Ornamental Cabbage Quality Improved by Continual Fertilization through Head-color Coloration

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Abstract. Current fertilizer recommendations for ornamental cabbage (Brassica oleracea var. acephala) suggest applying 150 to 300 mg L–1 N until the initiation of color development, after which fertilization should be reduced or discontinued. Because these plants are actively growing during cool weather when coloration is initiated, nutrient deficiencies may reduce overall plant quality. The objectives of this study were to investigate N to K ratios for plant growth of ornamental cabbage and the effects of continual and discontinued fertilization during the period of coloration. Fertilizing with 150 to 200 mg L–1 N and 150 to 200 mg L–1 K produced high-quality plants and sufficient tissue concentrations of N and K. Center-head coloration was not inhibited by N concentrations as high as 250 mg L–1. Cessing fertilization prior to center-head coloration resulted in the rapid depletion of N, P, and K concentrations in the lower foliage, leading to the appearance of deficiency symptoms. Leaves of cabbage plants were still actively growing at market date. We hypothesize that discontinuing fertilization to induce color development may be detrimental in ornamental cabbage because plants are still actively growing at cool temperatures. Color development is due to absence of chlorophyll in the youngest leaves (white cultivars) and synthesis of anthocyanins in the chlorophyll-deficient leaves (pink and red cultivars). Anthocyanin, a flavonoid pigment, is responsible for most of the red, pink, and blue colors observed in plants (Salisbury and Ross, 1992; Taiz and Zeiger, 1998). Although color development is important for sales of ornamental cabbage, discontinuing fertilization may reduce overall plant quality.

Materials and Methods

Nitrogen and potassium concentration (Expt. 2). Plugs (2.1 2.1 2.5 cm) of ‘Osaka White’ were transplanted into 2.96-L (20.8-cm diameter) round plastic containers on 29 Aug. 1999. The root substrate used was Fafard 4-P (Fafard, Anderson, S.C.), which contained: 4 sphagnum peat: 2 pine bark: 2 vermiculite: 1 perlite (by volume). A continual liquid fertilization program was initiated on 19 Feb. with a 4 N–K factorial with N and K levels varying from 100, 150, 200, to 250 mg L–1 in a completely randomized design with five single-plant replications. Ammoniacal-nitrogen was 32% to 39% of the total nitrogen in all treatments with all other nutrients constant among treatments (Gibson, 2000). Macronutrients and micronutrients were from reagent grade salts. Foliar sprays of dimazinozide (2,2-dimethylhydrazide) (B-Nine, Uniylo Chemical, Middlebury, Conn.) at 2500 mg L–1 (using a volume of 204 mL m–2) were applied on 23 Feb. and 5 Mar. Plants were grown under natural day-length with greenhouse setpoint temperatures of 18.3 °C day/15.5 °C night until 6 Apr. From 6 until 22 Apr., the plants were placed in a dark cooler at 7.2 °C for 12 h (19:00-07:00) to induce color development and returned to the greenhouse during the day. On 12 Mar. and 6 Apr., plant height (measured from the pot rim to the top of the plant) and plant diameter (measured at the widest dimension and then turned 90°) were recorded. On 22 Apr., plant height, plant diameter, and diameter of the white portion of the rosette were recorded.

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to determine dry weight (g). Every 2 weeks, the “color diameter” (diameter of the whorl of colored leaves at the center of the plant at the widest dimension and also at 90° from that dimension) was measured to determine if fertilization had an effect on color development.

**Discontinuing fertilization (Expt. 3).** Subgroups of 10 and five plants from each fertilizer rate in Expt. 2 were irrigated with tap water beginning on 31 Oct. [12 weeks after sowing (WAS)]. Two weeks later, data were collected to determine the effects of applying no additional fertilizer to ornamental cabbage. Five replications of the three tap water treatments were harvested for dry weight and tissue analysis on 14 Nov. (14 WAS) to be compared against continually fertilized plants. Also, on 14 and 28 Nov., plant height, plant diameter, and color diameter were measured. Elemental concentrations in tissue were determined as in Expt. 1.

Data were subjected to analysis of variance by general linear model and regressions determined by PROC REG (SAS Institute, Cary, N.C.). Means were separated by least significant differences (LSD) at $P \leq 0.05$.

