Poultry Feather Meal Application in Organic Flue-Cured Tobacco Production

Matthew Vann,* Nathan Bennett, Loren Fisher, S. C. Reberg-Horton, and Hannah Burrack

ABSTRACT

Information on N management in organic flue-cured tobacco production is limited. Research was conducted from 2012–2013 to determine the effects of two certified organic N sources applied at three rates on the yield, quality, and chemical constituents of flue-cured tobacco. These organic N sources included Nature Safe 13–0–0 (NS) and Nutrimax 12–1–0 (NM), both of which consisted of hydrolyzed poultry feather meal. Application rates for both fertilizer sources were 17 kg N ha$^{-1}$ above recommendation (B$+$), at recommendation (B), and 17 kg N ha$^{-1}$ below recommendation (B$-$). A conventional control containing urea-ammonium-nitrate (UAN) was applied at the B application rate. Tobacco yield and quality were similar among conventional and organic N programs. Leaf N concentration, SPAD measurements at flowering, and total alkaloid concentration of cured leaves responded positively to increased N application rates, regardless of organic fertilizer source. The largest increases in nitrogenous-based leaf constituents were observed in this study where B$+$ treatments were applied; however, those increases did not translate into increased leaf yield or quality and could delay the initiation of leaf senescence in growing seasons with low soil moisture. Results from this study demonstrate the acceptability of poultry feather meal sources for organic tobacco production, and confirm that application rates of organic N sources should follow conventional recommendations.

Core Ideas

- Poultry feather meal is acceptable in organic flue-cured tobacco production.
- Application rates of organic N should reflect those in conventional production.
- Soil moisture is critical for N mineralization and assimilation.

Increasing demand for organic cigarette products has created a niche marketing opportunity for flue-cured tobacco (Nicotiana tabacum L.) producers. North Carolina is the leading producer of organic tobacco in the United States, with more than 3.8 million kg produced on 1630 ha in 2015 (USDA-NASS, 2016a). The farm gate value of organic tobacco in North Carolina is estimated at more than US$29.2 million (USDA-NASS, 2016a). Relative to conventional tobacco production in the state, organic production is small, accounting for only 2.3% of the total crop hecctareage and 4.2% of the total crop value (USDA-NASS, 2016a, 2016b, 2016c); however, producers have found success due to the value-added nature of the product. Estimates from the U.S. Department of Agriculture (USDA) reported an average price of $4.11 and $7.67 kg$^{-1}$ for conventional and organic tobacco, respectively (USDA-NASS, 2016a, 2016c). Despite expanded production and grower interest, many questions about production practices remain, particularly regarding approved sources of organic N and appropriate application rates.

Nitrogen is the key nutrient in flue-cured tobacco fertility programs (Flower, 1999; Raper and McCants, 1966), and has a greater effect on yield and quality than any other nutrient (Vann and Smith, 2014). When N availability is limited, yield is reduced; conversely, when N availability is excessive, leaf quality is reduced (Peedin, 1999). The difference between deficient and excessive N can be as little as –/+ 17 kg N ha$^{-1}$ from base recommendations (Vann and Smith, 2014). Flue-cured tobacco that is N deficient is typically light in color, low in yield, high in sugar, and lacks the nicotine concentration desired by consumers (Flower, 1999; Peedin, 1999). Alternatively, excessive soil N, whether from inadequate moisture or overfertilization, will increase nicotine concentration and lower sugar concentration in the leaf (Peedin, 1999). Flue-cured tobacco produced in high-N systems is characterized by leaves that are dark brown to black in color, chaffy in texture, and pungent in smoke flavor (Flower, 1999). For this reason,
high quality flue-cured tobacco is typically grown on welldrained, sandy soils where nutrient availability is limited in the absence of supplemental nutrient application (Collins and Hawks, 2013). In addition, soil organic matter in these systems is typically <1%, as tobacco is slow to ripen and difficult to cure when humid matter is >0.8% (Peedin, 1999).

