Lower-Leaf Removal and Nitrogen Application Programs for Flue-Cured Tobacco Production

Camden E. Finch, Matthew C. Vann,* Loren R. Fisher, Randy Wells, and A. Blake Brown

ABSTRACT

With a current global over-supply of flue-cured tobacco (Nicotiana tabacum L.), tobacco producers in North Carolina have been encouraged to remove the lowermost leaves prior to harvest due to their low value in manufactured products. The objective of this research was to compare lower-leaf removal programs. Research was conducted in 2016 and 2017 to quantify the agronomic effects of three lower-leaf removal programs (0, 4, and 8 leaves plant \(^{-1}\)) and the subsequent delivery of four N application rates (0, 5.6, 11.2, and 16.9 kg N ha\(^{-1}\) above base recommendation). All treatments combinations were applied during the early flowering stage of growth (8–10 wk after transplanting), when plants were approximately 120 cm tall. Programs absent of leaf removal generally produced the highest cured leaf yield. The addition of 16.9 kg N ha\(^{-1}\) increased yield when compared to lower N application rates within the 4-leaf removal program. Nitrogen application did not affect yield in the 8-leaf removal program. Cured leaf value was greatest in the 0-leaf removal program (USD $10,131 ha\(^{-1}\)) and was reduced in the 4- and 8-leaf programs by $1611 and $2645 ha\(^{-1}\), respectively. Lower-leaf removal programs reduced their presence by more than 50%. Ultimately, if these programs are to be encouraged or required by industry, the removal of four leaves per plant proved to be more practical when paired with additional N, due to moderate yield reduction and lower-stalk leaf production.

Core Ideas

- Lower-leaf removal will reduce cured leaf yield but can reduce the portion of lower-demand stalk positions
- Nitrogen application after leaf removal is of limited value and is currently discouraged
- If these programs are to find commercial success, a higher selling price should be offered by leaf purchasers

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Abbreviations: LCPRS, Lower Coastal Plain Research Station; OTRS, Oxford Tobacco Research Station; SPAD, soil plant analysis development.
tobacco, which has more desirable smoking characteristics, demands a higher price per kilogram, and is more actively sought by global manufacturers (Edwards, 2005).

Previous investigations provide mixed results regarding the agronomic impacts of leaf removal programs to cured leaf yield and value. For example, Suggs (1972), Currin and Pittner (1980), and Stocks (1988) reported that the removal of the lowest three or four leaves does not reduce yield but, rather, increases leaf price per kilogram, when compared to harvesting all leaves in studies conducted in the southeastern United States. In contrast, Court and Hendel (1989) measured a 10.7% yield and 11.2% value loss per hectare when the three lowest leaves were removed in the Canadian Province of Ontario. In recent evaluations, Edwards (2005) also reported yield (4–9%) and value (11–20%) reductions with the removal of four leaves per plant. Most importantly, Edwards (2005) did not reduce the presence of lower-stalk grades with this leaf removal program, which was the primary objective of their evaluations.

Despite observational differences with 3- or 4-leaf removal programs, conclusive evidence demonstrates significant yield and value reductions when leaf removal exceeds three or four leaves per plant (Suggs, 1972; Currin and Pittner, 1980; Stocks, 1988; Court and Hendel, 1989; Edwards, 2005). In a 6-leaf removal program, Stocks (1991) reported a yield loss of 800 kg ha\(^{-1}\), which translated to a $2780 ha\(^{-1}\) reduction in value. The removal of eight leaves per plant was evaluated by Edwards (2005), who documented yield and value reductions of 21–23% and 20–22%, respectively. This leaf removal program proved to be of marginal success in the attempt to reduce lower-stalk grades of tobacco (Edwards, 2005). In further evaluations in the US state of North Carolina, the removal of eight leaves per plant reduced cured leaf yield by 21–30% but has been shown to completely eliminate the non-desirable lower-stalk grades of tobacco (Fisher et al., 2016b). Further economic evaluation from Edwards (2005) indicated that the 8-leaf removal program increased cured leaf quality and price per kilogram; however, those increases were not great enough to offset the substantial income reduction associated with yield loss.

