two adults, and whether the presence of children has any bearing on purchasing branded plant material. In addition, an exploration of the consumer's willingness to pay for a product like PGS should be assessed to understand if this program could command a higher retail price. Understanding these motives will help create an effective marketing plan to reach out and connect with the target audience (Iacobucci, 2001). This will enable the product and subsequent promotions to be directed towards enhancing and reinforcing the consumer's desired experience, which, in turn, will increase consumer interest and enjoyment of gardening. It will also result in greater financial rewards for the program and the nursery industry (Gobe, 2001).

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Influence of Soil and Nutrient Management on Growth and Quality of Collards

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ADDITIONAL INDEX WORDS. *Brassica oleracea*, tipburn, deep tillage, programmed-release fertilizers

SUMMARY. High temperature and humidity during summer months in the southeastern U.S., in addition to crop nutritional status, are suggested to be the primary reasons for tipburn incidence in collards (*Brassica oleracea* Acephala Group) adversely affecting their marketability. A 2-year study was conducted to evaluate the efficiency of grower's standard practice (GSP), GSP + gypsum, and a programmed-release fertilizer (PRF) under conventional and deep tillage on collard yield and tipburn incidence. Subsoiling significantly increased yield over conventional tillage. Nutrient supply through PRF did not increase the yields; however, it resulted in either similar or higher levels of macro- and micronutrient levels both in soils and collard tissue compared to GSP and GSP + gypsum treatments. The occurrence of tipburn in collards is dependent on several factors, including nutritional, physiological, and environmental stresses. Regression analyses of tipburn ratings at harvest time and the soil and tissue nutrient content suggested that 47% of the variation could be attributed to soil and tissue levels of sulfur (S), zinc (Zn), and phosphorus (P). It is important, therefore, to ensure an optimum supply of nutrients to the plants to maintain the quality of the yields. The advantage of PRF in sandy

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soils, and identification of other factors affecting the tipburn in collards should be further investigated.

Collards are grown in the southeastern U.S., typically on coastal plain soils that are deep sands and classified by the USDA Soil Survey (USDA-SCS, 1976) as excessively drained with low organic matter, low cation exchange and nutrient holding capacities. The crop is harvested throughout the year with planting taking place for 10 months, assuring a very reliable market supply during summer months. High temperature and humidity during summer months in the region, however, can cause tipburn, an inward cupping and marginal burn of the young collard leaves, adversely affecting their marketability (Johnson, 1991). Tipburn is a physiological disorder that causes necrosis of the outer margins of newly developing leaves due to calcium (Ca) deficiency (Aloni, 1986). Although tipburn resistance is genetic, its occurrence is also influenced by various environmental stresses (Collier and Tibbitts, 1982; Cox et al., 1976). Factors influencing both increased and decreased vegetative growth of plants can induce tipburn and therefore make it very difficult to predict its incidence and can cause significant economic losses (Saure, 1998).

Restricted root growth in Chinese cabbage (*Brassica rapa*) was found to increase the risk of tipburn incidence (Aloni, 1986). The crop is heavily fertilized, as often as every 2 weeks with nitrogen (N) and potassium (K). Excess N and K are known to increase chances of tipburn incidence (Brumm and Schenk, 1993). Light intensity, humidity, soil conditions, plant growth vigor, internal calcium distribution, and physiological stresses

are some of the other factors reportedly influencing tipburn. However, the magnitude and the precise role of these factors are not well understood (Saure, 1998).

Traditionally, a restrictive plow pan is allowed to develop below the root zone because of high hydraulic conductivity of the sandy soils. This may restrict deeper root penetration, effectively reducing the root zone for water and nutrient uptake. Collards are irrigated generally twice per week because of high evaporative demand during the hot months. In spite of a plow pan, frequent irrigation can lead to nutrient leaching beyond the root zone. High temperatures and evaporation during summer months can lead to difficulties in managing nutrients and water in the root zone, and thereby can increase the potential for tipburn incidence. Soil and nutrient management information on collards is limited. This study was developed therefore with the objective of determining the influence of subsoiling and different fertilization practices on the productivity, fertilizer use efficiency, and tipburn incidence of collards.

