1. Introduction

High nutritional-value broccoli (*Brassica oleracea* var. *italica*) is an important vegetable containing high vitamin, chlorophyll and protein concentrations (Page et al., 2001). Broccoli heads compose of hundreds of immature florets arranged in whorls on a fleshy stem and each floret consists of an immature flower enclosed within chlorophyll-containing sepals (Page et al., 2001). Therefore broccoli is high in chlorophyll and the plants need a large amount of N for its photosynthesis activities.

Adequate inputs of N nutrients based on growth stage needs can promote plant N assimilation and partitioning within plants (Vogen, 2003; Li et al., 2006, 2008; Yoldas et al., 2008). Negative effects influencing broccoli growth and quality (e.g. stem rot, leaf scorch and bacterial soft rot) may be reduced by adequate N inputs (Gallagher, 1966). Broccoli N concentrations can increase significantly by increasing N input rates (Vogen, 2003; Yoldas et al., 2008). Too much nitrate in food is a concern for human health (Cardenas-Navarro et al., 1999).

The objectives of this study were to assess the effects of N treatments on broccoli whole plant N uptake and heading ability and to regulate N temporal reserves in sources and enhance N delivery to head sinks to produce high quality broccoli.

2. Materials and Methods

2.1 Experimental treatments and design of the broccoli field study

The broccoli field study was conducted in two soil types in a 9-ha commercial field (45º10'09" N, 64º22'34" W) in Annapolis Valley, Nova Scotia during July and September 2007. One soil was a well drained Kentvill (Kt) sandy loam, and the other was an imperfectly drained Woodville (W) sandy loam.

The crop management practice was a 3-year rotation regime (broccoli-cabbage-wheat). The N nutrition treatments for broccoli crops consisted of the post-seeding application at the rates of 0 (control), 25, 50, 75 and 100 kg ha^{-1}, responding respectively to 0, 25%, 50%, 75% and 100% of post-transplanting N recommendation rates in the region. The N treatments were arranged with four replicates using a split-block design with soil type as the main plot. The broccoli cultivar 'Everest' was used in the study.

A new seeding technology, double-row direct seeding, was used to seed broccoli directly in the field. The seeding was done on 20 July. The double-row spacing was 0.3 m between the two rows and plants was 0.25 m apart in the row. The spacing between the double-rows was 0.91 m.

In the nutrient management, there was a pre-seeding application of 100 kg N ha^{-1} using ammonium phosphate ($(NH_4)_3PO_4$, 35-7-0) by broadcast across the whole field a day before the direct seeding. Four weeks after the direct seeding, the broccoli plants reached the shoot-tip straightened stage (shoot-tip section 0. 6-1 cm), the N treatments were hand applied by side-dress to the plants using calcium-ammonium nitrate (NH_4NO_3-Ca, 27.5-0-0). The plot size was 6 x 10 m. No irrigation was applied as there was sufficient rainfall during the growing season.

2.2 Broccoli field study measurements

Whole plants were sampled weekly to determine broccoli plant N uptake ability at different growth stages after the N treatment application. Plant samplings was done five times at five different dates, which were corresponding to the shoot-tip straightened stage (or 6-7 true leave unfolded stage; bowed-crown stage at curd initiation; early heading stage with 1-2 cm head diameter reached; heading reached 4-8 cm (or 40-60% expected size) head diameter; and at mature stage when broccoli head typical size and form reached and head was tightly closed.

Biomass of leaves, stems, roots and whole plants, root lengths and weighs and sizes of broccoli heads were measured. Plant samples were dried in the oven at 70ºC and ground to pass a 0.5-mm sieve. Broccoli plant N concentrations were analyzed using LECO FP-528 Analyzer.

Soil samples (0-0.15 m) were taken for analysis of gravimetric water content, pH and soil mineral N. Soil samples were air dry. Soil gravimetric water content was determined at 110ºC and soil pH was measured using (m/v 1:1) ratio. The 2N KCl-extracted NH_4 and NO_3 concentrations were analyzed using Kjeldahl stream method (Li et al., 2003).

Broccoli was harvested on 22 September for a 58-day growing length. Three whole plants were hand harvested in each plot for determination of whole plant biomass and dry matter, head fresh weights, head size and dry weights. Broccoli whole plant total N uptake was estimated using plant total N concentration and whole plant dry matter.

Data statistics were done using SAS PROC UNIVARIATE and PROC GLM. Comparison of the means was done using Honestly Significant Difference (HSD) test (SAS Institute, 1990).

