ments (125 and 175 mg N/liter) that gave optimal plant growth and quality fell within these ranges (Table 2). Thus, the values obtained by PT for these two treatments could be used to predict nutrient status for optimal growth of poinsettia. For example, if one used the PT method and obtained EC and $\text{NO}_3\text{-N}$ values ranging from 2.5 to 3.2 dS·m⁻¹ and 230 to 312 mg·liter⁻¹, respectively, optimal growth and quality of poinsettia could be expected, provided environmental factors were not limiting. The above values are predicted values from regression analysis of data in Table 2 rather than the actual values.

This work supports the use of PT as a rapid and easy method for monitoring medium soluble salts and specific nutrients to indicate whether optimal nutrient levels are

present for promotion of plant growth. We caution about the use of standard values established for other extraction techniques for making assessments of the nutritional status of a crop with the PT method. Additional work and grower experiences are needed to establish PT medium nutrient levels that promote optimal growth of other greenhouse crops.

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Leaf Tipburn in Cauliflower as Affected by Cultivar, Calcium Sprays, and Nitrogen Nutrition

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Abstract. Two separate field experiments were conducted to determine the influence of Ca sprays and N fertilizer rate on leaf tipburn incidence in 'Snow Crown', 'Self Blanche', and 'Imperial 10-6' cauliflower. Incidence of leaf tipburn was highest in 'Snow Crown' each year and varied with year in 'Self Blanche' and 'Imperial 10-6'. Delaying planting of 'Snow Crown' by 3 weeks decreased tipburn incidence by 20% and decreased the number of tipburned leaves per tipburned plant by 60%. Sprays of CaCl₂ or calcium chelate had no effect on cauliflower productivity, nutrition, or tipburn incidence. Increasing N fertilizer rate from 67 kg N/ha to 201 kg N/ha linearly increased yield without significantly affecting tipburn incidence. Concentrations of Ca in tips of nontipburned leaves were two to five times greater than those in tips of tipburned leaves of comparable physiological age. Basal leaf regions had similar Ca concentrations, regardless of tipburn status. Use of resistant cultivars appears to be the best method of reducing tipburn incidence in cauliflower.

Leaf tipburn in cauliflower is characterized as a tip necrosis of young expanding leaves surrounding the enlarging curd. Necrotic leaves can lower product quality and, in severe cases, may discolor the curd due to secondary pathogen infection and cause a loss in marketable heads (Maynard et al., 1981). Similar disorders have been reported in other vegetable crops, including cabbage (Maynard et al., 1965), brussels sprouts

(Maynard and Barker, 1972), and lettuce (Thibodeau and Minotti, 1969) and all have been related to Ca nutrition. Maynard et al. (1981) reported that Ca concentrations in cauliflower leaves were generally lower in tipburned regions of leaves than in similar regions in nontipburned leaves. A Ca gradient within tipburned leaves has also been reported, with lower concentrations near the leaf tip and higher concentrations near leaf basal areas (Rosen et al., 1987). Although Ca nutrition has been implicated in these disorders, applications of Ca to the soil in field studies have shown inconsistent effects on preventing tipburn incidence (Rosen et al., 1987). Effects of foliar applications of Ca sprays were not successful in preventing tipburn incidence in lettuce (Misaghi et al., 1981), but no data could be found for cauliflower.

Exploiting genotypic differences in susceptibility to tipburn has been an effective means of reducing the problem (Nieuwhof, 1960). Tipburn incidence, however, can be modified by several environmental factors, including relative humidity, temperature, soil moisture, and soil fertility (Collier and Tibbitts, 1982). Increasing the air temperature, lack of soil moisture, or excessive soil moisture tend to enhance tipburn incidence. One common characteristic of tipburn is that occurrence is usually greatest in young, rapidly growing leaf tissue, particularly during curd enlargement. High rates of N fertilizer have been reported to increase incidence and/or severity of tipburn in cauliflower (Jenkinson and Campbell, 1957) and cabbage (Nieuwhof et al., 1960). The finding with cauliflower prompted Jenkinson and Campbell (1957) to suggest that tipburn-resistant genotypes be selected under conditions of high N fertility.

