A Proposed Tool for Preharvest Estimation of Cabbage Yield

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Additional index words. *Brassica oleracea*, maturity, yield, crop quality

Summary. Declines in cabbage (*Brassica oleracea* var. *capitata*) crop quality may result from delaying harvest to allow for greater total yield. An accurate, reliable, rapid and inexpensive method to estimate yield before harvest not requiring direct weight measurements would assist cabbage growers and handlers in harvest scheduling. Results from 3 years of study during which a tool to predict cabbage yield was developed and tested are reported here. The tool was developed using plots containing a total of 13 cabbage varieties (fresh market and processing types) planted in May to July 1999 and 2000 at the Ohio Agricultural Research and Development Center (OARDC) Vegetable Crops Research Branch in Fremont, Ohio. Exhaustive measurement of marketable yield and traits of hundreds of individual heads taken from these plots revealed simple mathematical relationships among head number, size, density, and yield. The tool was tested by comparing marketable yield predicted using a formula based on these head trait relationships to direct measures of crop yield in three different studies: 1) a factorial of nine varieties and 2 planting dates completed in Fremont in 1999, 2000, and 2001, 2) a survey of 12 commercial cabbage fields in northwestern Ohio encompassing six varieties and various planting dates and fertility regimens, in 2001, and 3) a factorial of 32 varieties and 2 planting dates (10 May, 20 June) completed in Fremont in 2001. The R^2 for predicted and actual marketable yield in commercial fields and experimental plots ranged from 0.72 to 0.97. Of 510 individual estimatesof marketable yield, 48% were within 10% of actual yield values. The average quotient of predicted divided by actual marketable yield for 510 estimates made for commercial and experimental samples in 1999–2001 was 0.975. Results from this study were applied to the development of a table of potential use to crop managers in obtaining preharvest estimates of cabbage crop marketable yield. The table and its underlying assumptions are easily adjusted for local conditions.

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Cabbage production occurs year-round in the U.S. and is a major industry in several areas. Head traits impact crop marketability and are often influenced by environmental conditions, especially during later stages of head maturation. Adverse weather contributing to physiological disorders or pest or disease outbreaks can lower marketable yield. Growers and crop managers typically attempt to balance the sometimes-conflicting goals of maximum tonnage and high crop quality. Unfortunately, their efforts can be hindered by an inability to obtain rapid, accurate, and inexpensive estimates of marketable yield before harvest. Direct measures of weight are inconvenient partly because suitable scales are often costly and difficult to transport. Likewise, predicting cabbage maturity based on heat or solar radiation unit accumulation, as suggested by Isenberg et al. (1975), may be difficult for some users and is rarely practiced in commercial settings. A different type of tool, such as an empirically-based chart or table requiring easily obtained information, may provide crop managers with an opportunity to more closely monitor marketable yield development or loss and select appropriate harvest dates. The first known example of such a tool for cabbage is discussed here. The tool is based on the premise that head density and volume values may be used to estimate head weight and, therefore, marketable yield.

Subjective estimates of head firmness were impacted by variety, season, and other management factors, including within-row spacing (Greenland et al., 2000; Orzolek et al., 2000; Stofella and Fleming, 1990). However, for 13 varieties planted in the spring and summer of 2 years in Ohio, direct measures of head density were unrelated to marketable head size (Kleinhenz, 2001). Also, head polar to equatorial diameter values rarely deviated significantly from 1.0, permitting the treatment of cabbage heads as spheres in the calculation of head volume (Kleinhenz, 2001). A potentially unique benefit of these previous observations to cabbage crop managers has been captured for the first time in the yield estimation tool reported here. Estimates of marketable yield are possible so long as three values are known: number of marketable heads per unit area, head volume, and head density. The goals of this work were to 1) develop an empirically-derived constant for head density, 2) examine relationships between marketable yield predicted using head volume and density values and that measured directly with a scale, and 3) assuming strong relationships between predicted and actual marketable yield, develop a user-friendly table for in-field estimation of crop marketable yield.

