Updating Nitrogen Fertility Recommendations for Mid-Atlantic Vegetable Crops

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Commercial nitrogen (N) recommendations for Virginia-grown fresh market tomatoes (Solanum lycopersicum) and pumpkin (Cucurbita pep var. pepo) need revision to provide more accurate recommendations for current agricultural production systems. For tomato, two N application methods (banded and incorporated) × five N rates (0, 100, 200, 300, and 400 lb/acre N) were applied to polyethylene mulched fresh market tomatoes grown on a sandy loam soil during three growing seasons. For all treatments, 50% of total applied N was applied pre-plant and 50% via fertigation. Pre-plant N was 100% incorporated or 33% incorporated and 67% banded for the incorporated and banded treatments, respectively. Then, plots were fumigated and polyethylene mulch was laid. Nitrogen rates for maximum yield ranged from 164–195 lb/acre N for the incorporated method and 178–215 lb/acre N for the banded method. The banded method produced greater yields in 2 seasons, and unlike the incorporated method, did not experience crop loss in a hot, dry season. For pumpkin, we applied 20, 40, 80, and 120 lb/acre N in a split application between at-planting and sidedress when plants begin to run on a sandy loam and silt loam soil. All pumpkin plots were planted following high-residue rye cover crops. Optimal yield ranged from 0–120 lb/acre N across the three-year study. Overall, Virginia commercial N fertilizer recommendations for fresh market tomato should be updated to 178–215 lb/acre N using the banded method for optimum yields and to prevent crop loss in unseasonable years. Pumpkin N rates may also need to be increased and should be based on in-season tissue tests and yearly seasonal variations as necessary N rates ranged widely.

Accurate nutrient recommendations are necessary for specific soil types, climates, and crop varieties. Data needed for development of commercial fertilizer recommendations for fresh market tomatoes and pumpkin grown in Virginia are not available, as production systems have changed drastically in recent years. Fresh market tomato cropping systems now include polyethylene mulch, drip irrigation, fumigation, and hybrid varieties resulting in greater yields per acre compared to historic levels, which results in the need for greater inputs. Likewise, pumpkin production systems have evolved and now commonly include high-residue cereal cover crops prior to pumpkin planting.

Currently, the University of Florida, Institute of Food and Agriculture Sciences (UF/IFAS) recommends 20% to 25% N broadcast in the row with the remainder banded 2- to 3-inches deep in the bed shoulders. As water moves upward through the bed via capillary forces, the nutrient band slowly dissolves and becomes plant available (Geraldson and Whisenant, 1993; Ozores-Hampton et al., 2012). However, Florida has different soils, irrigation practices, and climates compared to the Mid-Atlantic. Hochmuth and Hanlon (2000) stated that research in Florida has shown equal yields were possible with less N via fertigation than banded N and seepage irrigation. Research data are not available for the behavior of banded N fertilizer with drip irrigation for fresh market tomato in the Mid-Atlantic region.

Ozores-Hampton et al. (2012) observed multiple N rates (20, 60, 120, 180, 240, 300, 360, and 400 lb/acre of N) applied to fresh market tomatoes grown using polyethylene mulch with subsurface irrigation on a fine sand near Palmetto, FL. The objectives were to determine a range of N rates that would provide optimum yields and postharvest quality, and maximum economic returns. Petiole sap NO3-N readings were taken throughout the growing season. During fruit development (11 weeks after transplant), petiole sap NO3-N concentrations fell below sufficiency levels.
at fertilizer rates below 180 lb/acre N and 360 lb/acre N for the two independent years of the study, and had positive correlation with marketable yield. The two-year study had maximum yields after two harvests (97% of yield) fertilized with 153 and 265 lb/acre of N for 2007 and 2008, respectively. Postharvest fruit quality was not impacted by N fertilizer rate. In Ozores-Hampton et al. (2012), N rates that produced maximum yields were nearly identical to the N rates that maximized grower profits.