The objective of the present experiments was to evaluate the response of three commonly grown cauliflower cultivars to foliar-applied Ca sprays and N nutrition in relation to productivity, nutrition, and tipburn incidence.

The study was conducted over 2 years (1986-1987) at the Sand Plain Research Farm in Becker, Minn., on a Hubbard loamy sand (Udorthentic Haploboroll). Soil properties before planting were similar each year. Selected chemical properties averaged over years are as follows (0 to 15 cm): organic matter (wet digestion), 2.3%; pH [1 soil : 1 water (w/v)] 6.4; P (Bray Pi), 37 mg·kg⁻¹; K, Ca, and Mg (1 N ammonium acetate), 135, 694, and 192 mg·kg⁻¹, respectively. Extractable nitrate-N (2 N KCl) in the top 0.3 m was 6 mg·kg⁻¹.

In 1986, the effects of foliar-applied Ca sprays on tipburn incidence and cauliflower productivity were evaluated. In 1987, using the same cultivars, the effects of N nutrition and planting date were evaluated. In both years, 'Snow Crown' (early season maturing), 'Imperial 10-6' (mid- to late-season

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Table 1. Effect of cultivar and foliar Ca sprays on cauliflower yield, tipburn incidence, and nutrient composition of recently matured wrapper leaves (1986).^a

Criterion ^b	Yield (Mg·ha ⁻¹)		Tipburned plants* (%)	Tipburned leaves per tipburned plant	Leaf nutrient composition (%)				
	Total	Marketable			N	P	K	Ca	Mg
Cultivar means									
Snow Crown	20.8 b	19.9 b	97.7 a	8.5 a	4.10 a	0.52 b	3.27 b	1.01 a	0.30 a
Imperial 10-6	24.3 a	23.0 a	35.2 b	5.3 b	3.32 b	0.47 c	3.03 c	0.58 c	0.20 c
Self Blanche	23.7 a	22.5 a	12.8 c	3.8 b	4.18 a	0.56 a	3.43 a	0.74 b	0.27 b
Calcium treatment means									
Control	24.1 a	22.7 a	53.1 a	6.0 a	3.91 a	0.52 a	3.24 a	0.77 a	0.26 a
CaCl ₂	22.4 a	22.0 a	42.1 a	6.1 a	3.85 a	0.51 a	3.24 a	0.77 a	0.26 a
Calcium chelate	22.4 a	20.8 a	50.5 a	5.5 a	3.83 a	0.53 a	3.26 a	0.72 a	0.25 a

^aMean separations, within column and main effect, by Duncan's multiple range test, $P = 0.05$.

^bThe cultivar × Ca interaction was nonsignificant in all cases.

^cAnalysis of variance carried out using inverse sine transformation. Data are presented in original scale.

Table 2. Effect of cultivar/planting date and N fertilizer on cauliflower yield, tipburn incidence, and nutrient composition of recently matured wrapper leaves (1987).^a

Criterion	Yield (Mg·ha ⁻¹)		Tipburned plants ^b (%)	Tipburned leaves per tipburned plant	Leaf nutrient composition (%)				
	Total	Marketable			N	P	K	Ca	Mg
Cultivar/planting date means									
Snow Crown—early planting	17.2 a	10.6 ab	97.8 a	9.7 a	2.88 b	0.45 bc	3.09 b	0.63 a	0.23 b
Snow Crown—late planting	17.0 a	9.0 b	77.5 b	3.5 b	2.90 b	0.50 a	3.22 a	0.49 c	0.22 b
Imperial 10-6	18.2 a	13.1 a	16.9 c	2.2 c	2.26 c	0.43 c	2.84 c	0.55 b	0.18 c
Self Blanche	13.9 b	8.2 b	70.6 b	4.6 b	3.17 a	0.47 b	3.16 ab	0.62 a	0.25 a
Nitrogen treatment means (kg·ha⁻¹)									
67	11.4	1.1	70.2	5.3	2.14	0.43	2.99	0.58	0.21
134	17.3	11.5	69.4	5.0	2.78	0.47	3.12	0.55	0.22
201	21.2	18.2	57.4	4.7	3.48	0.49	3.12	0.58	0.24
Linear	**	**	NS	NS	**	**	NS	NS	**
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
Cultivar/plant × N rate	NS	NS	NS	NS	NS	NS	NS	**	NS