Materials and methods

Tool development. Seven varieties of fresh market cabbage ('Blue Dynasty', 'Bronco', 'Cheers', 'DPSX315', 'Emblem', 'Red Dynasty', 'SuperElite Hybrid') were planted to the field using a cone-type two-row transplanter on 11 May 1999, 18 June 1999, 12 May 2000, and 30 June 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio. Six varieties of processing cabbage ('Almanac', 'Bravo', 'Geronimo', 'Hinova', 'NIZ 95-23', 'Score') were also planted to the field on 11 May 1999, 18 June 1999, 15 May 2000, and 6 July 2000 in parallel but spatially distinct studies. The two-row plots were arranged in a randomized complete block design with four (2000) or five (1999) replications per variety per planting date in both studies. Plots measured 4.6 m (15.09 ft) (fresh market) or 9.1 m (29.86 ft) (processing) long with 76.2 cm (30 inches) between rows and 27.9 cm (10.98 inches) (fresh market) or 45.7 cm (17.99 inches) (processing) between transplants. Preplant fertilizer applications, based on local recommendations and soil tests, included 71.7 kg·ha^{-1} (64 lb/acre) of P via 0N–20.1P–0K and 291.4 kg·ha^{-1}

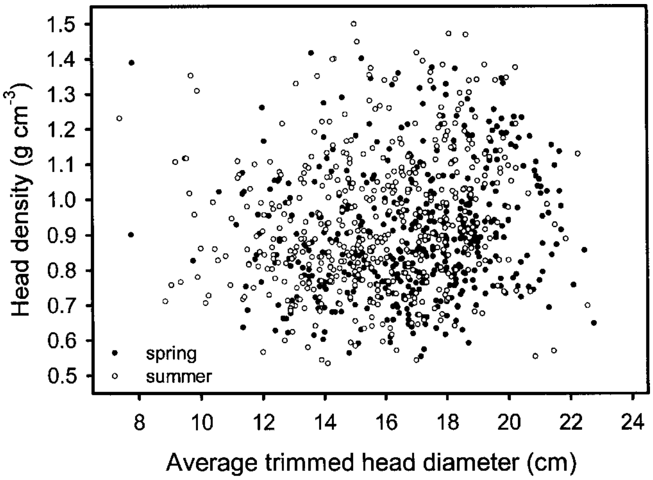

Fig. 1. Head density and diameter relationships for a total of 954 individual heads of 13 varieties of fresh market and processing cabbage after spring and summer planting in 1999 and 2000 at the Ohio Agricultural Research and Development Center, Vegetable Crops Research Branch in Fremont, Ohio. Diameter values represent the mean of polar and equatorial diameters for each head. Head density was calculated using estimates of head volume and direct measures of weight. (1 cm = 0.39 inch, 1.0 g·cm^{-3} = 0.578 oz/inch^3).

(260 lb/acre) of K via 0N–0N–49.8K in September to October 1998 and 1999 and 78.5 kg·ha^{-1} (70 lb/acre) of N via 45N–0P–0K spread and incorporated about 2 weeks before planting in 1999 and 2000. Each transplant was provided with about 150 mL (5.1 fl oz) of a dilute nutrient solution containing N and P automatically at planting. Standard pest management strategies based on scouting, thresholds, and application of labeled pesticides were employed. Plots were provided with 0.254 cm (0.10 inch) and 1.270 cm (0.50 inch) of irrigation on 1 July 1999 and 16 July 1999, respectively.

At maturity, all heads were collected from the center 3.0 m (9.84 ft) of both rows in each plot. Heads were scored as marketable or unmarketable (too small, split, rotten, or containing evidence of damage due to physiological disorders, disease, or insect feeding) and weighed as a group. Five marketable heads were then selected at random from the harvested group for further evaluation. Five outer leaves were removed from each head before they were reweighed individually using an electronic scale [FV-60KWP (A and D Co., Ltd., Tokyo, Japan) or CW11-2EO (Ohaus, Pine Brook, N.J.)]. Heads were then cut in half longitudinally and the polar and equatorial diameters recorded. Head polar:equatorial diameter values rarely deviated significantly from 1.0 (Kleinhenz, 2001). Therefore, heads were treated as spheres in calculating head volume using average head diameter values and a standard geometric formula ($1.33 \times 3.1415927 \times r^3$, where r = average head radius). Head density (g·cm^{-3}) was then calculated using weight values taken at harvest and estimated head volume. Thus, for each variety, direct, paired measures of head weight and polar and equatorial diameter and calculated head volume and density values were collected on 25 and 20 individual heads per planting date in 1999 and 2000, respectively (a total of more than 500 heads in each year). Head density appeared to be independent of head size (Fig. 1). Overall, average head density equaled 0.947 g·cm^{-3} (0.5465 oz/inch^3).