The ability to control both the quantity and duration of N availability during growth and ripening (senescence) has a greater effect on the chemical and physical characteristics of tobacco than any other management factor (Peedin, 1999). Fertility programs must be managed to provide adequate N for the first 70 to 80 d after transplanting (Flower, 1999). Nitrogen availability in the rhizosphere must be depleted soon after floral initiation to reduce the synthesis of nitrogenous compounds (primarily nicotine), which, promotes starch synthesis, creating a sugar/nicotine ratio favored by manufacturers and consumers (Flower, 1999; McCants and Woltz, 1967). To ensure that N is sufficient for high yield, and that it declines at a critical period to ensure acceptable quality, application rates ranging from 55 to 90 kg N ha$^{-1}$ have been determined as optimum for most flue-cured tobacco producing soils in North Carolina (Vann and Smith, 2014). Application rates are dependent on factors such as soil texture, depth to subsoil, rainfall, and previous crops (Peedin, 1999; Vann and Smith, 2014).

In addition to application rate, N form can be just as important to yield and quality. Readily available synthetic N sources containing various combinations of ammonium and nitrate-N are preferred over those containing large quantities of slow-release N in conventional production; however, these sources of N are restricted in organic production (Peedin, 1999; Vann and Smith, 2014; Williams and Miner, 1982).

Feather meal is a high-N-containing by-product of the poultry processing industry which contains approximately 15% N in the form of non-soluble keratin and is available in several certified organic forms (Hadas and Kautsky, 1994; Hartz and Johnstone, 2006). Incubation studies have reported 55 and 65% N recovery 2 and 8 wk following application, respectively (Hadas and Kautsky, 1994; Hartz and Johnstone, 2006). Over an 11 wk period, Choi and Nelson (1996) observed that N release was rapid following application, with most occurring during the first 5 wk and a negligible amount occurring during the last 6 wk. Nitrogen mineralization curves that exhibit rapid early season release followed by a rapid decline in availability are desired by organic tobacco producers.

Information from field studies designed to evaluate feather meal for fertility management are limited. Vann et al. (2017) and Spargo et al. (2016) report similar organic field corn ($Zea mays$ L.) yield when feather meal and pelleted poultry litter were applied at equivalent rates of total N. Similar results were observed by Wild et al. (2011) in organic rice ($Oryza sativa$ L.) production. Gaskell (1999) determined that early bell pepper ($Capsicum annuum$ L. var. $annuum$) yield and size were greatest in treatments receiving feather meal at 180 kg N ha$^{-1}$ when compared to treatments receiving the same application rate from compost, pelleted chicken manure, fish meal, liquid fish, liquid soybean meal, or seabird guano. The high feather meal application rates documented by Gaskell (1999) could be cost-prohibitive to low-value field crops; however, Hartz and Johnstone (2006) have proposed that feather meal sources are less costly than other high-N organic fertilizer sources, such as fish powder, blood meal, and seabird guano.

At present, the effects of feather meal on the yield, quality, and chemical constituents of flue-cured tobacco are not known and may serve as a critical component of N fertility management in organic tobacco production. The objectives of this study were to (i) compare two sources of organic N for usability for organic tobacco production, (ii) quantify the effects of organic N application rate on nitrogenous leaf constituents, and (iii) more accurately define recommendations for N fertility management in the production of organic flue-cured tobacco.

**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 2012 and 2013 growing seasons. Tobacco was produced on a Norfolk sandy loam soil (fine-loamy, kaolinitic, thermic Typic Kandiudult) at the LCPRS in both years of the study and a Helena sandy loam (fine, mixed, semiactive, thermic Aquic Hapludult) and Appling sandy loam (fine, kaolinitic, thermic Typic Kanhapludult) at the OTRS in 2012 and 2013, respectively. Soil pH at all four field sites ranged from 5.8 to 6.2 with <1% OM, per recommendations from the North Carolina Cooperative Extension Service (Vann and Smith, 2014). Tobacco at all sites was produced according to North Carolina Cooperative Extension Service recommendations (Fisher, 2014).

Treatments were replicated four times in each environment in a randomized complete block design with a 2 (main effect of organic N source) × 3 (main effect of N application rate) factorial treatment arrangement. The conventional UAN treatment was replicated and randomized within each environment. Individual plots contained four treated rows, each 4.47 m wide by 13.7 m long at the LCPRS and 4.47 m wide by 13.7 m long at the OTRS. The center two rows of each plot were used for data collection and harvest. The flue-cured tobacco cultivars NC 71 and NC 196 (Gold Leaf Seed Company, Hartsville, SC) were produced at the LCPRS in 2012 and 2013, respectively. The cultivar CC 27 (Cross Creek Seed Company, Raeford, NC) was produced in both OTRS environments. Planting density in all environments was 14,820 plants ha$^{-1}$.

