Effects of Nitrogen Applications on Direct-seeded Broccoli from a Single Harvest Adjusted for Maturity

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Abstract. A single harvest method using horticultural maturity rating data was tested in 2 years of N application field trials with broccoli. Using analysis of variance with the maturity data as covariates, it was possible to evaluate how broccoli yield response to N was influenced through the effect of N on maturity. This single harvest method simplified field operations and facilitated interpretation of N uptake data. Nitrogen treatments did not significantly alter maturity of broccoli in either year. Broccoli yield increased with up to 250 kg ha⁻¹ of N in both years. Sweet corn, which was grown adjacent to the broccoli in the first year, did not respond to similar applications. Nitrogen did not preferentially increase vegetative growth of broccoli, but in one year increased head yield. Nitrogen accumulated in the head of broccoli. The corn crop accumulated extra N in the vegetation and this was assumed to be luxury uptake. The difference in response to N of corn and broccoli was assumed to be the result of a difference in N use or uptake efficiency rather than overall demand, since the total above-ground uptake by corn and broccoli was quite similar.

Broccoli (Brassica olerica L. var. italica), which is also called calabrese (1), is a vegetable crop produced in many parts of the world (2, 5, 11, 12). Although fertilizer trials on this crop have been reported, comparison, interpretation, and extrapolation of the results have been difficult, since soil, weather, and crop management have differed. The management difference that introduces the most difficulty for comparison of fertilizer response trials is whether the crop is direct-seeded or transplanted. Besides the large influence that the size of transplant may have on growth (16), the transplant and its rooting medium introduce an unknown quantity and quality of nutrient.

Another management factor that must be considered is whether multiple or single harvesting is done (14). For fertilizer response trials, where knowledge of relationships between plant uptake of nutrients and soil analyses are desirable, a single harvest is much more convenient for interpretation of results. Since broccoli is harvested at physiological immaturity (13), the effect of fertilizer on the rate of maturation should not be ignored in single-harvest trials.

This study was designed initially to examine the influence of S and N on two distinctly different direct field-seeded horticultural crops, broccoli and sweet corn, and to test a single-harvesting method on effect of the fertilizer on yield and on the degree of maturity. Since, in the first year of the study, N did not affect sweet corn yield, a subsequent trial concentrated on N application on broccoli. This report examines the effectiveness of a combined single-harvest, maturity-rating method for fertilizer response trials of broccoli. The effect of N on growth and N uptake by broccoli and sweet corn is compared to assist in the interpretation of results.

Materials and Methods

Two adjacent plots, each divided into four blocks, were established 24 May 1979 at Agassiz Research Station’s #2 farm (British Columbia, Canada). Treatments formed a 3 × 3 factorial experiment with 3 levels (0, 100, and 225 kg ha⁻¹) of N as NH₄NO₃ (34–0–0) and 3 levels (0, 11, and 22 kg ha⁻¹) of S as sulphate of potash (0N–0P–50K–16S). Muriate of potash (0N–0P–42K) was applied on each treatment unit such that the entire plot received 112 kg ha⁻¹. Ammonium phosphate (11N–21P–0K) at 230 kg ha⁻¹ had been incorporated into the entire area, except one extra treatment unit in each block of the sweet corn plot, which had an application of triple super phosphate (0N–20P–0K at 250 kg ha⁻¹). The actual N application rates for the nine treatments common to corn and broccoli were N at 25, 125, and 250 kg ha⁻¹ because of the 25 kg ha⁻¹ applied by NH₄H₂PO₄ used as the source of P. The extra treatment unit in the corn plot contained N at 0 kg ha⁻¹ treatment, but triple super phosphate contributed 6 kg ha⁻¹. Dolomite at 2.2 t ha⁻¹ had been incorporated 23 Apr. and difononate and borax (B at 2.2 kg ha⁻¹) on 24 May on both plots. The broccoli plot was treated with treflan on 24 May and birlane was placed in the seed row. Atrazine and alachlor were sprayed on the corn plot 1 June. Sweet corn (‘Jubilee’) was hand-seeded 29 May and broccoli (‘Premium Crop’) precision-seeded 30 May. The corn was thinned to 69 × 23 cm spacing 25 June and broccoli thinned to 43 × 30 cm spacing on 29 June–3 July. Each treatment unit contained 3 rows. Broccoli treatment units measured 180 × 1100 cm and corn treatment units were 200 × 560 cm.