Experiments designed to investigate the effects of lower-leaf removal programs (0, 2, 4, and 6 leaves plant\(^{-1}\)) that were followed by N application (0, 5, 10, and 25 kg N ha\(^{-1}\) above base recommendation) have been conducted in the flue-cured tobacco growing country of Zimbabwe (Marowa et al., 2015). Nitrogen is the single most important nutrient for tobacco leaf development and is often in limited supply at later stages of the growing season (Collins and Hawks, 2013b); therefore, it was hypothesized by Marowa et al. (2015) that further exposure to N may induce upper-stalk leaf growth compensation for lower-stalk leaf removal. Marowa et al. (2015) reported that maximum yield was achieved following the removal of two leaves per plant and the subsequent application of 25 kg N ha\(^{-1}\). However, cured leaf quality was poor due to under-ripeness related to late-season N assimilation (Marowa et al., 2015). The removal of four leaves and the application 10 kg N ha\(^{-1}\) resulted in a 21% cured leaf value increase relative to treatments absent of leaf removal and N application due to improved leaf quality (Marowa et al., 2015). Ultimately, Marowa et al. (2015) suggested that commercial tobacco farmers in Zimbabwe should consider the removal of the four lowermost leaves and the subsequent application of 10 kg N ha\(^{-1}\) to improve cured leaf quality and value when high yielding cultivars are planted.

Given the variable success of historical leaf removal programs and new initiatives that may promote N application following leaf removal, modern investigations were warranted in North Carolina flue-cured tobacco production. The objectives of this study were to (i) quantify the effects of leaf removal and N application to cured leaf agronomic characteristics, (ii) determine the feasibility of leaf removal programs using a modern cultivar, and (iii) develop extension recommendations for North Carolina flue-cured tobacco producers.

**METHODS AND MATERIALS**

**Site and Experimental Design**

Field experiments were conducted at the Lower Coastal Plain Research Station (LCPRS) located in Kinston, NC, and the Oxford Tobacco Research Station (OTRS) located in Oxford, NC, during the 2016 and 2017 growing seasons. Tobacco was grown on a Norfolk loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults) in the LCPRS environments as well as a Vance sandy loam (fine, mixed, semiactive, thermic Typic Hapludults) and Appling sandy loam (fine, kaolinitic, thermic typic Kanhapludults) in the OTRS environments in 2016 and 2017, respectively. The soil pH ranged from 5.5 to 5.8. Treatments were replicated four times in each environment in a randomized complete block design with a 3 (main effect of leaf removal number) × 4 (main effect of N application rate) factorial arrangement. Individual plots consisted of four treated rows, each measuring 4.47 × 13.7 m at the LCPRS and 4.88 × 13.7 m at the OTRS. The center two rows of each plot were used for data collection and harvest. Plots were fertilized with base N application rates of 78 and 84 kg N ha\(^{-1}\) in the LCPRS and OTRS environments, respectively, and were based on recommendations of Vann and Inman (2016). The cultivar NC196 (Gold Leaf Seed Company, Hartsville, SC) was planted to a density of 14,820 plants ha\(^{-1}\) in all growing environments.

**Description of Lower-Leaf Removal Programs and Nitrogen Application**

Three leaf removal programs were evaluated: no leaves removed at flowering (0), four leaves removed at flowering (4), and eight leaves removed at flowering (8). Leaf removal numbers were selected based on previous research by Edwards (2005) and Fisher et al. (2016b), which demonstrated the need for the removal of eight leaves per plant to reduce non-desirable grades of lower-stalk tobacco. Each leaf removal program was paired with four different N application rates that were delivered immediately following leaf removal: 0, 5.6, 11.2, and 16.9 kg N ha\(^{-1}\) above base recommendation.