Virginia fresh market tomato fertilizer recommendations have not progressed with advancements in production, and have varied during the past. From 2004–07, Virginia Cooperative Extension recommended application of 40 lb/acre N pre-plant, and three to four applications of 40 lb/acre of N via fertigation, totaling 160–200 lb/acre of N over the growing season (Bratsch et al., 2004; Bratsch et al., 2005; Kuhar et al., 2006; Kuhar et al., 2007). In 2008, 2009, and 2010, recommendations were to apply 40–45 lb/acre of N pre-plant, and to sidedress 40–45 lb/acre of N, totaling 80–90 lb/acre of N over the growing season for sandy loam and loamy sand soils (Kuhar et al., 2008; Kuhar et al., 2009, 2010). Research using current production practices for Virginia must be conducted to provide accurate recommendations to optimize productivity, yields, and fertilizer use efficiency, while limiting N losses. The objective of this study was to evaluate the effects of N rate and application method on yield of polyethylene mulched, fumigated, drip irrigated tomatoes grown in the Mid-Atlantic, as well as tomato N uptake, and N remaining in the soil to maximize yields and minimize N losses to the environment.

Pumpkin growers have numerous management tactics to consider when growing fruit for fresh market systems. Particularly, nitrogen fertilizer is difficult to manage in all vegetable production systems as numerous pathways are readily available to “lose” nitrogen; which decreases a farmer’s overall fertilizer use efficiency. Reduced fertilizer use efficiency is problematic in systems that are in conversion from conventional tillage to no-tillage and if farmers begin to utilize high-residue cover crops. No-till and high residue cover crops (such as cereal rye) are excellent farming practices for overall reduction of sediments and nutrients from agricultural fields; however, by adding more carbon and organic matter to the soil the farmer changes the overall carbon:nitrogen ratio of the soil system. Increasing carbon and organic matter significantly increases overall soil health and tilth but more nitrogen is needed to bring the soil’s carbon:nitrogen ratio back to equilibrium (10 parts carbon to 1 part nitrogen). The project investigator demonstrated this phenomenon with row crops and found that 60% more N was actually needed when high-residue cover crops were incorporated into the farming system (Reiter et al., 2008a). The project investigator also used a nitrogen tracer (N$$^{15}$$) to track amounts of N fertilizer added to rye cover crops that would be available to the following cash crop. Reiter and coworkers (2008b) determined that cover crops could be fertilized with nitrogen fertilizer to increase biomass to build organic matter and that fertilizer would supply up to 30% of the nitrogen needs for the following cash crop through natural nitrogen cycling for up to 3 years. Current Virginia Cooperative Extension recommendations were based on conventional crop production systems and offer no guidance for farmers utilizing no-tillage or cover crops; which is the predominant system used by pumpkin growers. Text in the Commercial Vegetable Production Recommendations—Virginia currently states a need of 50–100 lb/acre of N with nitrogen “broadcast and disk-in” (Wilson et. al., 2012) for conventional pumpkins, with no recommendation for no-till pumpkins or systems using cover crops.

Materials and Methods

Tomatoes

This study was established in the spring seasons of 2009, 2010, and 2011 (three site years) on a Bojac sandy loam soil (coarse-loamy, mixed, semiactive, thermic Typic Hapludults) [U.S. Department of Agriculture (USDA), 2002] at the Virginia Tech Eastern Shore Agricultural Research and Extension Center in Painter, Virginia (lat. 37.59°N, long. 75.77°W). Bojac sandy loam has approximately 59% sand, 30% silt, and 11% clay in the Ap horizon (0–18 inches). The soil was conventionally tilled, and 8-inch raised beds (3-ft wide) were constructed on 6-ft centers. In a single pass, beds were fumigated with methyl bromide and chloropirgin (67:33, w:w) at the rate of 300 lb/acre, and 1.25–mil-thick polyethylene mulch was applied over the bed. Drip tubing (Aqua-Traxx; Toro, Riverside, CA) with emitters spaced 12 inches apart and a delivery rate of 5.6 L/100 m per min at 0.55 bar was placed 3–4 inches from the bed center. Four- to 5-week-old tomato seedlings (‘BHN 602’; BHN Seed, Immokalee, FL) were transplanted on 18-inch in-row spacings, resulting in a plant population density of approximately 4800 plants acre. Tomato seedlings were transplanted in single row, 40-ft single row plots, on 20 May 2009, 21 May 2010, and 27 May 2011. Production practices, besides N management, were conducted according to Kuhar et al. (2009).