In 1982, broccoli (‘Premium Crop’) was direct-seeded 28 May at the main farm of Agassiz Research Station (about 4 km from the #2 farm). Treatments of N at 0, 25, 125, and 250 kg ha⁻¹ as NH₄NO₃ (34–0–0) were applied in a randomized block experiment with four blocks. Each block contained one treatment unit of N at 25 and 250 kg ha⁻¹ but two treatment units of N at 0 and 125 kg ha⁻¹. One treatment unit of N at 0 and 125 kg ha⁻¹ was for single harvest and the other was for multiple harvest. The entire plot had been fertilized with triple super phosphate (0N–20P–0K) at 365 kg ha⁻¹ and sulphate of potash–magnesia (0N–0P–18K–22S) at 500 kg ha⁻¹ on 11 May. Seeding rate and method, plot size, and treflan, birlane, and borax applications were similar to 1979 and thinning was done 28 June.

A single harvest of broccoli, timed to coincide with the estimated maximum proportion of horticulturally mature plants,
was carried out on 27-28 Aug. 1979 and 23 Aug. 1982. Multiple harvesting of horticulturally mature heads was carried out from 10 Aug. to 10 Sept. 1982. Heads were judged to be horticulturally mature when the buds were tightly closed and forming a dense mass (1) and before formation of secondary buds. A total of 30 plants was sampled from the center row of each treatment unit. The entire plant was cut at ground level for both single and multiple harvest. For multiple harvest all plants were divided into head and vegetative portions and separately weighed, chopped, and subsampled for dry weight determination. For single harvest, half of the plants were separated for head yield measurements and the other half were processed as whole plants. Prior to single harvest, the maturity of the heads was determined for a sample of 30 heads using four categories, namely, no head, immature head, mature head, and overmature head. The proportion of the 30 heads in each category was recorded. Twenty corn plants per treatment unit were harvested from the center row for total fresh yield estimates. Ten of the plants were used to determine ear yields and the other 10 for total plant yield. Primary ears were kept separate. The secondary ears accounted for only a small proportion of the yield. After the primary ears were dried, the grain was removed for dry grain yield determination. Plant material was dried at 65°-70°C for dry matter content and N analyses. Nitrogen was determined by a modified Kjeldahl procedure (10). Plant NO₃-N was assumed to be proportionate and therefore insignificant.

The effect of fertilizer on maturity level was evaluated using multivariate analysis. The multivariate response had the number of plants at each maturity level as its components. Analyses of variance and analyses of covariance with adjustment for maturity levels were conducted on the three variables to test the total effect and the effect adjusted for maturity level by the fertilizer applications. To facilitate comparing single and multiple harvest data, a maturity index was calculated by adding the proportion of immature heads to the proportion of mature heads multiplied by 2, and the proportion of overmature heads multiplied by 3. Thus, the maturity index could range from 0 to 3 and would equal 2 if all the heads were horticulturally mature. To simplify comparisons between the 1979 and 1982 results, the 1982 data were analyzed in two ways. First, the four N treatments at single harvest were analyzed for comparison with 1979. Then the data comprising the 2 × 2 factorial experiment of harvest methods and N fertilization rates were analyzed.

There was normal rainfall early in the 1979 growing season but it was dry, particularly during July, in comparison to the mean of 91 years of measurements. In 1982, June was dry, July was wet, and August had near-normal precipitation. For both years the mean air temperature was near normal but sunshine was greater than normal, particularly in 1979. Irrigation was not applied in either plot year.

Sulfur did not affect any component of plant yield and N uptake by broccoli and sweet corn in the 1979 trial; therefore, the presentation of results will be confined to N averaged over the three S levels.