**Description of Nitrogen Sources and Treatments**

Two Organic Materials Review Institute (OMRI)-approved N sources, NS and NM, were used. Materials were selected based on their high N content, low P content, and commercial availability to tobacco producers. Both materials were applied at three different rates: 17 kg N ha$^{-1}$ above recommendation (B+), at recommendation (B), and 17 kg N ha$^{-1}$ below recommendation (B–). Base application rates for the LCPRS and the OTRS were 73 and 79 kg N ha$^{-1}$, respectively, and were based on recommendations put forth by Vann and Smith (2014). An additional treatment of liquid 28% UAN was applied at the B application rate in each environment and served as a conventional comparison.
Field Operations

Research was designed to evaluate the effects of organic N sources and application rates; however, field sites were not organically certified and general management practices employed were not organically approved to prevent confounding variables. Examples of these practices are the use of herbicides for weed suppression and synthetic suckercides for axillary bud control (Fisher, 2014). Similar approaches to organic research have been used where questions of limited scope were asked and where determination of organic yields under completely organic management was not the goal (Mischler et al., 2010; Spargo et al., 2016).

Nitrogen percentage, as indicated by the manufacture of each fertilizer source, was used to calculate the total quantity of material applied within each treatment. Organic N sources (NS and NM) were broadcast applied and incorporated into the soil with a field cultivator prior bedding. Transplanting occurred immediately after bedding on the same day as N application in each environment. Dates for N application and transplanting are as follows: 19 Apr. 2012 and 15 Apr. 2013 at the LCPRS and 8 May 2012 and 16 May 2013 at the OTRS. Liquid UAN was split-applied in a sidedress application of one-half the base rate 10 d after transplanting and one-half the base rate at layby to reflect conventional practices. Applications of UAN were delivered with a CO₂–pressurized backpack sprayer containing a single TG-3 full-cone nozzle at an operating pressure range of 100 to 125 kPa. Sidedress placement of UAN was a single band, 10.2 cm away from the row-ridge at a 10.2-cm depth.

Data Collection

Leaf N concentration was quantified at three intervals during each growing season: at layby (4–6 wk after transplanting, when plant height was 40 cm), at flowering (8–10 wk after transplanting, when plant height was 120 cm), and after curing. At the layby and flowering intervals, green leaf samples were collected from the fourth leaf below the apical meristem. Leaf dimensions for each sample were approximately 10 cm in width and 15 cm in length. Cured leaf samples were comprised of a weighted sample representing the four harvested stalk positions. Leaf samples were dried at 65°C for 72 h and ground to <80-mesh. Total N concentration was quantified using the macro-Kjeldahl method described by Nelson and Sommers (1973) at the North Carolina State University Tobacco Analytical Services Lab. Leaf color and chlorophyll concentration at flowering were measured with a Konica Minolta SPAD-502 chlorophyll meter (Konica Minolta Sensing Americas, Inc, Ramsey, NJ) on the fourth leaf below the apical meristem. SPAD measurements were recorded on the same day as green leaf sampling at flowering and averaged across 10 plants within each plot. Plots were harvested four times in each growing environment and leaves were cured in a forced-air bulk curing barn. After curing, leaves were weighed to quantify yield and assigned a USDA government grade. Each government grade is associated with a numerical grade index value ranging from 1 to 100 that describes leaf maturity and ripeness (Bowman et al., 1988). Fifty-gram composite cured leaf samples were also collected from each treatment for analysis of total alkaloid and reducing sugar concentrations using the methods outlined by Lewis et al. (2012).

Data Analysis

Analysis of variance was conducted using the PROC MIXED procedure in SAS version 9.4 (SAS Institute, Cary, NC) to test the effects of organic N source and application rates on tobacco yield, quality, and chemical constituents. Dunnett’s t test was used to compare the conventional UAN treatment to each combination of organic N source and application rate in the first analysis (Table 1). In the second analysis, the conventional UAN treatment was removed for comparison of organic N sources and application rates only (Table 2). In both analyses, N source and application rate were considered to be fixed factors, while environment and replication were considered as random factors. Treatment means were reported using least square means. Means were separated using Fisher’s Protected LSD at \( P \leq 0.05 \). Results were pooled across all growing environments and the main effects of organic N source and application rate were reported in the absence of a significant interaction between the two factors. Figures were created using SigmaPlot version 12.5 (Systat Software, Inc., San Jose, CA).