Materials and methods

A 2-year field study on a coastal plain soil during the summers of 1997 and 1998 (two growing seasons) was conducted on a commercial farm located in Lexington County, S.C. The soils were classified as Lakeland series (thermic, coated, Typic Quartzipsamments) that are excessively drained sands, more than 6.56 ft (2.0 m) deep. The plots were 20 ft (6.1 m) long and consisted of 3-ft-wide (0.9 m) rows with an in-row plant spacing of 1 ft (0.3 m). In both years, the experiment was conducted as a randomized complete block with a split-plot design; the treatments were replicated four times. Type of tillage was the main treatment

consisting of either: 1) subsoiling (SS) using an in-row subsoiler with two 24-inch-deep (61.0 cm) shanks on the tool bar; or 2) conventional tillage (CT) using moldboard plow to a depth of 6 inches (15.2 cm). Subplots comprised three fertilizer treatments: 1) N applied as per the grower's standard practice (GSP) through a fertilizer blend 22N-0P-18.3K; 2) N (GSP) + Ca²⁺ (through gypsum); and 3) a programmed-release fertilizer blend 20N-2.2P-12.4K (PRF)—a polyolefin-coated urea formulation, commercially known as Meister blend (Helena Chemical Co., Memphis, Tenn.). For both years, the actual amounts and application frequencies for each fertilization practice for each subplot are detailed in Table 1.

Six-week-old 'Topbunch' collard plants, pulled from a grower transplant bed, were mechanically transplanted. Fertilizers were applied to the study plots by hand at the rates detailed in Table 1. The PRF was applied in-furrow and GSP and GSP+ gypsum treatments were banded by the row. All the standard pest and cultural management practices were performed as needed. The grower managed irrigation, which consisted of 1/2 to 3/4 inch (12.7 to 19.1 mm) of water applied twice a week using a center pivot fitted with a regulator, except at times when adequate precipitation was received (Fig. 1). Ten consecutive marketable plants from the middle row of each plot were hand-harvested to measure the yield parameters. The first year, plants were completely devoid of tipburn symptoms. During the second year, all 20 plants in one row were rated for tipburn incidence. The rating scheme had five levels based on the intensity of tipburn incidence: no evidence = 1; cupping of the interior leaves = 2; cupping of the older leaves = 3; necrotic margins of younger interior leaves = 4; necrosis of

Table 1. Fertilizer application rates per treatment and frequency of application per year applied to collards plots in 1997 and 1998.

Treatments	Frequency of application				Total
	1	2	3	4	
	----- Application rate [N–P–K–Ca ^z (lb/acre)] ^y -----				
GSP ^x	33–0–27.4–0	44–0–36.5–0	55–0–45.6–0	66–0–54.8–0	198–0–158.4–0
GSP + gypsum ^w	33–0–27.4–57.5	44–0–36.5–57.5	55–0–45.6–0	66–0–54.8–0	198–0–158.4–115
PRF ^v	120–13.1–74.7–0	---	---	---	120–13.1–74.7–0

^xN = nitrogen; P = phosphorus; K = potassium; and Ca = calcium.

^y1 lb/acre = 1.12 kg·ha⁻¹.

^xGSP = growers standard practice applied through the fertilizer blend (22N-0P-18.3K). Applications were at 2-week intervals, beginning at planting.

^wGSP + gypsum = Ca²⁺ applied through gypsum at 500 lb/acre (560.4 kg·ha⁻¹) in two equal doses.

^vPRF = programmed release fertilizer applied through Meisterblend (20N-2.2P-12.4K), a 60-d release.

Fig. 1. Rainfall and temperature pattern between collards planting and harvesting periods during 1997 and 1998 at the research site [$^{\circ}\text{C} = 5/9(^{\circ}\text{F} - 32)$; 1 inch = 25.4 mm].

growing point = 5. Any plants rated 4 or 5 had no market value.