This study was a 4 N rate x 2 N application method factorial arrangement plus a 0-N control, for 9 total treatments. The control treatment received no N fertilizer for the duration of the study. All other treatments had 50% of the total N rate applied pre-plant via granular ammonium nitrate (AN) (34N–0P–0K), under the polyethylene mulch, and 50% applied through fertigation via liquid urea-AN (32N–0P–0K) throughout the growing season. Pre-plant N was applied using two methods: a banded method and an incorporated method. The banded and incorporated methods received 33% pre-plant N (16.7 % total N) and 100% pre-plant N (50% total N) as AN incorporated into the bed using a rototiller. The remaining 67% pre-plant N (33.3 % total N), for the banded method, was applied as AN in a band on the top of the bed, halfway between the drip tape and the edge of the bed. Both application methods consisted of four total N rate applications of 100, 200, 300, and 400 lb/acre N. Therefore, 50, 100, 150, and 200 lb/acre of N were applied pre-plant under the polyethylene mulch, and 50, 100, 150, and 200 lb/acre N applied via fertigation, respectively. Fertilized N was applied bi-weekly and increased as the growing season progressed to match plant N uptake (Wilson et al., 2012). Yield was calculated by harvesting mature green fruit two to three times, depending on the season and fruit production, which is the standard agronomic practice. Fruits were separated by size according to USDA standards (USDA, 1991) and weighed. Medium, large, and extra-large fruit weights were combined to determine total marketable yield. The overall experimental design was a factorial arrangement of 4 N rates x 2 N application methods and a 0–N control in a randomized complete block design that had treatments replicated four times, giving a total plot combination of 36 plots. Statistical analysis was conducted in JMP (version 9; SAS Institute, Cary, NC). Analysis was conducted to determine if year was significant. If year was significant, data were analyzed by year. If year was not significant, data were combined and analyzed over years using an analysis of variance. Means were separated using Student’s t least significant difference test (LSD$$_{0.05}$$) at α = 0.10. For continuous variables, such as N rate,
regression analyses were conducted on data to find peak N rates for production ($\alpha = 0.10$).

**Pumpkins**

In Fall 2012 and Fall 2013, we planted cereal rye cover crop at two locations. The locations included the Eastern Shore Agricultural Research and Extension Center in Painter, VA, (Bojac sandy loam; 59% sand in the upper horizon) and Brann Farms in Riner, VA, (Groseclose and Ploplimento silt loam; 43% sand). Both of these areas and production systems are representative of the two main pumpkin producing regions of Virginia, which included continuous no-tillage pumpkin production in rotation with a corn cash crop. We collected background soil samples for nitrogen and other nutrients at 0–6 inches and 6–20 inches to monitor nutrient status within the soil profile before planting. In all cases, insignificant amounts of soil nitrate were available (< 5 ppm NO$_3$-N) and soil N would provide little confounding nitrogen to the experiment. At heading, prior to cover crop desiccation, we harvested 1/4 m$^2$ areas to determine cover crop biomass production; which averaged 2394 lb biomass/acre. Aboveground biomass was also sampled for N determination within the plant tissue. Cover crop biomass consisted of 1.49% N, 44.65% carbon (C), a resulting C:N ratio of 30:1 and 0.16% sulfur. At heading in late April, the rye cover crop was killed using an herbicide. Pumpkins were planted, irrigation installed, and pumpkins were fertilized with potassium, phosphorus, and other nutrients as recommended by the soil tests. At planting nitrogen treatments were then applied using urea treated with an herbicide. Pumpkins were planted, irrigation installed, and pumpkins were fertilized with potassium, phosphorus, and other nutrients as recommended by the soil tests. At-planting nitrogen treatments were then applied using urea treated with a urease inhibitor at 0, 20, 40, 80, and 120 lb/acre N. When plants began to run, sidreland nitrogen applications were made. In 2013 and 2014; pumpkins were harvested in September at Brann Farms and October at the Eastern Shore Agricultural Research and Extension Center.