<table>
<thead>
<tr>
<th>Treatment comparison</th>
<th>Leaf N concentration</th>
<th>SPAD</th>
<th>Yield</th>
<th>Quality</th>
<th>Leaf chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At layby</td>
<td>At flowering</td>
<td>After curing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS B– vs. UAN B</td>
<td></td>
<td>ns</td>
<td>0.0154</td>
<td>0.0269</td>
<td>ns</td>
</tr>
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<td>NS B vs. UAN B</td>
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<td>ns</td>
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<td>0.0114</td>
<td>ns</td>
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<tr>
<td>NS B+ vs. UAN B</td>
<td></td>
<td>ns</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>NM B– vs. UAN B</td>
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<td>ns</td>
<td>0.0047</td>
<td>0.0029</td>
<td>ns</td>
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<tr>
<td>NM B vs. UAN B</td>
<td></td>
<td>ns</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>

† Data are pooled across four growing environments.
‡ NM, Nutri Max (12–1–0); NS, Nature Safe (13–0–0); UAN, liquid 28% urea-ammonium-nitrate; B–, base nitrogen application rate -17 kg ha\(^{-1}\); B, base nitrogen application rate; B+, base nitrogen application rate +17 kg ha\(^{-1}\).
§ Base nitrogen application rates at the Lower Coastal Plain and Oxford Tobacco Research Stations were 73 and 79 kg N ha\(^{-1}\), respectively.
¶ Data are pooled across three growing environments.
# ns; not significant at the \( \alpha = 0.05 \) level.

Table 1. Analysis of variance of leaf N concentration at three sampling intervals, SPAD measurements at flowering, tobacco yield, tobacco quality, total alkaloid concentration, and reducing sugar concentration resulting from organic N treatment comparison to the conventional control treatment using Dunnett’s t test†.
Table 2. Analysis of variance of leaf nitrogen concentration at three sampling intervals, SPAD measurements at flowering, tobacco yield, tobacco quality, total alkaloid concentration, and reducing sugar concentration resulting from organic N fertilizer application†.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Leaf N concentration</th>
<th>SPAD</th>
<th>Yield</th>
<th>Quality</th>
<th>Alkaloids</th>
<th>Sugars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At layby</td>
<td>At flowering‡</td>
<td>After curing</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>p &gt; F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N Source (S)</td>
<td>ns§</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Application rate (R)</td>
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<td>ns</td>
<td>ns</td>
<td>0.0102</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>S × R</td>
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<td>ns</td>
<td>0.0445</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

† Data are pooled across four growing environments.
‡ Data are pooled across three growing environments.
§ ns; not significant at the α = 0.05 level.

Table 3. Tobacco leaf N concentration, SPAD measurements at flowering, yield, quality, and leaf chemistry response to organic N treatments compared to the conventional fertilizer treatment using Dunnett’s t test. Data are pooled across four growing environments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Leaf N concentration</th>
<th>SPAD</th>
<th>Yield</th>
<th>Quality†</th>
<th>Alkaloids</th>
<th>Sugars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Source† Rate‡§</td>
<td>At layby</td>
<td>At flowering#</td>
<td>After curing</td>
<td>kg ha⁻¹</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NS B–</td>
<td>4.12</td>
<td>2.68</td>
<td>1.59*</td>
<td>42.33*</td>
<td>2722</td>
</tr>
<tr>
<td></td>
<td>NS B</td>
<td>4.16</td>
<td>2.77</td>
<td>1.64</td>
<td>41.98*</td>
<td>2768</td>
</tr>
<tr>
<td></td>
<td>NS B+</td>
<td>4.46</td>
<td>2.74</td>
<td>1.73</td>
<td>43.83</td>
<td>2767</td>
</tr>
<tr>
<td></td>
<td>NM B–</td>
<td>4.16</td>
<td>2.58</td>
<td>1.65</td>
<td>41.69*</td>
<td>2619</td>
</tr>
<tr>
<td></td>
<td>NM B</td>
<td>4.24</td>
<td>2.60</td>
<td>1.63*</td>
<td>42.00*</td>
<td>2635</td>
</tr>
<tr>
<td></td>
<td>NM B+</td>
<td>4.30</td>
<td>2.74</td>
<td>1.60*</td>
<td>42.76</td>
<td>2756</td>
</tr>
<tr>
<td></td>
<td>UAN B</td>
<td>4.72</td>
<td>3.00</td>
<td>1.91</td>
<td>45.38</td>
<td>2816</td>
</tr>
</tbody>
</table>