**Field Operations**

Tobacco at all sites was produced using standard practices recommended by the North Carolina Cooperative Extension Service (Fisher, 2016) from transplanting to flowering (when plant height measured approximately 120 cm). At the onset of flowering, the apical meristem (flower) was removed from all plants, with 20 leaves remaining to ensure uniformity among treatments. Immediately following flower removal, lower-stalk leaves were removed per treatment designation.
Leaves were counted from the bottom of each stalk upward, manually removed from each plant, and then discarded from the experimental area. Nitrogen was sourced from 28% liquid urea-ammonium-nitrate and was delivered immediately following leaf removal. Liquid urea-ammonium-nitrate was mixed accordingly with water for a total solution volume of 187 L ha⁻¹ and applied to the soil surface in a single band per plot row approximately 10 to 12 cm from the row ridge. Applications were delivered using a CO₂–pressurized backpack sprayer containing a single TG-5 full-cone nozzle at an operating pressure of approximately 100 kPa.

Data Collection

Tissue samples were collected three times during the growing season: before flower removal, 5 wk after flower removal, and after curing to evaluate N assimilation among treatments. Tissue samples collected before flower removal were from the fourth or fifth leaf below the apical meristem, while those collected 5 wk after flower removal were selected from the uppermost leaf on each stalk. Samples were collected from five randomly chosen plants within each plot and leaf dimensions for both sampling intervals measured approximately 10 width × 15 cm length. Five cured leaf samples were collected at random from the final harvest position of each plot. After sample collection, tissue was dried at 65°C for 72 h and ground to <80 mesh. Total N concentration was then quantified using the macro-Kjeldahl method described by Nelson and Sommers (1973) at the North Carolina State University Tobacco Analytical Services Laboratory.

Specific leaf weight was quantified at two different intervals, immediately prior to flower removal and 5 wk after flower removal using a 23.7-mm disc probe. Five discs were collected from tip leaves (upper most leaves on stalk) and five from cutter leaves (middle leaves on stalk) within each plot at the designated intervals. Samples were dried at 65°C for 48 h and immediately weighed. The average weight of each stalk position group was quantified and divided by the surface area of the disc probe (441 mm⁻²) to determine specific weight for each sample. Soil plant analysis development (SPAD) measurements were quantified in the same event as disc samples using a Konica Minolta SPAD-502 m (Konica Minolta Sensing Americas, Ramsey, NJ). The SPAD measurements were measured from the uppermost leaf on a plant, approximately 3/4 the distance toward the tail end of the leaf. Ten SPAD readings were collected within each plot and then averaged to provide a chlorophyll content estimate. In 2017, leaf length and width measurements were collected from 10 plants per plot 5 wk after flower removal. The uppermost leaf on each of the 10 plants was utilized for data collection.

Forty individual plants within each plot were harvested four different times in accordance with standard practices. During the first harvest, the four lowest leaves (lugs) were harvested. During the second interval, the next four leaves up the stalk (cutters) were harvested. During the third interval, the next 6–8 leaves (leaf) were harvested. The last interval harvested the remaining leaves on the stalk (tips). Depending on prior leaf removal treatment, some plots were not harvested during the first and/or second interval, as the leaves from those stalk positions had already been removed and discarded. Following each harvest, leaves were cured, weighed, and assigned a USDA quality grade. Each USDA quality grade has an associated numerical grade index value ranging from 1–100 that describes leaf maturity and ripeness (Bowman et al., 1988). Likewise, each grade has an associated monetary value (Fisher et al., 2016a) that was used to calculate per hectare value. Cured leaf price per hectare was quantified by determining the yield of each harvested stalk position and then multiplying the yield by the value associated with the cured leaf USDA quality grade assigned to each stalk position. Cured leaf price was derived by dividing per hectare value by cured leaf yield per hectare. Grade distribution was calculated by determining the percentage of lug (X), cutter (C), and leaf/tip (B) grade designations within each plot. Composite cured leaf samples (50 g) were also collected from each treatment for analysis of total alkaloid and reducing sugar concentrations using the methods outlined by Davis (1976).