**Results and Discussion**

**N and K Concentration (Expt. 1)**

_f Plant growth._ Neither the N × K interaction, nor the K main effects were significant over time; therefore, only the effects on growth at the four levels of N, which were significant, are presented. Plants increased in height over the 13-week period. Plants fertilized with N at 200 or 250 mg·L⁻¹ were 10% taller than those with N at 150 mg·L⁻¹, and 30% taller than those with N at 100 mg·L⁻¹ (Fig. 1A). No further increase in height was observed after week 10 for plants fertilized with N at only 100 mg·L⁻¹, and symptoms of N deficiency (purpling with a lighter green color of the lower foliage) appeared.

Plants reached their maximum diameter by week 10 (data not shown). Plants fertilized at N concentrations of 200 or 250 mg·L⁻¹ were significantly wider (52.8 and 53.6 cm, respectively) than those fertilized with 100 or 150 mg·L⁻¹, although a difference of 1.7 cm might have little commercial significance.

Coloration was first observed 12 WAS and was measured from 13 WAS until termination of the experiment. Data are not shown, as all plants had similar-sized color diameters (5.3–6.7 cm) regardless of N treatment. Fertilizer N rates of 200 and 250 mg·L⁻¹ did not delay color development or affect final color diameter, in contrast to reports by Luczai (1992), who stated that continual fertilization inhibits color development.

Before subjecting the plants to the 7.2 °C night temperature, uniform expansion of healthy green foliage was observed for the plants treated with N at 150 and 200 mg·L⁻¹. Plants grown with N at 250 mg·L⁻¹ resulted in foliage that was upright in leaf arrangement with the inner leaves having a cup-like habit, which made the plants look abnormally columnar. This characteristic may make the

Fig. 1. Regression lines were generated from means of the treatments on 22 Apr. (13 WAS), and symbols are means of the treatments. **, ***Significant at $P \leq 0.01$ or 0.001, respectively; L = linear; Q = quadratic. (A) The effect of nitrogen concentration on plant height of ‘Osaka White’ ornamental cabbage plants (Expt. 1) (n = 20); (B) the effect of nitrogen concentration on leaf N concentration (Expt. 1) (n = 20).

Fig. 2. Plant height of ‘Osaka White’ ornamental cabbage plants over time (Expt. 2). Regression lines were generated from means of the treatments, and symbols are means of the treatments (n = 15). **, ***Significant at $P \leq 0.001$; L = linear; Q = quadratic.
plants undesirable to the consumer. Although N concentration did not have an effect on plant diameter, plant height was affected, and plants fertilized with N at 150 mg·L⁻¹ were more suitable for wholesale production because more plants would fit on shipping carts. A nitrogen concentration of 200 mg·L⁻¹ produced taller plants than did lower N levels, a trait which may be desired by consumers.

**Tissue analysis.** Tissue N concentration increased with N fertilization rate (Fig. 1B). Plants treated with N at 100 mg·L⁻¹ had a tissue concentration of 2.86% N, which was below the adequate range of 3.5% to 4.5% (Whipker et al., 1998). Based on regression analysis, the fertilization concentration should be ≥140 mg·L⁻¹ N to provide a foliar N concentration of 3.5%.

As the concentration of K increased from 100 to 250 mg·L⁻¹, K tissue concentration also increased (3.61%, 3.68%, 3.85%, and 4.12%, respectively, for 100, 150, 200, and 250 mg·L⁻¹ K). Potassium fertilization rates of 100 to 200 mg·L⁻¹ were within the acceptable range of 3.0% to 4.0% (Whipker et al., 1998), but K at 250 mg·L⁻¹ exceeded the range. This result suggests that fertilizing with K at 250 mg·L⁻¹ led to luxurious accumulation of K. For all N × K fertilization concentrations, tissue concentrations of Ca and Mg were 0.8% to 0.9% and 0.5% to 0.6%, respectively, and within the adequate range (Whipker et al., 1998).

**N Fertilization Concentration (Expt. 2)**

**Plant growth.** No significant differences occurred over time for the heights of plants fertilized with N at 150, 200, or 250 mg·L⁻¹. However, plants increased in height until week 14, then became shorter (Fig. 2). This reduction in plant height is due to the expansion of the colored foliage that arises from the center, causing the upper foliage to flatten and bend downward.

Diameters of plants fertilized with N at 150 mg·L⁻¹ were significantly smaller throughout the growth period than those fertilized with N at either 200 or 250 mg·L⁻¹ (Fig. 3). The lower mature leaves bent downward as the plant developed center color and resulted in a reduction in plant diameter.