Results and Discussion

The date of single harvest was quite similar in both years, being 27 and 28 Aug. in 1979 (89-90 days after seeding) and 23 Aug. in 1982 (87 days after seeding). Maturity, as evaluated by the maturity index, was similar in 1982 (2.1 ± 0.3) and in 1979 (1.9 ± 0.2). Analysis of the proportion of plants in each maturity category showed that only the proportion of mature heads in 1979 was significantly affected by rate of N application. The proportion of mature heads increased with increasing rate of N application (0.58, 0.68, and 0.72 at 25, 125, and 250 kg·ha⁻¹ of N, respectively). There were no effects of N on maturity proportions in the 1982 single harvest trial, nor was the mean maturity date affected by the treatments in the 1982 multiple harvest trial. The mean maturity dates were 83 and 85 days after seeding for N at 0 and 125 kg·ha⁻¹ treatments, respectively.

Head dry weight increased with N rate in both years and vegetation yield only in the 1982 trial (Table 1), resulting in an increase in the proportion of the head to the total plant in 1979, but not in 1982. The proportion of heads in the maturity categories were significant covariates in 1979 for dry yield analysis, but the adjustment did not alter the significance of N rate.

The percentage of dry matter in the head of broccoli apparently was affected (decreased) only in 1979 by increased N rates (Table 1). The vegetative dry matter content in 1982, when adjusted by maturity data, was not affected by N application, suggesting that N had a negligible effect or affected the dry matter content indirectly through an influence on maturity.

The absence of any significant interactions between harvest method and N rate treatments in 1982 (Table 2) confirmed the observation that N had a negligible influence on rate of maturity. Application of N at 125 kg·ha⁻¹ increased both head and vegetation dry yield and the proportion of the head. The dry matter percentage of both plant parts decreased with N application. Multiple harvesting the plants as the heads reached horticultural maturity resulted in a decreased dry yield and proportion of head than harvesting at one date. Vegetation dry yield was similar when harvesting was done both ways, but dry matter content was slightly less for multiple than single harvest.

The results show that by incorporating a maturity rating of broccoli, a single harvest method can be used to determine whether treatment effects were direct or indirect through a treatment effect on maturity. A single harvest is useful for fertilizer trials when the uptake of the nutrient is of particular interest. The negligible advance in maturity with increased rate of N was similar to observations by Letey et al. (11), but Cutcliffe et al. (5) and Cutcliffe (3) found that N applications delayed maturity. Further work is required to determine whether the effect of N on maturity was due to the differences in soil and climate, cultivar of broccoli grown, or planting method (direct-seeded vs. transplanted). This apparent variability of N effect on broccoli maturity emphasizes the importance of including a maturity factor in experiments using a once-over harvest.

The relatively high responsiveness of broccoli to N that was observed was similar to observations in other parts of the world (3, 5-8, 11). Sampling the total plant and not just the head showed that N did not preferentially increase vegetative growth. This finding is encouraging for plant spacing considerations in that N applications would not adversely affect the efficient use of field space. This conclusion is supported by the results of combined N and spacing studies (3, 6). Unfortunately, there is a dearth of published information on the relative effect that N has on vegetation as opposed to head growth, so the universality of this observation cannot be evaluated. Letey et al. (11) did measure the head and total top weight in their study in California but did not calculate the relative proportion of the head to the total.

The N concentration in the broccoli head increased with increased rate of N in both years (Table 3). The concentration of N in the head was generally greater in 1979 than in 1982. Vegetation N concentration was increased in 1982 with increased N rate. In 1979 there was an effect on unadjusted vegetation N
Table 1. Yield responses (adjusted for maturity) of direct-seeded broccoli above-ground components to N fertilizer in two years.

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Year</th>
<th>Nitrogen (kg-ha⁻¹)</th>
<th>SE of N treatments</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>1979</td>
<td>0.94</td>
<td>0.80</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>0.99</td>
<td>2.76</td>
<td>5%</td>
</tr>
<tr>
<td>Vegetation</td>
<td>1979</td>
<td>3.27</td>
<td>8.81</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>3.17</td>
<td>2.76</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 2. Effect of harvest method and N fertilizer on direct-seeded broccoli above-ground components in 1982.