A total of 510 estimates of marketable yield were made using the formula $Y = N \times V \times D \times 0.90$, where Y = marketable yield, N = number of marketable heads per unit area, V = average head volume (cm^3), D = average head density (0.947 g·m^{-3}), and 0.90 = correction factor. Preliminary tests of the tool using data collected in Fremont, Ohio in 1999 and 2000 revealed that estimates of marketable yield made without the correction factor tended to exceed actual marketable yield values by about 10%. Therefore, a correction factor was included in the formula.

Tool testing. Estimates of marketable yield were calculated using head size and number data from three studies: 1) a factorial of nine varieties and two planting dates (May to July) completed in Fremont in 1999, 2000, and 2001, 2) a survey of 12 commercial cabbage fields in northwestern Ohio encompassing six varieties ('Bravo', 'Bronco', 'Cheers', 'Ducatt', 'Genesee', and 'Matsumo') and various planting dates and fertility regimens, in 2001, and 3) a factorial of 32 varieties and two planting dates (10 May, 20 June) completed in Fremont in 2001. All estimates of marketable yield were based on the number of marketable heads and their average volume for individual 2.29 to 4.60 m^2 (24.7 to 49.5 ft^2) areas. Calculated yield values from the three experiments were compared to actual yield values for the same areas recorded with a scale [FV-60KWP (A and D Co., Ltd.) or CW11-2EO (Ohaus)] at harvest. Thus, paired values of calculated and actual marketable yield were compared for 510 experimental areas encompassing a wide range of production and environmental conditions (e.g., variety, planting date, fertility, soil type, climate). Associations between predicted and actual marketable yield values were described using tests of correlation and plots depicting the percent deviation of predicted from actual yield values. With this approach, it was possible to gauge the accuracy and reliability of the yield-estimation tool described above.

Results and discussion

Isenberg et al. (1975) briefly considered the possible use of head size as a predictor of cabbage maturity but instead suggested the use of heat or solar radiation unit accumulation. Unfortunately, data regarding head size-maturity relationships were omitted from Isenberg et al. (1975) so direct comparisons of that with the work described here are difficult. In this study, correlations between actual and calculated cabbage crop marketable yield values were strong and the differences between these values tended to be minor, suggesting that the tool may be useful in estimating crop yield. Correlation coefficients (R^2) of actual versus predicted marketable yield equaled 0.84, 0.97, and 0.72 in three separate tests (Fig. 2A, B, and C, respectively). Associations between actual and predicted yield values were weakest in experimental plots in Fremont in 2001 (Fig. 2C), intermediate in research plots in Fremont in 1999–

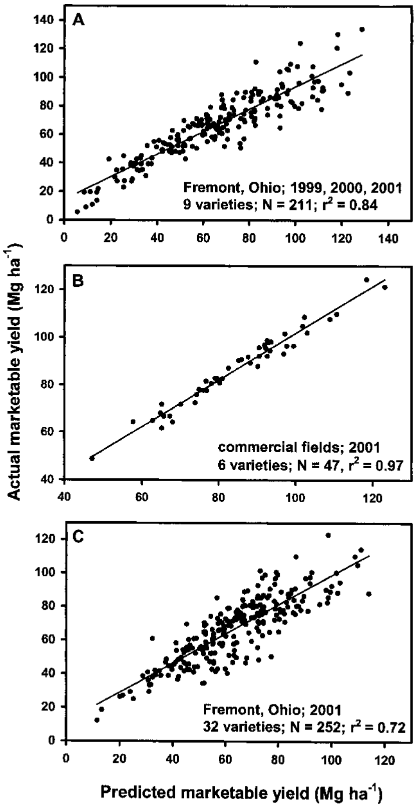

Fig. 2. Relationships between marketable yield measured directly with a scale and calculated using head number, size, and density data in three cabbage crops grown in 1999, 2000, and 2001. (1.0 Mg·ha^{-1} = 0.446 ton/acre).