^aMeans separations, within columns and Main effect, by Duncan's multiple range test, $P = 0.05$. Nonsignificant (NS) or significant at $P = 0.01$ (**).

^bAnalysis of variance carried out using inverse sine transformation. Data are presented in original scale.

Table 3. Effect of cultivar/planting date and N interaction on Ca composition of recently matured cauliflower leaves (1987).

N rate (kg·ha ⁻¹)	Cultivar/planting date			
	Snow Crown (early)	Snow Crown (late)	Imperial 10-6	Self Blanche
	% Ca			
67	0.57	0.52	0.60	0.63
134	0.58	0.46	0.55	0.61
201	0.73	0.49	0.50	0.61
Linear N rate	**	*	**	NS
Quadratic N rate	*	**	NS	NS

NS, *, ** Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

maturing), and 'Self Blanche' (late-season maturing) cauliflower were initially grown as transplants in the greenhouse. Seeds were planted the last week in May in transplant flats containing a 1 peat : 1 sand : 1 soil mixture (by volume). Two weeks after emergence, seedlings were fertilized with (mg·liter⁻¹) 1.00 N, 44P, and 81 K at each irrigation. In 1987, a second seeding of 'Snow Crown' was planted on 19 June. Before planting, 50 kg K/ha, 40 kg S/ha, and 25 kg Mg/ha as potassium-magnesium sulfate was broadcast and disked in the field. Overhead irrigation was used to supplement rainfall to provide a total of 35 mm of water per week.

In 1986, the treatments included three cultivars and three Ca sprays in a randomized complete block factorial arrangement using four replications. Transplants were planted on 30 June and supplied with 0.3 liter of starter solution [800N-800P-460K (mg·liter⁻¹)] in each transplant hole. Spacing was 0.41 m within the row and 0.91 m between rows. Each plot consisted of four 4.9-m rows. Seven days after planting, 27 kg N/ha, 17 kg P/ha, 105 kg K/ha, and 1.1 kg B/ha were banded 5 cm deep and 8 cm to the side of each plant. Additional N as ammonium nitrate (56 kg N/ha) was sidedressed at 21, 36, and 48 days after trans-

planting to provide 201 kg N/ha for the growing season; this total includes 6 kg N/ha from the starter solution. The foliar Ca spray treatments included: 1) water-sprayed control, 2) CaCl₂·2H₂O (27% Ca), and 3) calcium trihydroxyglutarate (Nutri-Cal, 8% Ca; CSI Chemical Corp., Bondurant, Iowa). Calcium chloride was applied at the rate of 1.8 kg Ca/ha per application mixed with 380 liters of water. Calcium chelate was applied at the rate of 1.0 kg Ca/ha mixed with 95 liters of water. All treatments, including the water-sprayed control, were applied with X-77 surfactant (Chevron Chemical Co., San Francisco) at the rate of 0.06% v/v. The first spray was applied 4 weeks after transplanting. 'Snow Crown' was sprayed twice more, and 'Self Blanche' and 'Imperial 10-6' were sprayed three more times at 7-day intervals. Heads were not tied. The middle 3.3 m in the center two rows (16 heads per plot) were harvested when curd diameter was between 13 and 17 cm. At each harvest date, the number of tipburned leaves per plant and trimmed curd fresh weight were recorded.