* Significantly different from the UAN treatment at the 0.05 probability level.
† NS, Nature Safe (13–0–0); NM, Nutrimax (12–1–0); UAN, liquid 28% urea-ammonium-nitrate.
‡ B–, base nitrogen application rate -17 kg ha⁻¹; B, base nitrogen application rate; B+, base nitrogen application rate +17 kg ha⁻¹.
§ Base N application rates at the Lower Coastal Plain and Oxford Tobacco Research Stations were 73 and 79 kg N ha⁻¹, respectively.
¶ Quality is assigned on a scale of 1 to 100, with 100 having the highest quantitative rating.
# Data are pooled across three growing environments.

Fig. 1. Leaf N concentration at layby as affected by organic N application rate. Data are pooled across four growing environments and the main effect of organic N source. Means followed by the same letter are not significantly different at P ≤ 0.05 based on Fisher’s Protected LSD. Base application rates for all Lower Coastal Plain Research Station and Oxford Tobacco Research Station environments were 73 and 79 kg N ha⁻¹, respectively. Abbreviations: B–, base nitrogen application rate -17 kg ha⁻¹; B, base nitrogen application rate; B+, base nitrogen application rate +17 kg ha⁻¹.
Leaf Nitrogen Concentration

Layby. Leaf N concentration in organic treatments was similar to that of the conventional UAN treatment at the layby sampling interval (Table 3). At this interval, the conventional N treatment had received only 50% of the total N outlined in the protocol, while organic treatments had received 100%. It is likely that leaf N concentration in the conventional treatment would have been significantly increased above that of organic N treatments had the full N application rate been applied by this interval. Previous research has shown that N release from feather meal sources is 50 to 60% of the total N applied between 2 and 5 wk following application (Choi and Nelson, 1996; Hartz and Johnstone, 2006; Hadas and Kautsky, 1994). It is therefore plausible that >50% N mineralization from organic N sources was observed at layby in this study, and that plant growth response was comparable to a conventional N source applied at a one-half rate. In the absence of the conventional treatment, N concentration was greatest in treatments receiving the B+ application rate (Fig. 1). The main effect of organic N source was not significant. Results are similar to Drake et al. (2015a) which reported an increase in N concentration in leaf tissue sampled at layby in treatments receiving higher application rates of N prior to sampling.

At Flowering. All organic N source and application rate combinations were similar to the UAN treatment (Tables 1 and 3). In the absence of the UAN treatment, differences in organic N source and application rates were not observed (Table 2). Results likely indicate that N release from organic sources was complete when sampling occurred. Nitrogen mineralization from feather meal sources has been reported as minimal at sampling intervals greater than 6 wk following material application (Choi and Nelson, 1996); tissue samples were collected 8 to 10 wk after material application in this study.

After Curing. Nitrogen concentration in the NS B and B+, as well as the NM B– treatments, was similar to the UAN treatment. All other organic treatments were statistically lower (Table 3). Results indicate that N availability to plants was greatest in the conventional treatment for the duration of the season and further confirm the observations of Choi and Nelson (1996) regarding N mineralization from feather meal sources. Results are similar to those reported by Wild et al. (2011), who observed greater total N concentration in rice fertilized with a conventional N source (ammonium sulfate) when compared to counterpart treatments receiving poultry feather meal.

A significant interaction of organic N source × application rate was observed when the UAN treatment was removed from the data analysis. Similar to the data analysis that included UAN, treatments receiving NS at the B+ application rate contained the highest N concentration (Fig. 2). The other treatment combinations were not different from one another (Fig. 2). At previous sampling intervals, leaf N concentration in treatments comprised of NS or the B+ application rate were numerically higher than other treatments, although the differences were not always significant. It is possible that the increased N concentration of cured leaves from the NS B+ treatment was due to the nature of the composite sample collection, which included lower and mid-stalk leaf positions. Given that N concentration at layby was highest in B+ treatments, increases in lower and mid-stalk positions are possible and may have amplified the N concentration in composite samples.
SPAD Measurements at Flowering