SOIL AND TISSUE SAMPLING. Soil samples were collected at pre-plant and at the harvest stages using a hand-held auger from 0–6 inches depth. A foliage sample for tissue analysis was collected from youngest mature leaves after the weights were recorded for yield computation. Both soil and tissue samples were analyzed at the Agricultural Service Laboratory, Clemson University. Soil samples were assayed with Mehlich-1 extractant for macro- and micronutrients and were determined on an inductively coupled plasma spectrophotometer (ICP). The tissue samples were analyzed for total N using the N-combustion method and all the other nutrients were determined by digestion of the tissue using the wet combustion method and ICP.

STATISTICAL ANALYSIS. Analysis of variance (ANOVA) for a split-plot design was performed by combining data from the 2 years. Means were

separated using Tukey's W-procedure. Before combining data sets from both years, an individual ANOVA for each year was performed and the assumption of homogeneity of variances between the 2 years was checked using an F-test. Square root transformation was performed as required for the F-test. Transformed variables were rechecked for homogeneity. Transformed values were back-transformed and reported. Multiple regression analysis was performed to determine the influence of soil and tissue nutrient contents on the tipburn ratings in collards. A correlation matrix was used to assess the collinearity among the independent variables. All statistical calculations were done using SAS (2000).

Results and discussion

Subsoiling increased collards' yield significantly compared to conventional tillage treatments (Table 2), confirming the observation made by Reeves et al. (1990), where the presence of tillage

pans was found to limit crop yields on sandy soils of the southern coastal plain of the United States.

Type of tillage system did not have any significant influence on nutrient levels in the soil (Table 2). Lakeland soils of the study site are categorized as excessively permeable with an average conductivity rate over 11.8 inches/h ($30 \text{ cm}\cdot\text{h}^{-1}$) (USDA-SCS, 1976). Deep plowing and sandy texture of the soil often limit accumulation of nutrients in the root zone. However, this was compensated by frequent applications of both water and nutrients as per the GSP, which suppressed the benefits from subsoiling. Similar observations were reported by Reeves and Touchton (1991) on sandy soils of Alabama, where water infiltration and N leaching from deep tillage treatments were found to offset any yield response from reducing compaction. However, presence of a subsurface hardpan was found to have relative advantages and disadvantages.

Table 2. Mean soil nutrient levels and collards yield as influenced by the year of production, the two tillage systems, and the three fertilizer treatments.

Parameter ^z	Year		Tillage system		Fertilizer treatment		
	1997	1998	Subsoiling	Conventional	GSP ^y	GSP + gypsum ^x	PRF ^w
	----- (lb/acre ^v) -----						
P	144.8 b ^u	160.0 a	168.5 a	173.1 a	177.6 a	157.2 a	177.6 a
K	138.3 a	30.4 b	104.0 a	91.3 a	117.5 a	72.8 b	102.7 a
Ca	860.4 a	590.8 b	823.2 a	803.4 a	852.3 a	810.5 a	777.1 a
Mg	123.1 a	85.5 a	118.0 a	115.8 a	139.3 a	90.1 b	121.2 a
Zn	10.6 a	8.3b	11.2 a	10.1 a	11.6 a	10.2 a	10.1 a
Cu	2.8 b	4.5 a	4.1a	4.1a	4.3a	3.8 a	4.2 a
Mn	83.2 a	52.1 b	11.5 a	10.6 a	11.1 a	10.1 a	12.0 a
Yield	23,907 b	31,249 a	29,089 a	26,067 b	27,220 a	27,195 a	28,319 a

^zP = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Zn = zinc; Cu = copper; and Mn = manganese.

^yGSP = growers standard practice applied through the fertilizer blend (22N-0P-18.3K).

^xGSP + gypsum = gypsum applied at 500 lb/acre (560.4 kg·ha⁻¹).

^wPRF = programmed release fertilizer applied through Meisterblend (20N-2.2P-12.4K).

^v1 lb/acre = 1.12 kg·ha⁻¹.

^uDifferent letters following means indicate significant differences ($P < 0.05$). Only means in the same row and within year, tillage system, or fertilizer treatment should be compared.