In 1987, the same three cultivars were transplanted into the field 1 July, and a second planting of 'Snow Crown' was transplanted 20 days later. In a 4 × 3 factorial

Table 4. Effect of N fertilizer on N composition of tip and basal regions of immature tipburned and nontipburned 'Snow Crown' and 'Self Blanche' wrapper leaves sampled at harvest (1987).

N rate (kg·ha ⁻¹)	Leaf region	Cultivar			
		Snow Crown (late planting)		Self Blanche	
		Tipburned	Nontipburned	Tipburned	Nontipburned
		%N		%N	
67	Tip	3.48	2.68	3.68	3.80
134	Tip	4.24	3.48	3.92	3.99
201	Tip	4.85	4.24	4.40	3.92
67	Base	3.02	2.95	3.55	3.87
134	Base	3.26	3.71	3.60	3.86
201	Base	4.25	4.17	4.39	3.98
Sources of variation ^a					
Nitrogen rate (N)		**		*	
Linear		**		*	
Quadratic		NS		NS	
Leaf region (R)		**		NS	
Tipburn status (T)		**		NS	
N × R		NS		NS	
N × T		NS		**	
R × T		**			
N × R × T		NS		NS	

^aAnalyses of variance carried out on data within each cultivar.

NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

Table 5. Effect of N fertilizer on Ca composition of tip and basal regions of immature tipburned and nontipburned 'Snow Crown' and 'Self Blanche' wrapper leaves at harvest (1987).

N rate (kg·ha ⁻¹)	Leaf region	Cultivar			
		Snow Crown (late planting)		Self Blanche	
		Tipburned	Nontipburned	Tipburned	Nontipburned
		%Ca		%Ca	
67	Tip	0.05	0.35	0.33	0.75
134	Tip	0.07	0.19	0.34	0.66
201	Tip	0.08	0.18	0.27	0.59
67	Base	0.25	0.40	0.55	0.79
134	Base	0.29	0.32	0.57	0.63
201	Base	0.35	0.33	0.51	0.55
Sources of variation ^a					
Nitrogen rate (N)		*		**	
Linear		NS		**	
Quadratic		NS		NS	
Leaf region (R)		**		**	
Tipburn status (T)		**		**	
N × R		*		NS	
N × T		**		**	
R × T		**		**	
N × R × T		NS		NS	

^aAnalyses of variance carried out on data within each cultivar.

NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

treatment arrangement, each cultivar/planting date was provided with three levels of N fertilizer: 67, 134, and 201 kg N/ha as ammonium nitrate in two or three split applications. A split-plot design was used with four replications. Nitrogen was the main plot and cultivar/planting date was the subplot. Starter solution, banded fertilizer application, plant population, and plot size were the same as in 1986. In addition to starter solution N (6 kg N/ha) and N supplied 7 days after planting (27 kg N/ha), 34 kg N/ha was topdressed and irrigated into all plots 21 days after planting. At 35 days after planting, the remainder of the N fertilizer was topdressed. At this time, the 67-kg N/ha treatment did not receive any additional N, the 134-kg N/ha treatment received 67 kg N/ha, and the 201-

kg N/ha treatment received 134 kg N/ha. Harvest procedures were the same as in the previous year.

In both years, recently matured wrapper leaves surrounding the curd were sampled during head enlargement. Leaves selected did not show symptoms of tipburn. Samples were dried for 48 hr at 60°C and ground in a Wiley mill to pass through a 40-mesh screen. Total N after 1 hr of digestion at 370°C in concentrated H₂SO₄ was determined conductimetrically (Carlson, 1978). Other elements were determined after ashing and resuspending in 2 N HCl using an inductively coupled plasma spectrometer (Munter et al., 1984). In 1987, tipburned immature wrapper leaves from tipburned plants and leaves of similar physiological age from nontipburned plants were