SPAD measurements in NS and NM sources applied at B+ application rate were similar to the UAN treatment; however, B and B– treatment measurements in both sources were lower (Table 1). In the absence of the UAN treatment, SPAD measurements were affected by N application rate, with the B+ treatment having the highest recorded measurement (43.29 SPAD units). Base and B– treatments were not different from each other in this analysis. Nitrogen application rate and SPAD are sometimes correlated in tobacco production (Drake et al., 2015a, 2015b). Organic N source did not affect SPAD measurements. Despite observations indicating differences among N application rates, it is unlikely that results had a significant agronomic impact as the B+ application rate only increased SPAD measurements by 1.28 to 1.56 SPAD units relative to B– and B application rates, respectively. Furthermore, treatment differences for N application rate were not observed for leaf N concentration at flowering, which further indicates the unlikelihood of practical differences among treatments.

Tobacco Yield and Quality

Tobacco yield was not different when each organic treatment was compared to the conventional UAN treatment (Table 1), nor was it different when both organic sources were compared in the absence of UAN (Table 2). Organic N application rate did not affect yield, which is not surprising given that only 50 to 60% N release is likely to occur from poultry feathers within a single growing season (Choi and Nelson, 1996). Assuming that 50% of the total N was mineralized, this means that differences in plant available N were +/− 8.5 kg ha−1 from base applications, which is unlikely to have a significant effect on crop yield under most growing conditions. Furthermore, tobacco quality was not affected by organic N source or application rate, thus indicating that late-season N release and assimilation was not a factor influencing the observations in this study. Results indicate that organic N should be applied at rates similar to those used for conventional production. Application rates above recommendation could result in excessive N availability during the growing season, specifically when early to mid-season soil moisture is limiting and late-season precipitation occurs.

Total Alkaloids

When compared to the UAN treatment, total alkaloid concentration was lowest in NS and NM treatments applied at B– (Table 3). A similar trend was observed in the absence of UAN, as treatments containing B and B+ application rates produced the highest total alkaloid concentration in organic programs (Fig. 3). Tobacco alkaloids are nitrogenous chemical constituents whose concentration has been correlated to N fertility levels and leaf N concentration (Woltz et al., 1949; Bush, 1999). At layby, leaf N was statistically greatest in B+ treatments (Fig. 1); treatment differences were not observed at flowering, though B+ treatments were numerically greatest (data not shown). With N availability and assimilation occurring at the greatest rate in B+ treatments, total alkaloids in the same treatment should be the highest among all treatments.

Reducing Sugars

Reducing sugar concentration was lowest in the UAN and NS B+ treatments (Table 3). All other organic treatments resulted in reducing sugar concentration that was significantly greater than UAN. Reducing sugar and total alkaloid concentration are inversely related (Flower, 1999; McCants and Woltz, 1967); therefore, results indicate that N availability was

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Fig. 3. Cured leaf total alkaloid concentration after curing as affected by the interaction of organic N source and application rate. Data are pooled across four growing environments and the main effect of organic N source. Means followed by the same letter are not significantly different at $P \leq 0.05$ based on Fisher’s Protected LSD. Base application rates for all Lower Coastal Plain Research Station and Oxford Tobacco Research Station environments were 73 and 79 kg N ha−1, respectively. Abbreviations: B–, base nitrogen application rate −17 kg ha−1; B, base nitrogen application rate; B+, base nitrogen application rate +17 kg ha−1.
likely greatest over a longer period of time in the UAN and NS B+ treatments. Similar results were recorded in the absence of UAN, as the NS B+ treatment contained the lowest reducing sugar concentration (Fig. 4).

CONCLUSIONS

Results from this study indicate that NS and NM fertilizer sources are acceptable for the production of flue-cured tobacco in organic systems. Both sources appear to fit the need of high-N materials, with rapid early season N release, and sharp declines in availability as the season progresses. Late-season greening (from N assimilation) was not observed in treatments receiving either fertilizer source. The lacking evidence of late-season greening likely indicates that N release from both sources occurred in the early portion of each growing season.

Application rate of either organic N source should follow recommendations provided by the North Carolina Cooperative Extension Service, which are specific to individual growing environments. While evidence of delayed N mineralization and assimilation was not observed in treatments receiving either fertilizer source. The application rate of either organic N source should follow recommendations provided by the North Carolina Cooperative Extension Service, which are specific to individual growing environments.

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REFERENCES