In this study, no significant differences were found in yield levels in either of the 2 years among the three fertilizer treatments (Table 2). Ristimäki and Papadopolous (2000) observed through their studies on three vegetable crops at three locations that the slow-release fertilizer gave an equal or even slightly higher yield of better quality than conventional fertilizers. Improved availability of nutrients throughout the season, reduced labor costs, and reduced losses to the environment make slow-release fertilizers potentially more favorable over multiple applications of soluble fertilizers (Allen, 1984). Our research showed that PRFs were a viable alternative with regard to nutrient availability and uptake efficiency, time and labor efficiency, and yields. A separate study on economical analyses

is needed, however, to understand the market viability of including PRFs in commercial production systems.

Nutrient content of collard leaf tissue was found to be similar both years between the two tillage treatments (Table 3). Differences in uptake patterns resulting from different depths of tillage were masked by frequent applications of fertilizer and irrigation. Similar observations were found in most *Brassica* species (Ekeberg and Riley, 1997). Because soil and tissue analyses only gave a one-time snapshot and not a trend, it was apparent that over the long term the plants were able to exploit and recover more nutrients from the subsoiled plots compared to conventionally tilled plots. This observation agreed with the fact that the yield was found to be significantly

higher in subsoiled compared to conventional shallow tillage.

Percent tissue N concentration was found to be significantly higher with the single PRF application at planting compared to the GSP + gypsum treatment (Table 3). The PRF blend was able to supply N to the plants at a consistent and continuous rate that resulted in greater N accumulation in the leaf tissue, indicating greater N use efficiency. Application of soluble N as in GSP treatments to sandy soil, combined with frequent irrigation, is subject to higher potential leaching below the root zone. Lettuce (*Lactuca sativa*) production through conventional fertilization on sandy soils in Arizona showed a high potential for N leaching and the use of controlled-release fertilizer was suggested as an

Table 3. Nutrient concentrations of collards leaf tissue as influenced by the year of production, the two tillage systems, and the three fertilizer treatments.

Nutrient ^z	Year		Tillage system		Fertilizer treatment		
	1997	1998	Subsoiling	Conventional	GSP ^y	GSP + gypsum ^x	PRF ^w
	----- (%) -----						
N	5.08 a ^v	4.87 a	5.05 a	4.91 a	4.89 ab	4.85 b	5.19 a
P	0.67 a	0.57 a	0.64 a	0.61 a	0.63 a	0.61 a	0.64 a
K	3.78 a	2.96 b	3.40 a	3.36 a	3.32 a	3.34 a	3.48 a
Ca	1.52 a	1.00 b	1.35 a	1.20 a	1.18 a	1.31 a	1.33 a
Mg	0.45 a	0.26 b	0.36 a	0.35 a	0.35 b	0.32 b	0.39 a
S	1.32 a	0.98 b	1.16 a	1.14 a	1.04 b	1.36 a	1.05 b
	----- [ppm (mg·kg ⁻¹)] -----						
Zn	82.48 a	62.64 b	69.88 a	78.21	65.50 b	91.19 a	65.44 b
Cu	3.42 a	3.96 a	3.46 a	3.92 a	3.69 a	3.88 a	3.50 a
Mn	96.21 a	59.58 b	74.71 a	81.08 a	61.56 b	86.25 a	85.88 a

^zN = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; Zn = zinc; Cu = copper; and Mn = manganese.

^yGSP = growers standard practice applied through the fertilizer blend (22N-0P-18.3K).

^xGSP + gypsum = gypsum applied at 500 lb/acre (560.4 kg·ha⁻¹).

^wPRF = programmed release fertilizer applied through Meisterblend (20N-2.2P-12.4K).

^vDifferent letters following the means indicate significant differences ($P < 0.05$). Only means in the same row and within year, tillage system, or fertilizer treatment should be compared. 1 lb/acre = 1.12 kg·ha⁻¹.

Table 4. Comparison of collard leaf tissue nutrient concentrations (ranges observed in the study) with previously published sufficiency ranges found from the literature.