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Harvest method</th>
<th>Nitrogen (kg-ha⁻¹)</th>
<th>Generalized SE for harvest method and N rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Single</td>
<td>6.9</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Multiple</td>
<td>8.0</td>
<td>0.12</td>
</tr>
<tr>
<td>Vegetation</td>
<td></td>
<td>1.6</td>
<td>2.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 3. Plant N responses (adjusted for maturity) of direct-seeded broccoli above-ground components to N fertilizer in two years.

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Year</th>
<th>Nitrogen (kg-ha⁻¹)</th>
<th>SE of treatment</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>1979</td>
<td>NA</td>
<td>6.9</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>4.2</td>
<td>6.3</td>
<td>1%</td>
</tr>
<tr>
<td>Vegetation</td>
<td>1979</td>
<td>NA</td>
<td>1.6</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>2.4</td>
<td>3.5</td>
<td>1%</td>
</tr>
</tbody>
</table>

Unadjusted values were significant at the 5% level.

sures (Table 4). Nitrogen application increased N concentrations of and uptake by both plant parts but not the proportion of N uptake into the head (Table 4). This response was consistent with a separate analyses of the four N rates in that same year (Table 3). The N concentration was higher when multiple sampling was done than when single sampling was done but uptake of N was just the opposite (Table 4). The response of N uptake into the head to the method of harvest followed the response of dry yield rather than N concentration.

The relatively high response to N rate and large proportion of N in the head of broccoli support the observation that N applications should not preferentially affect vegetative growth. The proportion of N in the head, however, was not changed significantly in either year. The proportion of N in the head as compared to total above-ground plant uptake varied considerably from year to year. In 1979, the proportion ranged from 54% to 59%, while in 1982 it ranged from 36% to 38%. Both these proportions are considerably higher than the proportion of N in the head of broccoli reported by Magnifico et al. (12) in a study in Italy. In their study, the N in the head accounted for 11% of the above-ground N uptake. These measurements were made on broccoli that took more than 140 days to produce the main head, so the variety used and growing conditions were quite different from our study. Also, the Italian study showed a much higher above-ground plant uptake of N (540 kg-ha⁻¹) than that measured in the present study (155 to 269 kg-ha⁻¹). It is evident that the influence of N on general growth of broccoli is not well-understood.

The apparent high demand of N for head production suggests that split applications may be useful for increasing N use efficiency. Welch et al. (15) found that split applications of N increased the yield of cauliflower. It would be difficult to transpose that information directly to broccoli, since large differences in N uptake are evident in broccoli growth in different countries. Letey et al. (11) found that side-dress N application resulted in greater head yields than with N injection in irrigation. They also showed that N uptake rate was relatively high in the month just preceding harvest. Several workers have shown that increasing N application rates increased the incidence of hollow stem (4, 9, 11). In all cases the N was applied very early in the growth of the crop (pretransplanting to thinning). Information on N uptake from this study suggests that N applications just prior to bud initiation may result in increased head yield without a decrease in quality due to hollow stem.

Nitrogen and S applications did not affect stover or grain dry yield of sweet corn (data not shown) on a plot directly adjacent to broccoli that responded to N application. Uptake of N by corn stover was increased by the 250 kg-ha⁻¹ rate over the 25 and 125 kg-ha⁻¹ rates, but uptake by the grain remained constant. The increased N uptake into the stover with no affect on dry weight of corn by N application was evidence of luxury uptake. Total N uptake by the above-ground plant was significantly increased by the application of N in both broccoli and corn (99% and 95% significance levels, respectively). Nitrogen uptake by broccoli reached 157 and 156 kg-ha⁻¹ at 125 and 250 kg-ha⁻¹ application rates, respectively, from 118 kg-ha⁻¹ with 25 kg-ha⁻¹ application. On the other hand, sweet corn N uptake increased to 142 kg-ha⁻¹ with the 250-kg application rate from uptake of 129 and 127 kg-ha⁻¹ with 25 and 125 kg-ha⁻¹ application rates, respectively.