Data Analysis

Data for leaf N concentration, specific leaf weight, SPAD measurements, leaf length and width, crop yield, quality, price, value, grade distribution, percent total alkaloids, and percent reducing sugars were subjected to an analysis of variance using the PROC MIXED procedure in SAS 9.4 (SAS Institute, Cary, NC). In the analysis, leaf removal number and N application rate were considered fixed factors, while environment and replication were considered random factors. Treatment means were reported using least square means and separated using Fisher’s Protected LSD test at P ≤ 0.10. Figures were created using Sigma Plot 13.0 (Systat Software, San Jose, CA).

RESULTS AND DISCUSSION

Leaf Nitrogen Concentration, Specific Weight, Chlorophyll Content, and Morphology

Significant differences for each variable were not observed prior to flower removal, thus indicating that leaf development prior to treatment application did not influence later observations. Five weeks after leaf removal and N application, cutter leaf specific weight and tip leaf chlorophyll content showed no response to treatments imposed. Tip leaf length and width were not significantly affected by leaf removal or N application when quantified in 2017; however, a trend was observed noting numerical increases in both variables as leaf removal number increased (Table 1). This trend was important as it may explain statistical differences that were documented with respect to the ratio of leaf length to leaf width, which was reduced as leaf removal number increased (Table 1). The reduced ratio indicated that as leaf removal was increased from zero to four leaves per plant and from four leaves to eight leaves per plant, tip leaves became wider and longer. The interaction of leaf removal number and N application rate was significant for specific tip leaf weight. A general trend was not apparent; however, specific leaf weight declined as N application rate increased within the 8-leaf removal programs (Fig. 1). Leaf N concentration demonstrated a positive response to N application rate 5 wk after treatment (Table 2), a trend that was not observed after curing.

Excess N application and increased leaf N concentration have been documented to increase leaf expansion while decreasing leaf thickness (Collins and Hawks, 2013b). While this response is desirable in the production of a large thin leaf, such as that which is required for cigar wrapper, it is undesirable for flue-cured
tobacco due to reduced yield and filling value in manufactured products (Flower, 1999). Five weeks after N application, tip leaf N concentration was increased by as much as 0.17 to 0.20% in the 11.2 and 16.9 kg N ha\(^{-1}\) treatments (Table 2). This documented increase may have proved sufficient for additional leaf expansion. Tip leaf specific weight was also lowest within these application rates (Fig. 1), which supports this hypothesis.

The effects of lower-leaf removal to leaf expansion are not well documented. Marowa et al. (2015) reported that leaf expansion was reduced as leaf removal number was increased from 0 to 6; however, the authors further noted that the expansion was primarily attributed to the time of flower removal which varied among treatments. Flower removal transitions the plant from reproductive growth to vegetative growth resulting in additional resource utilization for leaf development (Flower, 1999; Marowa et al., 2015; Peedin, 1999). As a result, the benefits of early flower removal to leaf expansion are much greater than those realized when this practice is delayed (Peedin, 1999). In this study, flower removal occurred on the same day for each treatment within a given environment, which likely explains the disagreement with Marowa et al. (2015).

**Tobacco Yield**

Tobacco yield was influenced by the interaction of the main effects of leaf removal number and N application rate. Cured leaf yield was greatest in the absence of leaf removal in treatments receiving 5.6 and 11.2 kg N ha\(^{-1}\), but was reduced when 16.9 kg N ha\(^{-1}\) was applied (Fig. 2). Excess N has been shown to increase leaf expansion, thereby reducing leaf thickness and subsequently reducing cured leaf yield (Parker, 2009; Collins and Hawks, 2013b). Yield was further reduced in the 4-leaf removal program; however, a positive response was observed to an additional 11.2 and 16.9 kg N ha\(^{-1}\) (Fig. 2). Despite the positive effects associated with the highest N application rates in the 4-leaf removal program, cured leaf yield was significantly less than what was documented in treatments absent of leaf removal (Fig. 2). Nitrogen did not improve cured leaf yield within the 8-leaf removal program (Fig. 2), thus indicating that additional N, when applied at rates similar to those utilized in this study, will not compensate for such extreme yield loss.