also sampled at harvest. Samples from both tipburned and nontipburned categories were collected from the late-planted 'Snow Crown' and from 'Self Blanche'. Because only a few 'Imperial 10-6' plants exhibited tipburn, only nontipburned plants of this cultivar were sampled. Similarly, all early planted 'Snow Crown' exhibited tipburn and, therefore, only tipburned leaves were sampled. Leaves were cut into tip and basal regions. About 2 cm of leaf tissue from the tip and base (excluding the midrib) of the leaves were sampled. Leaf tip and basal regions were dried separately and prepared for elemental analyses as described above.

The data were subjected to analysis of variance and means were compared with Duncan's multiple range test. Tipburn incidence percentage data were transformed using the inverse sine conversion before analysis of variance (Steel and Torrie, 1980); however, data are presented on the original scale in the text.

Except for tissue Ca concentrations the 2nd year, interactions between cultivar and nutrition were not significant and, therefore, main effects of cultivar and nutrition will be discussed separately. Symptoms of tipburn first appeared on immature leaves during curd enlargement. In both years, 'Snow Crown' had the highest incidence and greatest severity of leaf tipburn (Tables 1 and 2). 'Self Blanche' had the lowest incidence in 1986 and 'Imperial 10-6' in 1987. Differences in tipburn incidence were not associated with large differences in marketable yield. However, had heads been tied, tipburn may have had more of an impact on marketable yields. Year-to-year variation in cultivar response indicates that environmental conditions can modify the effect due to genotype. Indeed, in the present experiment, delaying transplanting of 'Snow Crown' by 3 weeks decreased tipburn incidence by 20% and decreased the number of tipburned leaves per tipburned plant by 60%. This decrease in tipburn coincides with an approximate 4°C decrease in air temperature during curd enlargement.

Hochmuth (1984) reported that Ca efficiency in cauliflower seedlings, as measured in nutrient solution culture, was greatest in 'Imperial 10-6', intermediate in 'Snow Crown', and lowest in 'Self Blanche'. Results of this field experiment suggest that more than seedling Ca efficiency is involved in cauliflower leaf tipburn. Significant differences due to cultivar in mature wrapper leaf elemental concentrations were detected both years. 'Imperial 10-6' tended to have lower nutrient concentrations than the other two cultivars.

Foliar-applied CaCl₂ or Ca chelate had no effect on tipburn incidence, yield, or wrapper leaf nutrient composition (Table 1). The difficulty in directing the sprays to expanding young leaves apparently limited the effectiveness of foliar-applied Ca. Although cauliflower leaves were not tied, the growth habit of the plant is such that direct spray contact of young leaves was not uniform with

the spray procedures used in this study. As a result, levels of Ca in the inner wrapper leaves were unaffected by the spray treatments. Lack of a consistent response to foliar-applied Ca in field studies is in agreement with reports for other crops (Misaghi et al., 1981).

Increasing N fertilizer rate from 67 to 201 kg-ha⁻¹ linearly increased total and marketable yield (Table 2). This response is similar to that reported for cauliflower by Welch et al. (1987), but is greater than that reported for maximum cauliflower yields by Dufault and Waters (1985). Variable results in response to N fertilizer may be due to differences in residual soil nitrate before planting, release of N from soil organic matter, and/or nitrate leaching during the growing season.

Effects of N fertilization on the percentage of plants showing tipburn were nonsignificant. In addition, the number of tipburned leaves per tipburned plant was not affected by N fertilizer application. These results contrast with other reports, where increasing N fertilizer was associated with an increase in tipburn incidence (Jenkinson and Campbell, 1957; Nieuwhof et al., 1960). The lack of a N effect on tipburn in the present experiment may be due to the fact that recently developed cultivars generally have been selected under optimum N fertilizer regimes and those showing a tipburn response under these conditions would have been rogued out, as suggested by Jenkinson and Campbell (1957). Such a practice would tend to minimize the effects of N on tipburn incidence. In addition, the two lower N rates used in this study were less than the optimum rate used for cauliflower production. Had excessive rates of N been used in this study, a different response may have been observed. The results of this experiment clearly indicate that lowering N fertilizer rates below optimum levels is not an effective control measure for cauliflower tipburn and that significant yield loss may result from such a practice.