2001 (Fig. 2A), and strongest in data derived from the sampling of commercial fields in 2001 (Fig. 2B). Collectively, data in Fig. 2 represent numerous genotype–environment combinations derived from the use of many varieties, planting dates and locations, and other factors. Nevertheless, predicted and actual yield values were strongly correlated (Fig. 2). In addition, the ratio between predicted and actual marketable yield values tended to be near 1.0, suggesting that the method described here can result in accurate estimates of marketable yield (Fig. 3). For example, 70.2% of the 47 individual predicted–actual marketable yield values from 12 commercial fields in 2001 were within the range of 0.9 to 1.0 with an additional 27.7% in the range 1.0 to 1.1 (Fig. 3). Furthermore, about 44% of the 211 individual predicted–actual marketable yield values from Fremont in 1999–2001 were within the range of 0.9 to 1.1 and, overall, 48% of the 510 estimates of marketable yield for experimental and commercial plots in 1999–2001 were within 10% of actual yield values for the same areas recorded directly with a scale (Fig. 3). Based on the outcomes of these tests, a user-friendly format for the application of this method for predicting cabbage marketable yield is proposed in Table 1. By counting the number of marketable heads in several 4.6 m^2 (50 ft^2) areas and measuring their average trimmed diameter, crop managers may rapidly obtain accurate estimates of marketable yield. Repeated estimates could then be used to monitor crop condition and, along with other information (e.g., weather forecasts, labor and equipment availability), target harvest dates which effectively balance the need for total tonnage and high crop quality. The tool assumes that the ratio of head polar and equatorial diameter for moderately trimmed heads does not deviate significantly from 1.0 (i.e., heads are spheres) and that head density equals 0.947 g·cm^{-3}. Violation of either or both of these assumptions may reduce the accuracy of predictions and may have contributed to the modest declines from linearity noted in Fig. 2A and C and deviation from 1.0 in Fig. 3. It is important to note that alternative, empirically derived estimates of cabbage head density, for example, would allow for easy adjustment of the tool for local conditions. For example, year, genotype, planting date, and within-row spacing have been shown to impact the firmness or density (Greenland et al., 2000; Isenberg et al., 1975; Kleinhenz, 2001; Kleinhenz and Schult, 2000a; Kleinhenz and Schult, 2000b; Kleinhenz et al., 2001; Orzolek et al., 2000; Stofella and Fleming, 1990) and diameter and length (Fornaris-Rullan et al., 1989; Sundstrom and Story, 1984) of mature cabbage heads. Likewise, these and other factors, including nutrient and soil management, are thought to affect cabbage head weight (Bottenberg et al., 1997; Everaarts and De Moel, 1998; Fornaris-Rullan et al., 1989; Kleinhenz, 2001; Kleinhenz and Schult, 2000a; Kleinhenz and Schult, 2000b; Kleinhenz et al., 2001). Average head density in seven varieties of fresh market cabbage planted in Fremont, Ohio in May and June was 0.853 g·cm^{-3} (0.4922 oz/inch^3) in 1999 (Kleinhenz and Schult, 2000a) but 1.090 g·cm^{-3} (0.6289 oz/inch^3) in 2000 (Kleinhenz et al., 2001). Using other genotypes, including experimental selections and currently uncommon varieties, Isenberg et al. (1975) reported that most storage cabbage cultivars are mature when head density equals 0.72 – 0.80 g·cm^{-3} (0.4154 – 0.4616 oz/inch^3). With data available for other growing areas or conditions, adjustments in the head density value used to calculate head weight are easily accomplished. Also, the formula $N \geq (z_{(\alpha/2)} \times \text{SD}/h)^2$, where N = number of samples, z = value of z from z table specific to confidence level, α = (100 – confidence level/100), SD = standard deviation of actual-estimated yield, and h = half-width of confidence level, can be used to estimate the minimum number of samples required to estimate yield at a specific level of confidence (B. Bishop, personal communication). For example, data in Fig. 2B suggest that a) 3 samples per field would be required to estimate yield within 13.4 Mg·ha^{-1} (6 tons/acre) with 90% con-