It is interesting that the effects of N on the marketable yield of broccoli and sweet corn were different even though they were grown on identically treated adjacent plots where the total uptake by the above-ground parts of the two crops was quite similar. It appears that the two crops differ in their efficiency in using the N available to them. The current general fertilizer N recommendation for broccoli (75 kg-ha⁻¹) is less than for broccoli (115 g-ha⁻¹) for coastal British Columbia. Nitrogen recommendations for British Columbia are based on limited local research and considerable extrapolation from other research. The results from this study, the limited published research on N for direct-seeded broccoli, and comparison of the two crops show that more research is required to develop efficient N fertilization methods.

## Literature Cited

Growth and Mineral Composition of Radish in Response to Nitrification Inhibitors

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Abstract. Nitrpyrin, etridiazol, fenaminozulf, sodium azide, and a formulated product of aromatic substances and alkenes were evaluated as nitrification inhibitors under greenhouse conditions for radish (Raphanus sativus L. 'Cherry Belle') fertilized with sewage sludge. Nitrpyrin and etridiazol inhibited nitrification, but their use restricted plant growth and lowered the Ca and Mg concentrations of the plants. Nitrification was inhibited slightly by fenaminozulf, which had little effect on plant growth and composition. Sodium azide and the formulated product were not effective as nitrification inhibitors. The azide was phytotoxic, but the formulated product had no toxic effects on growth. The toxic effects of chemicals with efficacy as nitrification inhibitors were due largely to the accumulation of NH₄-N in the medium. Chemical names used: 2-chloro-6-(trichloromethyl)pyridine (nitrpyrin); 5-ethoxy-3-trichloromethyl-1,2,4-thiadiazole (etridiazol); and sodium p-(dimethylamino)benzenediazonifonate (fenaminozulf).

The management and use of N fertilizers are of major concern in crop production. Conservation of N in the soil and increased efficiency of N use by crops are principal objectives in the management of N fertilizers. To conserve N and to reduce accumulation of nitrates in ground water or in vegetables, nitrification inhibitors may be employed (10, 12, 15, 19). A variety of compounds, including several fungicides, inhibit nitrification (1, 6, 16). However, nitrpyrin is one of the most effective chemicals used to inhibit nitrification and to conserve N in crop production (4, 11, 20).

Phytotoxicity from the use of nitrpyrin has been reported. Toxicity may be expressed as restricted growth, leaf chlorosis or necrosis, altered cation accumulation, and growth aberrations (3, 14, 17, 21, 22). Some of the toxicity symptoms, such as restricted growth, chlorosis, and altered cation accumulation, may be due to NH₄ toxicity, for NH₄-N accumulates in the soil if nitrification is inhibited by nitrpyrin following the application of ammonial, chemical or organic, fertilizers (22). The aberrations in growth may be due to the phytotoxicity of the nitrification inhibitors. Injury resembling that due to auxin has been noted on plants grown in media in which nitrpyrin was added (14, 17, 18). Azide salts (16) and carbon disulfide (1) are among other chemicals that are used as nitrification inhibitors and that may produce phytotoxicity, generally as necrosis.

The present study was designed to evaluate the effects of nitrification inhibitors on the growth and composition of radish and to assess whether these materials were phytotoxic and whether their application could induce NH₄ toxicity.

Materials and Methods

The study was conducted in greenhouses in Fall 1979 and 1980 at Amherst, Mass. Two experiments were conducted. The first experiment, in 1979, involved the use of several chemicals with known or potential use as nitrification inhibitors (see Tables 1 and 2). These materials were mixed into the growth medium at seeding. 'Cherry Belle' radish was seeded into a potting mix of 1200 g of 7 sandy loam : 3 peat : 2 sand (by volume) in 15-cm plastic azalea pots. The mix also contained Milorganite, Milwaukee Sewerage District, Milwaukee, Wis.). The treatments were arranged in five randomized complete blocks. Five plants were grown in each pot and were irrigated with about 100 ml of tap water daily. Harvest occurred at 6 weeks after seeding and when the roots were about 2.5 cm in diameter. Roots and shoots were harvested separately, with the fibrous roots being discarded. The tissues were dried at 80°C and were ground to pass a 30-mesh screen. Calcium, Mg, and K were determined by atomic absorption spectrophotometry on samples that were ashed by heat, concentrated nitric acid, and