3. Results and Discussion

3.1 Broccoli plant nitrogen uptake in different soil types

Broccoli whole plant biomass varied between 1040±201 g plant^{-1} and whole plant dry matter was 9-11% of the biomass. Broccoli head yield was 281±59 g plant^{-1} and head dry matter varied between 9-12% of the fresh weights. Nitrogen concentrations in broccoli leaf-stems varied between 4.97±0.31% in the Kentville soil and Woodville soil, and the broccoli whole plant total N uptake was 4.96±0.74 g plant^{-1} in the two soils. The broccoli plant development parameters (whole plant biomass, whole plant dry matter, head yield, head dry matter and head size) were significantly different in the two soil types (data not shown).

The comparisons of broccoli uptake ability between the two soil types showed that whole plant N uptake was significantly higher in the Woodville soil than in the Kentville soil (Fig. 1A). As the N treatments were equal for the broccoli plants in the two soil types, the factors causing the differences in plant N uptake between the two soils might be due to difference in SWC and soil pH (Fig. 1AB).

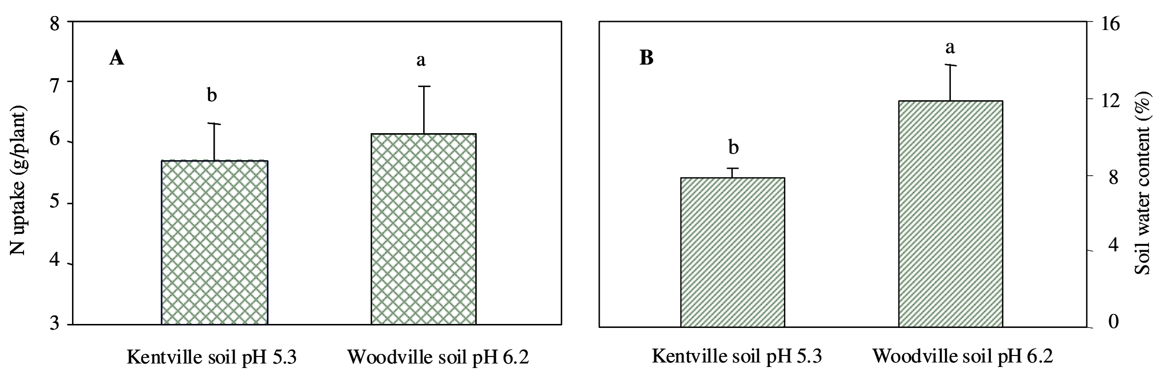

Fig. 1. Broccoli whole plant N uptake (A) and soil water content (B) in the Kentville soil and the Woodville soil. Each bar is the mean and standard error of n = 20.

3.2 Broccoli total N uptake and head yield related to nitrogen input rates

The peaks of whole plant N uptake (6.8 g plant^{-1}) appeared at the N rate of 50 kg ha^{-1} in the imperfectly-drained Woodville soil. The peak of whole plant N uptake was 6.3 g plant^{-1} appeared at the higher N input rate of 75 kg ha^{-1} in the well-drained Kentville soil. The highest broccoli head yields was up to 0.35 kg plant^{-1} (n = 20 plants), measured at the post-seeding N rate of 50 kg ha^{-1} in the Woodville soil. The maximum head yield was 0.29 kg plant^{-1} at the higher post-seeding N input rate of 75 kg ha^{-1} in the Kentville (Kt) soil.

There was a significant correlation between broccoli head yield and the accumulated N in leaves and stems (Eq. [1]). By plotting the broccoli head yield (Y_{bro}) against accumulation of N in leaves and stems (LS_N), the curve showed a significantly linear trend between the two variables described by the regression equation as follows:

$$Y_{bro} = 53.346\ LS_N - 47.43 \qquad R^2 = 0.56^{**} \quad P < 0.05\ (n = 40) \qquad [1]$$

This regression equation suggested that further regulating N temporal reserves in leaves and stems (sources), it could enhance broccoli heading ability.

4. Conclusions

Broccoli heading ability was associated with N nutrition. Broccoli head yield was related to whole plant total N uptake and correlation between broccoli yield and leaf-stem N reserves was significantly positive. Increase of plant N uptake could increase linearly broccoli head yield. Soil pH 6.2 could stimulate broccoli plant N uptake and head growth that could lead to a reduction of 25% N inputs and a higher crop performance.

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