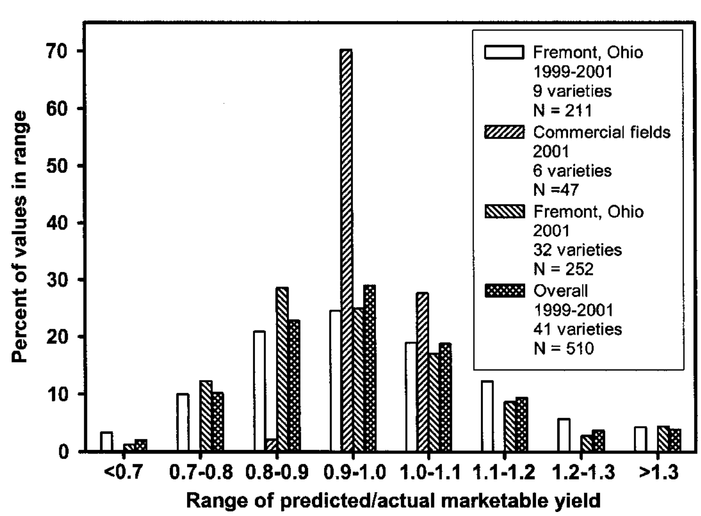

Fig. 3. Distribution of predicted/actual marketable yield values for three cabbage crops grown in 1999, 2000, and 2001. (1.0 Mg·ha^{-1} = 0.446 ton/acre).

Table 1. A proposed tool for rapid and inexpensive preharvest estimation of cabbage crop marketable yield. The table assumes that the ratio of head polar and equatorial diameter does not deviate significantly from 1.0 (i.e., heads are spheres) and that head density equals 0.947 $g\cdot cm^{-3}$ (0.5465 $oz/inch^3$).

No. of marketable heads in 4.65 m^2 ($50\ ft^2$)	Marketable yield[z] ($Mg\cdot ha^{-1}$)[y] Avg diam (cm) of trimmed heads[x]					
	10	12	14	16	1	
4	3.8	6.6	10.5	15.7	22.3	30.6
6	5.7	9.9	15.8	23.5	33.5	45.9
8	7.7	13.2	21.0	31.4	44.7	61.3
10	9.6	16.6	26.3	39.2	55.8	76.6
12	11.5	19.9	31.5	47.0	67.0	91.9
14	13.4	23.2	36.8	54.9	78.2	107.0
16	15.3	26.5	42.0	62.7	89.3	123.0

[z]The number of samples per field required to estimate yield depends on the desired confidence level of the estimate and the tendency of estimated values to differ from actual values. The formula $N \geq (z_{(a/2)}$ ¥ SD$/h)^2$, where N = number of samples, z = value of z from z table specific to confidence level, a = (100 – confidence level/100), SD = standard deviation of actual-estimated yield, and h = half-width of confidence level, can be used to estimate the minimum number of samples required to estimate yield at a specific level of confidence (B. Bishop, personal communication).
[x]1 cm = 0.39 inch.
[y]1.0 $Mg\cdot ha^{-1}$ = 0.446 ton/acre.

fidence or that b) 11 samples would be required to estimate yield within 6.7 $Mg\cdot ha^{-1}$ (3 tons/acre) with 90% confidence: a) $N \geq (1.645 \times 13.7/13.7)^2$, b) $N \geq (1.645 \times 13.7/6.87)^2$. Related studies are underway to test the success of the tool under additional conditions and to identify optimal sampling rates for estimating yield in commercial fields.

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