Concentrations of N, P, and Mg in mature wrapper leaves during head enlargement increased linearly with N rate (Table 2). Increasing N rate increased concentrations of leaf N from 2.14% to 3.48%. Fertilizer N effects on tissue Ca were inconsistent and depended on cultivar (Table 3). Rate of N had no effect on wrapper leaf Ca concentrations in 'Self Blanche'. In contrast, Ca levels in wrapper leaves increased in early planted 'Snow Crown' and decreased in 'Imperial 10-6' and late-planted 'Snow Crown' with increasing N rate. In studies with cabbage, increasing N rate increased Ca concentrations of the heads at harvest (Peck et al., 1983). The trend for decreasing Ca with increasing N rate in 'Imperial 10-6' and late-planted 'Snow Crown' suggests that, in some situations, higher than optimum rates of N

may be associated with increased tipburn incidence. However, in general, low leaf Ca concentrations in whole, mature wrapper leaves not showing tipburn that were sampled during curd enlargement were not associated with an increase in tipburn incidence. 'Snow Crown' in 1986 and early planted 'Snow Crown' in 1987 had the highest Ca concentrations in mature wrapper leaves, yet showed the greatest tipburn incidence in leaves at harvest.

Concentrations of N and Ca in basal and tip regions of immature wrapper leaves from tipburned leaves were compared to concentrations in the same regions from leaves of similar physiological age from nontipburned plants (Tables 4 and 5). Because tipburn incidence was high in early planted, 'Snow Crown', only tipburned leaves were sampled. Concentrations of N and Ca in these leaves were similar to tipburned leaves from late-planted 'Snow Crown' (data not presented). Tipburn incidence was low in 'Imperial 10-6'; therefore, only nontipburned leaves were collected. Concentrations of N and Ca were similar to 'Self Blanche' nontipburned leaves (data not presented).

Nitrogen concentrations in tip and basal regions increased with N rate in both 'Self Blanche' and late-planted 'Snow Crown' (Table 4). 'Tip regions of tipburned 'Snow Crown' leaves were higher in N than corresponding tips from nontipburned leaves. This trend was not observed in 'Snow Crown' basal leaf regions or in either region from 'Self Blanche' leaves.

Leaf Ca levels were dependent on leaf region, N rate, and tipburn status (Table 5). Nitrogen rate tended to decrease Ca levels in 'Self Blanche', but had variable effects on Ca levels in 'Snow Crown'. Nontipburned 'Snow Crown' leaves tended to decrease in Ca levels with N rate, while tipburned leaves tended to increase. In general, Ca levels in tips of tipburned leaves were two to five times lower than in tips of nontipburned leaves. Relative Ca differences were greater for 'Snow Crown' than for 'Self Blanche'. There was little difference between Ca composition of tipburned and nontipburned leaves in basal regions. These results clearly implicate Ca in the tipburn disorder and support previous reports on leaf tipburn in cauliflower (Krug et al., 1972; Maynard et al., 1981; Rosen et al., 1987). The tipburn problem appears to be due to a localized Ca deficiency within the leaf and cannot be predicted from Ca concentrations in whole, mature leaves not showing tipburn damage (Tables 1 and 2).

Results of these experiments suggest that cultivar selection is an effective means of minimizing tipburn incidence in cauliflower. Under the conditions used, foliar applications of Ca and reducing N rates below optimum levels were ineffective in controlling the disorder. For susceptible cultivars, such

as 'Snow Crown', selecting a planting date to ensure that head maturation occurs during cooler temperatures may help reduce tipburn incidence.

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