Parameter	N	P	K	Ca	Mg	S	Cu	Mn	Zn
	----- (%) -----					----- [ppm (mg·kg ⁻¹)] -----			
Sufficiency ranges ^z	2.20–5.00	0.50–0.70	2.40–4.20	0.40–3.00	0.25–0.50	1.10–1.70	5–12	30–100	20–70
GSP ^y	4.14–5.65	0.56–0.75	2.53–4.30	0.64–2.03	0.22–0.52	0.67–1.31	3–7	32–103	41–110
GSP+ gypsum ^x	3.58–5.73	0.45–0.83	2.37–4.15	0.72–2.07	0.21–0.46	1.04–1.64	3–6	40–170	52–166
PRF ^w	3.86–5.81	0.47–0.78	2.59–4.66	0.72–2.23	0.24–0.63	0.59–1.45	3–5	41–150	39–94

^zThese values are sufficiency ranges tissue nutrient concentration of *Brassica* species as reported by Bergman, 1992.

^yGSP = growers standard practice applied through the fertilizer blend (22N–0P–18.3K).

^xGSP + gypsum = gypsum applied at 500 lb/acre (560.4 kg·ha⁻¹).

^wPRF = programmed release fertilizer applied through Meisterblend (20N–2.2P–12.4K), a 60-d release. 1 lb/acre = 1.12 kg·ha⁻¹;

alternative (Sanchez, 2000). Hioki et al. (1996) concluded that applying controlled-release fertilizers in open-field cultivation of vegetables such as cabbage (*Brassica oleracea* Capitata Group) could increase yield, reduce labor costs, and minimize nutrient losses to the environment. Nutrient absorption through PRF (Table 4) was within the sufficiency range as reported by Bergman (1992) and the nutrient release rates were probably sustained through the harvest stage.

Both P and Ca content in the soil were found to be similar for all the nutrient treatments (Table 2). Additional Ca applied to GSP + gypsum treatment did not enhance extractable soil Ca levels. However, both K and magnesium (Mg) were significantly lower in soil that received GSP + gypsum application compared to the PRF and GSP treatments as the gypsum-bound Ca on cation exchange reduced both K and Mg. Because the concentrations of K and Mg were not statistically different in GSP and PRF, it confirmed that Ca domination was a result of gypsum application. The low soil K levels were indicative of the leaching phenomenon that the sandy soils in the southeastern U.S. usually are subjected to (Grimme, 1990; Sharma, 1989). We believe that in this case, irrigation frequency resulted in K leaching below the root zone. This trend was only observed in soil levels of cations; however, tissue concentrations of K and Ca were not significantly different among the three nutrient treatments (Table 3). The levels of tissue Mg were found to be higher in the PRF treatment compared to the other two treatments.

The concentrations of micronutrients in the soil and in mature collard leaves are shown in Tables 2 and 3. Levels of Zn, manganese (Mn), and copper (Cu) in soil were similar for all the fertilizer treatments. While the

plots that received the PRF treatments had significantly higher Mn concentrations, the plots that received GSP + gypsum showed no differences in the Mn concentrations in the tissue when compared to the GSP fertilizer regime. Overall, tissue concentrations of micronutrients were of little benefit in determining the effects of different fertilizer regimes on plant growth. However, it is important to note that the PRF treatment resulted in either similar or higher levels of macro- and micronutrient levels both in soils and collard tissue (Tables 2 and 3).

Tipburn incidence was observed only in the second year. Incidence of tipburn can cause significant economic losses in several commercially produced crucifers, and its occurrence is not predictable (Saure, 1998). Tipburn occurrence may vary considerably between years, fields, and planting times (Cubeta et al., 2000). Generally, tipburn is a physiological disorder that causes necrosis of the outer margins of newly developing leaves due to Ca deficiency (Aloni, 1986). Although past studies have indicated several external and internal factors as reasons behind the tipburn disorder, the conclusions were often varied and contradictory. Along with weather-related stresses, tipburn was also found to be related to the growth rate of the plants. Factors such as highly fertile soils, high N or manure application rates, or low plant densities that simulate the rate of growth and with it the demand of Ca, may also stimulate internal tipburn in cabbage (Everaarts and Blom-Zandstra, 2001; Nieuwhof, 1960). Tipburn-affected leaves are often larger, and the growth vigor of the plants is high with higher leaf water content than non-tipburn leaves. In our study, the plants were found to be larger and the mean weight of a single plant during the second year [2.5 lb (1.13 kg)], when tipburn was