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**Table 1.** Tip leaf length, width, and length:width ratio 5 wk after treatment as influenced by the main effects of lower-leaf removal number and N application rate. Data are pooled across four growing environments.

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Length</th>
<th>Width</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf removal number</td>
<td>cm</td>
<td>cm</td>
<td></td>
</tr>
<tr>
<td>0 leaves plant(^{-1})</td>
<td>54.8 a†</td>
<td>23.6 a</td>
<td>2.30 a</td>
</tr>
<tr>
<td>4 leaves plant(^{-1})</td>
<td>54.7 a</td>
<td>24.0 a</td>
<td>2.28 b</td>
</tr>
<tr>
<td>8 leaves plant(^{-1})</td>
<td>56.0 a</td>
<td>24.7 a</td>
<td>2.27 c</td>
</tr>
<tr>
<td>N application rate</td>
<td>% N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha(^{-1})</td>
<td>55.3 a</td>
<td>24.4 a</td>
<td>2.28 a</td>
</tr>
<tr>
<td>5.6 kg N ha(^{-1})</td>
<td>55.3 a</td>
<td>23.9 a</td>
<td>2.29 a</td>
</tr>
<tr>
<td>11.2 kg N ha(^{-1})</td>
<td>54.8 a</td>
<td>23.9 a</td>
<td>2.30 a</td>
</tr>
<tr>
<td>16.8 kg N ha(^{-1})</td>
<td>55.1 a</td>
<td>24.3 a</td>
<td>2.25 a</td>
</tr>
</tbody>
</table>

† Treatment means followed by the same letter within the same column are not significantly different at the α = 0.10 level.

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**Table 2.** Leaf N concentration before treatment application, 5 wk after treatment application (SWAT), and after curing as influenced by the main effects of lower-leaf removal number and N application rate. Data are pooled across four growing environments.

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Before treatment</th>
<th>5 SWAT</th>
<th>After curing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf removal number</td>
<td>% N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 leaves plant(^{-1})</td>
<td>4.66 a†</td>
<td>1.95 a</td>
<td>2.46 a</td>
</tr>
<tr>
<td>4 leaves plant(^{-1})</td>
<td>4.63 a</td>
<td>2.03 a</td>
<td>2.40 a</td>
</tr>
<tr>
<td>8 leaves plant(^{-1})</td>
<td>4.67 a</td>
<td>2.07 a</td>
<td>2.44 a</td>
</tr>
<tr>
<td>N application rate</td>
<td>% N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg ha(^{-1})</td>
<td>4.61 a</td>
<td>1.91 b</td>
<td>2.39 a</td>
</tr>
<tr>
<td>5.6 kg ha(^{-1})</td>
<td>4.72 a</td>
<td>1.98 ab</td>
<td>2.41 a</td>
</tr>
<tr>
<td>11.2 kg ha(^{-1})</td>
<td>4.67 a</td>
<td>2.08 a</td>
<td>2.45 a</td>
</tr>
<tr>
<td>16.8 kg ha(^{-1})</td>
<td>4.62 a</td>
<td>2.11 a</td>
<td>2.49 a</td>
</tr>
</tbody>
</table>

† Treatment means followed by the same letter within the same column are not significantly different at the α = 0.10 level.

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**Cured Leaf Grade Distribution**

