head yield. Nitrogen stored in leaves and stems should be in part mineralized to benefit the crop in rotation with cauliflower plants the following growing season.

**Correlation of cauliflower development and whole plant total N uptake**

Cauliflower plant physiological development status expressed using plant canopy reflectance in the near infrared band (NIR, center wavelength 830 nm), showed a strong coherence with whole plant biomass [eq. 1]. High plant reflectance in the near infrared band would mean strong plant growth vigor. The cauliflower whole plant biomass was exponentially decreased with the canopy reflectance in the water band (mid infrared MIR, center wavelength 1650 nm) [eq. 2]. The plants reflecting highly mid infrared reflectance were more water stressed, resulting in small canopy and small cauliflower head size (data not shown). The cauliflower plant growth vigor can be described using the relationships between whole plant biomass (C\(_{\text{Bio}}\)), plant near infrared reflectance (NIR) and mid infrared reflectance (MIR) as follows:

\[
\begin{align*}
C_{\text{Bio}} &= 180.38e^{0.0419\text{NIR}} \quad R^2 = 0.72^{**}, \quad n = 36 \\
C_{\text{Bio}} &= 6327.5e^{-0.0588\text{MIR}} \quad R^2 = 0.51^{*}, \quad n = 36
\end{align*}
\]

[1] [2]

There was also a significant correlation between cauliflower head yield (\(Y_c\)) and plant source N concentrations (PN\(_{\text{leaf-stem}}\)) for the three varieties (Fig. 4A). The correlation relationship between cauliflower head yield (\(Y_c\)) and whole plant total N uptake (PN\(_{\text{uptake}}\)) was also significantly linear (Fig. 4B), described by the regression equation as follows:

\[
\begin{align*}
Y_c &= 524.6 \text{PN}_{\text{leaf-stem}} - 1469 \quad R^2 = 0.40^{**}, \quad n = 36 \\
Y_c &= 176.2 \text{PN}_{\text{uptake}} - 804.3 \quad R^2 = 0.64^{**}
\end{align*}
\]

[3] [4]

Fig. 4. Regression analysis of cauliflower head yield vs. leaf-stem N concentrations (A), and cauliflower head yield vs. whole plant total N uptake (B) among three varieties ‘Minuteman’, ‘Sevilla’ and ‘Whistler’, with n = 12 each variety.
The linear regression relationship described in Eq. [3] showed that increasing N storage in sources (leaves and stems) can increase cauliflower head size.

Conclusions

Nitrogen nutrition had a significant, positive effect on cauliflower head development. Cauliflower whole plant total N uptake was within 8.6±1.3 g plant\(^{-1}\) and increase of plant N uptake could increase linearly cauliflower head yield. The cauliflower plant N uptake ability could be significantly different among varieties, which could be the reason causing difference in heading ability among the varieties. There was a need of higher N supply before curd initiation stage because of the need of N movement from sources (leaf-stems) to sinks (heads) within the plants. However, post-transplanting input rates higher than 45 kg ha\(^{-1}\) could prolong shoot-tip straightened stage and delay cauliflower heading. Selecting cultivars efficient in use of N can be an option for producing high quality cauliflower crops.

Acknowledgements

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