present, was significantly higher than the mean weight recorded during the first year [1.74 lb (0.789 kg)]. These results corroborate those found in previous studies (Everaarts and Blom-Zandstra, 2001; Palzkill et al., 1980). In the field, tipburn appeared on the lettuce leaves that expanded most rapidly, particularly before harvest (Brumm and Schenk, 1993), and the leaves were most susceptible during the cell expansion phase (Wissemeier, 1996). Brumm and Schenk (1993) reported that when the supply of N exceeded the demand, tipburn incidence was a possibility. Temperature and humidity are also considered primary influences on the occurrence of tipburn. Temperature patterns and cumulative rainfall during the crop growth periods were similar in both years (Fig. 1). Rainfall distribution during the second year was better at the beginning of the crop cycle, but most of the rain in the latter part was received through one event of 6.6 inches (16.76 cm). While a direct relationship between high temperature and tipburn incidence has not been established (Imai, 1987), a close relationship has been shown to exist between tipburn occurrence in lettuce and total evaporation during the week prior to harvest (Collier and Wurr, 1981).

Nutritional deficiencies have also been suggested as playing a role in tipburn incidence of crucifers. A regression analysis of tipburn ratings at harvest time in the second year as related to both soil and tissue nutrient levels resulted in the following model:

$$\begin{aligned} \text{Tipburn rating} = & 2.13 - 1.67S(t) \\ & + 0.0188Zn(t) \\ & + 0.00561P(s) \\ & - 0.111Zn(s) \end{aligned}$$

where (s) = soil concentrations and (t) = the tissue concentrations of corresponding nutrients, with the adjusted

$R^2 = 0.467$ ($P < 0.0001$). This suggests that a relationship existed between nutrients levels (S, Zn, and P) and tipburn incidence. The above relationship was checked for any collinearity between the variables. The above model explained 47% of the variation that can be attributed to soil and tissue nutrient concentrations. Peck et al. (1983) in their experiments on inbred cabbage lines and tipburn susceptibility found that Zn was the only element that had a consistently lower or higher concentration in both leaves and heads between tipburn-resistant and susceptible lines. They suggested that the concentration of Zn in plant parts might be used to guide the selection of tipburn-resistant lines. Variations between the observed and predicted ratings in our model suggested that there were other factors (soil, weather, non-nutritional stresses, etc.) that could influence tipburn. The model might be improved by identifying other factors that determine the susceptibility of the crops. Although Ca is believed to be playing the primary role in the incidence of tipburn, our analysis did not identify Ca as one of the nutrients influencing the incidence. Since Ca deficiency is highly localized and caused only in the newly emerging portions of the collards tissue due to lack of mobility from the older tissue, a routine tissue analysis involving the whole leaf may not show the deficiency. We suggest that more sophisticated tissue sampling and tissue separation techniques should be developed and adopted to capture the calcium concentrations in different regions of the leaves.

Conclusion

Subsoiling increased collard yields significantly over conventional tillage. Although increased yield was recorded, any possible benefits from subsoiling on soil nutrient levels could not be recorded from a one-time soil sampling at harvest. Considering PRFs as a source of N for successful collard production in sandy soils, the PRFs should be recommended as a viable alternative for sustained yields at lower fertilizer inputs. Further studies are required to document the economic benefits of using PRFs. While the tipburn incidence in collards is controlled by several factors and is unpredictable, the disorder is a result of nutritional disorders to a certain extent. The regression model developed in this study determined that

47% of the tipburn incidence depended on the soil and tissue nutritional status. It is important, therefore, to ensure an optimum supply of nutrients to the plants to maintain the quality of the crop. Identification of other factors will improve the predictability of tipburn incidence.

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