The trend of larger plant heights and diameters as N concentration increased with the outdoor study (Expt. 2) was similar to results from Expt. 1. Wholesale growers can fertilize with N at 150 mg·L⁻¹ to achieve smaller diameters for easier shipping, whereas retail growers could use N at 200 mg·L⁻¹ for large plants for retail customers.

The final dry weight of plants was significantly greater over time as the N fertilization rate increased from 150 to 250 mg·L⁻¹ (Fig. 4). At 14 weeks, the plants fertilized with N at 250 mg·L⁻¹ had 16% or 22% greater mass than plants fertilized with 200 or 150 mg·L⁻¹, respectively. At 16 weeks, differences were even more pronounced, as plants fertilized with N at 250 mg·L⁻¹ had 20% and 30% greater mass than those fertilized with N at 200 and 150 mg·L⁻¹, respectively.
**SOIL MANAGEMENT, FERTILIZATION, & IRRIGATION**

*Coloration.* Nitrogen concentration had no effect on color diameter. Coloration was first observed 11 weeks after sowing, and color diameter was measured at 3.0 cm on week 12 (Fig. 5). Ornamental cabbage growers market plants based on the presence of visible center color and not color intensity (S. Hood, personal communication). At week 14, plants were of marketable size, and plants had a colored center of =17 cm in diameter. These results indicate that continuing to fertilize ornamental cabbage with N at 150 to 250 mg·L\(^{-1}\) is not detrimental to center-head coloration. Therefore, growers can continue to fertilize through coloration and use cool temperatures below 12.7 to 15.5 °C to influence color development.

*Plant growth.* After 2 weeks (14 WAS), no significant differences in plant height or diameter occurred for plants fertilized on a continual basis compared to plants receiving tap water. Differences occurred after 4 weeks of tap water irrigation, when the plants became significantly shorter in height and smaller in diameter than plants irrigated with tap water for 2 weeks or continually fertilized (data not shown). Differences in growth were due to lower leaf loss and stunting of plants receiving tap water irrigation.

Color diameters were similar for plants receiving tap water for 2, 4, or 6 weeks compared to plants on a continuous fertilizer program, and color diameter increased from 17.1 cm at week 14 to 23.2 cm by week 16. This lack of effect of fertilizer duration on color diameter is in contrast to recommendations by Luczai (1998), who suggested that fertilization should be discontinued to induce coloration.

*Tissue analysis.* After only 2 weeks of discontinued fertilization, leaf concentrations of N, P, K, and Ca were significantly reduced compared to concentrations in plants that were fertilized on a continual basis (Table 1). Tissue values of N, P, and K for the tap water-irrigated plants were below the adequate range (Whipker et al., 1998). The deficient nutrient levels occurred rapidly. The current grower recommendation of discontinuing fertilization would seem to promote the induction of nutrient deficiencies instead of the desired development of center color.

**Conclusions**

Nitrogen concentrations greater than 140 mg·L\(^{-1}\) were required for ornamental cabbage plants during both the establishment and coloration phases of growth in order to provide foliar N concentrations greater than the lower adequate range of 3.5%. Fertilizing with 8 to 10 mg·L\(^{-1}\) P, 150 to 200 mg·L\(^{-1}\) K, 100 mg·L\(^{-1}\) Ca, and 50 mg·L\(^{-1}\) Mg on a continual basis was required to provide adequate plant growth. In Expt. 2, no differences in plant height occurred with N at 150 to 250 mg·L\(^{-1}\), but plant diameters increased with higher N concentrations. Therefore, growers should select a fertilization concentration that matches the marketing system, ranging from 150 mg·L\(^{-1}\) N for wholesale growers who require a greater density of plants on shipping carts to 200 mg·L\(^{-1}\) N for retail growers who may desire large-sized plants.

Center-head coloration was not inhibited by N concentrations as high as 250 mg·L\(^{-1}\). Discontinuing fertilization prior to coloration resulted in the rapid depletion of N, P, K, and Ca tissue concentrations in the lower foliage, leading to the appearance of deficiency symptoms and lower leaf loss. Traditional fertilization practices for many floriculture crops at visible flower bud development suggest that fertilization be discontinued or reduced significantly because plants require less nutrients for growth during anthesis (Nell, 1993). Anthesis of ornamental cabbage occurs only after a vernalization period (Opena et al., 1993), which may be months after visible center-head color.

During the time when anthocyanin production occurs, dry weight was still increasing, and nutrient demands were still high. Therefore, ornamental cabbage should still be considered an exception to other floriculture crops, as fertilization needs to be continued through center-head coloration in order to maintain adequate nutrient levels.

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