**Results and Discussion**

**Tomatoes**

Regression analyses were conducted for each application method in 2009, 2010, and 2011 to determine a predictive model for N rate providing optimum yields. In all years and application methods, except banded 2010, total marketable yield followed a quadratic function (Table 1). In 2009, the banded method produced the greatest yield (65,285 lb/acre) at 215 lb/acre of N, with an agronomic efficiency (peak lb marketable fruit per acre / peak lb/acre of N) of 303. In 2009, the incorporated method produced the highest yield (63,005 lb/acre) at 164 lb/acre of N with an agronomic efficiency of 385. The yield responses for the two methods were significantly different ($P = 0.09$). A N application rate of 215 lb/acre of N via the banded method had greater yield than the incorporated method.

In 2010 (Table 1), using the incorporated method resulted in the greatest yield (16,890 lb/acre) obtained at 36 lb/acre of N with an agronomic efficiency of 474. The banded method did not produce a significant yield response ($P = 0.37$). The incorporated method resulted in 79%, 45%, 31%, and 11% plant survival [(alive plants/total plants transplanted) x 100] at N rates of 100, 200, 300, and 400 lb/acre of N, respectively, in 2010. Plant injury resulted in small, stunted, and/or brown colored stems and leaves on plants. 2010 was unseasonably warm, accompanied by a severe drought in the beginning of the growing season. Soil temperatures under the black polyethylene mulch reached 60 °C, which likely inhibited root growth and plant development (Maynard and Hochmuth, 2007). We hypothesize the high temperatures and high N rates via the incorporated method caused injury to the plants, reducing yields, and resulted in increased inorganic soil N concentrations at 300 and 400 lb/acre of N incorporated.

The incorporated method resulted in severe plant injury in an unseasonably warm and dry season, suggesting that even though there was not a significant yield response, the banded method would be a superior application method in warm and dry years by reducing fertilizer injury (Geraldson and Whisenant, 1993).

In 2011 (Table 1), peak yield was observed at 178 and 195 lb/acre of N for the banded and incorporated method, respectively. The banded method produced the highest yield (50,022 lb/acre) at 178 lb/acre of N with an agronomic efficiency of 281. The incorporated method produced the highest yields (50,248 lb/acre) at 195 lb/acre of N with an agronomic efficiency of 258. Yield response curves for the banded and incorporated methods were statistically different ($P = 0.01$).

Commercial recommendations in Virginia have traditionally recommended incorporating pre-plant fertilizer in the bed area

### Table 1. Marketable yield (lb/acre) for fresh market tomato plants grown using polyethylene mulch on a Bojac sandy loam soil during 2009, 2010, and 2011.

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<th>Yield Response$^b$</th>
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<tr>
<td></td>
<td>-0.4268N$^2$ + 206.76N + 48313</td>
<td>ns$^a$</td>
<td>-0.1642N$^2$ - 13.249N + 19770</td>
<td>-0.5994N$^2$ + 239.92N + 32197</td>
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<td>0.38</td>
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<tr>
<td>$P$ value$^a$</td>
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$^a$1 kg·ha$^{-1}$ = 0.892 lb/acre.  
$^b$P value for regression equation.  
$^a$Nonsignificant.  
$^b$Highest order model (linear or quadratic) that was significant presented in kg·ha$^{-1}$.  
$^a$P value for Banded vs. Incorporated yield response comparison.
The banded method has traditionally been used in Florida in seepage irrigation systems (Olson et al., 2012); as the water table rises, the wetting front dissolves the fertilizer band in the bed, making fertilizer plant available. Commercial growers have adopted this banded method in Virginia in conjunction with drip irrigation by placing the fertilizer band on the top of the bed to dissolve with the wetting front from the drip emitters. Updating Virginia recommendations to accommodate for local commercial production practices, and to determine optimum rates that maximize yield and minimize losses to the environment, is environmentally and economically important.