The percentage of cured leaf grades designated as lugs was significantly reduced by the main effect of leaf removal number. Treatments absent of leaf removal produced the highest percentage of lug grade tobacco (30%). As leaf removal number increased to four and eight leaves per plant, lug grades were reduced to 14 and 2%, respectively (Table 3). Leaf removal number also impacted the percentage of harvested leaves categorized as cutters. Similar to lug grade designations, cutter grade designations were reduced in the 8-leaf removal program when compared to the 0- and 4-leaf removal programs, which produced similar results (Table 3). Finally, the 4- and 8-leaf removal program increased the percentage of leaf and tip grades relative to treatments absent of leaf removal (Table 3). Ultimately, the 8-leaf removal program nearly eliminated lug grades, significantly reduced cutter grades, and almost doubled the percentage of leaf grades when compared to the 0 leaf program. However, despite the increase in the leaf and tip grade proportion, total cured leaf yield (Fig. 2) and value (Table 3) were greatly reduced. The 4-leaf removal program appears to serve as a more moderate approach to adjusting cured leaf grade distribution due to the less extreme reductions in yield and value. The main effect of N application rate did not influence cured leaf grade distribution (Table 3), further indicating that this management practice may have limited value in commercial production.

**Tobacco Quality**

Cured leaf quality was not affected by leaf removal programs or N application rate (Table 4). A similar observation was put forth by Edwards (2005) in a leaf removal study conducted in the Piedmont growing region of North Carolina. Alternatively, Edwards (2005) also documented a reduction in cured leaf quality in the North Carolina Coastal Plain in 4-leaf removal programs that were harvested twice. It is plausible that the reduced number of harvests reported by Edwards (2005) resulted in under-ripe leaf characteristics that are indicative of poor leaf quality. Lastly, Marowa et al. (2015) reported an increase in cured leaf quality when four or six leaves were removed 6 wk after transplanting, but report a reduction in leaf quality when 5 to 25 kg N ha\(^{-1}\) was subsequently applied. Given the discrepancies documented among the various growing environments reported in this study and by Marowa et al. (2015) and Edwards
it is possible that the effects of leaf removal programs to cured leaf quality will be highly dependent on climate, cultivar, and other management decisions including N application.

Cured Leaf Price

Cured leaf price was not influenced by the main effect of lower-leaf removal number. However, previous reports (Suggs, 1972; Currin and Pittner, 1980; Stocks, 1988; Court and Hendel, 1989; Stocks, 1991; Edwards, 2005) suggested that leaf price was improved as leaf removal number increased due to the exclusion of low-value stalk positions. While this observation was not documented in this study, price was improved by $0.17 kg$ \textsuperscript{-1} as N application rate increased from 0 to 16.9 kg ha$^{-1}$ (Table 4).

Crop Value

Crop value was affected by leaf removal number, with maximum value ($10,131$ ha$^{-1}$) obtained in treatments absent of leaf removal (Table 4). Crop value was significantly reduced in the 4- and 8-leaf removal programs ($8521$ and $7486$ ha$^{-1}$, respectively), which were similar to one another. The decline in cured leaf value is directly related to the documented reductions in cured leaf yield within each leaf removal program, as differences were not observed relative to cured leaf quality. Edwards (2005) reported similar crop value trends in 4- and 8-leaf removal programs; whereas, Marowa et al. (2015) did not document differences in leaf removal or N application programs. Marowa et al. (2015) has suggested that quality is increased by N application in Zimbabwe, thereby maintaining crop value. Cured leaf value was also improved when 16.9 kg N ha$^{-1}$ was applied after leaf removal (Table 4).

Total Alkaloids

Total alkaloid concentration was influenced by the main effects of leaf removal number and N application rate. The removal of eight leaves per plant (2.82%) increased the total alkaloid concentration when compared to the zero (2.65%) and four (2.61%) leaf removals (Table 4). Previous research provides conflicting information regarding the effect of lower-leaf removal to nicotine and total alkaloid concentration. For example, Suggs (1972) reported that nicotine concentration was increased when the nine lowest leaves were removed, but no differences when six or less were removed. Alternatively, Currin and Pittner (1980), Stocks (1988), Court and Hendel (1989), and Edwards (2005) did not observe the same trends following lower-leaf removal. In this study, total alkaloid concentration may have been greatest in the 8-leaf removal program because cured leaf samples were comprised of samples representing the middle and upper-stalk positions, due to the implementation of lower-leaf removal programs. It is well established that the middle and upper-stalk leaves contain the highest concentrations of total alkaloids (Collins and Hawks, 2013a; Fisher, 2016); therefore, leaf removal may have indirectly influenced total alkaloid concentration.

For the main effect of N application rate, total alkaloid concentration increased with N application rate (Table 4). Specifically, the highest N application rate, 16.9 kg N ha$^{-1}$, resulted in the highest total alkaloid concentration at 2.79%, while the lowest N rate, 0 kg N ha$^{-1}$, resulted in the lowest concentration (2.61%) (Table 4). Collins and Hawks (2013b) have suggested that N application and nicotine/alkaloid concentration are highly correlated; therefore, increased N application would be expected to increase total alkaloid concentration.
Reducing Sugars

Cured leaf reducing sugar concentration was influenced by the main effect of leaf removal number. Treatments absent of leaf removal resulted in the greatest reducing sugar concentration (Table 4). As leaf removal number increased to four and eight leaves per plant, reducing sugar concentration declined (Table 4). As with total alkaloid concentration, it is unlikely that leaf removal directly influenced reducing sugar concentration as cured leaf composite samples were comprised of the stalk positions harvested within each treatment. For example, the 8-leaf removal program was largely absent of lower-stalk leaves which have the highest reducing sugar concentration among all stalk positions. Stocks (1991) presented findings that confirmed the fact that lower-leaf removal may not impact the reducing sugar concentration of remaining leaves.

CONCLUSIONS

Results from this experiment demonstrate that significant yield reductions are likely to occur when lower-leaf removal programs are utilized in the production of flue-cured tobacco. Additional N that is supplied immediately following leaf removal may improve yield compensation when utilized in moderate leaf removal programs, specifically those removing no more than four leaves per plant. However, the strategy does not result in a crop yield that is comparable to that which would be expected when leaf removal is not implemented. When leaf removal programs include an extreme number of leaves (eight leaves per plant), additional N does not compensate for yield loss. Despite the success of increasing the proportion of

Table 3. Flue-cured tobacco grade distribution as influenced by the main effects of lower-leaf removal number and N application rate. Data are pooled across four growing environments.

<table>
<thead>
<tr>
<th>Leaf removal number</th>
<th>% X</th>
<th>% C</th>
<th>% B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 leaves plant⁻¹</td>
<td>30 a</td>
<td>26 a</td>
<td>44 c</td>
</tr>
<tr>
<td>4 leaves plant⁻¹</td>
<td>14 b</td>
<td>27 a</td>
<td>59 b</td>
</tr>
<tr>
<td>8 leaves plant⁻¹</td>
<td>2 c</td>
<td>12 b</td>
<td>86 a</td>
</tr>
</tbody>
</table>

Table 4. Flue-cured tobacco quality, price per kg, value per hectare, total alkaloid concentration, and reducing sugar concentration as influenced by the main effects of lower-leaf removal number and N application rate. Data are pooled across four growing environments.

<table>
<thead>
<tr>
<th>Total alkaloids</th>
<th>Reducing sugars</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Leaf removal number</td>
<td>$\text{US kg}^{-1}$</td>
</tr>
<tr>
<td>0 leaves plant⁻¹</td>
<td>75 a‡</td>
</tr>
<tr>
<td>4 leaves plant⁻¹</td>
<td>75 a</td>
</tr>
<tr>
<td>8 leaves plant⁻¹</td>
<td>75 a</td>
</tr>
</tbody>
</table>

† Cured leaf quality is assessed on a scale of 1–100, with 100 being of the highest quality.
‡ Treatment means followed by the same letter within the same column and main effect are not significantly different at the $\alpha = 0.10$ level.
the desirable leaf and tip (B) grades of tobacco, crop value was reduced by 16 to 26% in the 4- and 8-leaf removal programs, which may jeopardize the economic sustainability of commercial tobacco farming operations. In order for these programs to find success, producers will need an increased market price to sustain the farm level income that is currently associated with commercial tobacco production. Furthermore, additional management practices, such as drip-irrigation or alternative approaches to N application or N sources, might prove beneficial and warrant further investigation within these programs.

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