We observed that the banded method produced higher marketable yields than the incorporated method at a N rate of 215 lb/acre of N in 2009. Additionally, the banded method did not experience crop loss in an unseasonable hot and dry season compared to the same N rates using the incorporated method in 2010. In 2011, yield responses resulted in an additional 225 lb/acre with 17 lb/acre less N applied using the incorporated method. Although the regression equations for banded and incorporated methods were significantly different in 2011, a difference in maximum yield of 225 lb/acre is negligible (< 0.5%). A study by Karlen et al. (1985) observed that applications of 115 and 195 lb/acre of N significantly increased yields compared to 60 lb/acre of N, which has similar rates to our study; however, unlike our study, the authors did not observe differences in marketable yield comparing incorporation and banding methods. We believe the use of the banded method displays the most potential for protecting against crop loss in unseasonably hot and dry periods while also providing optimum yields.

Pumpkins

Additions of rye cover crop biomass and high-yielding production systems do warrant investigation into N fertility regimes for pumpkin. Overall, we had a year effect with results differing between 2012 and 2013 (higher yielding years) vs. 2014 (lower yields). For pumpkin yield, overall highest yields were achieved with sidedress N applications of 60–120 lb/acre of N, depending on location (Fig. 1 and 2; Table 2). These highest yielding rates are significantly higher than the currently recommended 25–50 lb/acre of N that Extension recommends at sidedress when pumpkin vines begin to run. For producers wishing to maximize number of pumpkins per acre vs. overall yield (pounds produced per acre), 31–120 lb/acre of N is needed for highest number of marketable fruit produced (Table 1). For producers wishing to produce larger pumpkins with less focus on overall yield or pumpkin numbers per acre, 0–120 lb/acre of N is needed at sidedress (Table 2).

Using the current maximum sidedress nitrogen rate of 50 lb/acre of N, farmers at the 5-site years would have averaged 44,174 lb/acre of pumpkin. This value would be $4,859 per acre on a wholesale weight basis ($0.11/lb; USDA-Economic Research Service, 2014). The same farmers would have produced 52,609 lb/acre by applying the exact nitrogen rate necessary for highest yields; which is valued at $5,787 on a wholesale weight basis. Although difficult to predict the exact needed nitrogen rate, the potential for farmers to increase overall value by $928/acre could be realized with appropriate nitrogen monitoring procedures (a 19% value increase) that is equivalent to $2.78 million statewide on 3,000 acres. On a per pumpkin basis, optimal nitrogen rates would have produced 3764 pumpkins per acre over the 5 project site-year study; valued at $16,975 on a retail road stand basis ($4.51 per pumpkin; USDA-ERS). At the maximum current extension recommendation of 50 lb/acre of N at sidedress; 3522 pumpkins per acre would have been produced ($15,884/acre retail). Similar to wholesale yield, retail producers would possibly increase their value by $1,090/acre = $3.27 million on a statewide basis by knowing the exact nitrogen rate to apply at sidedress.

### Conclusion

Overall, Virginia Cooperative Extension recommendations should be updated for fresh market polyethylene mulched tomato production systems to a total N recommendation of 178–215 lb/acre by applying the exact nitrogen rate necessary for highest yields; which is valued at $5,787 on a wholesale weight basis.

| Table 2. Peak nitrogen rate response for pumpkin yield, pumpkin number, and pumpkin size for side-dress applications for silt loam (Brann Farms) and sandy loam (Eastern Shore) production systems utilizing no-till with cover crops. |
|-------------------------------------------------|-------------------|-------------------|-------------------|
| Pumpkin yield                                  | Pumpkin number    | Pumpkin size      |
|-------------------------------------------------|-------------------|-------------------|-------------------|
| Brann Farms                                    | 120 | 71 | 60 | 120 | 61 | 31 | 0 | 97 | 134 |
| Eastern Shore                                  | -- | 108 | 120 | -- | 74 | 85 | -- | 114 | 120 |
| Range                                          | 60–120 |                | 31–120 |                | 0–120 |
acre of N via 89–109 lb/acre of N using the banded application method (33% incorporated N + 67% banded N) and fertigation of an additional 89–108 lb/acre; which provides highest yields and reduces potential for plant injury. These N rates using the banded method will provide acceptable fertilizer recovery and reduce residual inorganic soil N, compared to higher N rates and the incorporated method. Likewise, pumpkin growers need to reevaluate their N fertilizer programs if they are using high-residue cover crops in their systems. Initially, growers made need to double their sidedress N applications for optimal pumpkin yield and size.

**Literature Cited**


