Evaluating Tissue Tests to Improve Nitrogen Management in Furrow-Irrigated Mid-South Corn Production

Chester E. Greub,* Trenton L. Roberts, Nathan A. Slaton, Jason P. Kelley, and Edward E. Gbur

ABSTRACT

The corn stalk nitrate test (CSNT) and ear-leaf N concentration (ELNC) are used to determine the adequacy of corn (Zea mays L.) N management programs and is used most extensively in the Midwest and northeastern United States. Information on the utility of both the CSNT and ELNC for irrigated corn produced in the mid-South is lacking. Twenty-four N rate trials were conducted in Arkansas between 2013 and 2016 to evaluate the utility of the ELNC and CSNT in a furrow-irrigated corn production system. An ELNC of 30 g kg\(^{-1}\) has been determined to differentiate between N-adequate and N-deficient corn plants at the R1 growth stage. The optimal CSNT concentration ranged from 170 to 1000 mg nitrate N kg\(^{-1}\) at maturity, indicating that adequate N was available to the corn crop to produce near-maximum grain yield. The N rate needed to achieve 95% relative grain yield (RGY) was consistently identified near the N rate where nitrate N began to accumulate in the corn stalk. A CSNT value of <170 mg nitrate N kg\(^{-1}\) was found to represent the low category, suggesting that N was limiting corn grain yield, whereas N availability was found to exceed the amount needed to maximize grain yield when CSNT values were >1000 mg nitrate N kg\(^{-1}\). The ELNC and CSNT can be used to adequately determine the N status of corn produced within a furrow-irrigated mid-South corn production system.

Core Ideas

- An ear-leaf N of 30 g kg\(^{-1}\) differentiated between N-adequate and N-deficient corn plants at the R1 growth stage.
- The optimal corn stalk nitrate concentration ranged from 170 to 1000 mg nitrate N kg\(^{-1}\) at maturity.
- Nitrogen availability was excessive when stalk nitrate concentration values were >1000 mg nitrate N kg\(^{-1}\).
- The N rate needed for 95% relative grain yield was consistently near the N rate where nitrate accumulated in the stalk.

NITROGEN IS a crucial component of corn production and is typically added to improve grain yield; however, N not assimilated by the crop can have adverse effects on the environment. Corn producers inadvertently apply N in excess of crop requirements as a result of generalized N fertilizer recommendations to ensure adequate N for maximum grain yield (Schroder et al., 2000). Improved N management techniques are needed to reduce environmental degradation from agricultural production systems. As a result of the potential for decreased producer profits and groundwater contamination of nitrate N from erroneous N fertilizer application rates to corn, research has focused on methods to improve the identification of improper N management.

Nitrate N has been found to accumulate in the lower portion of the corn stalk and its accumulation can be influenced by N fertilization and water availability (Hanway and Englehorn, 1958; Friedrich et al., 1979). This physiological response of nitrate N accumulation in corn has been further evaluated to develop a diagnostic tool to determine the N status of the crop. The CSNT is a post-season N management tool, developed in the Corn Belt (Binford et al., 1990, 1992; Blackmer and Mallarino, 1996), to evaluate the adequacy of a corn producer’s N fertilization program. The CSNT measures the nitrate N concentration at the base of the corn stalk at maturity. When excess N is taken up by the plant and not utilized in the developing grain, nitrate N will accumulate and remain in the corn stalk at maturity (Binford et al., 1990). The stalk nitrate N concentration at maturity remains low until enough N is available to the plant to achieve maximum grain yield. Once maximum grain yield is achieved, end-of-season corn stalk nitrate N increases as N availability increases. The results of the CSNT indicate adequacy of N uptake in relation to the N needs of the plant, lacking the ability to differentiate if N rate or N loss is preventing the accumulation of nitrate N in the corn stalk. The CSNT is used to determine the N status of a producer’s current corn crop to provide insight on potential adjustments to N fertilizer rates for the subsequent corn crops for a specific field. The CSNT uses corn stalk samples collected from the corn stalk segment 15 to 35 cm above the soil surface and measures the nitrate N concentration at maturity. The evolutionary aspect of this test is its ability to identify when excess N...
is available to corn, whereas the majority of tissue tests can only differentiate deficient from adequate N within the plant. The CSNT levels outlined by Blackmer and Mallarino (1996) define N availability as low (at 0 to 249 mg nitrate N kg⁻¹), marginal (250 to 699 mg nitrate N kg⁻¹), optimal (700 to 1999 mg nitrate N kg⁻¹), and excessive (>2000 mg nitrate N kg⁻¹). Fields that are classified in the low category have a high probability that N was limiting corn grain yield. Within the marginal and optimal category, adequate N was likely available to maximize grain yield. In the excessive category, N supply likely exceeded the amount needed to produce maximum grain yield. The initial research in Iowa (45 site-years) designated corn stalk nitrate N concentrations of 700 to 2000 mg nitrate N kg⁻¹ as optimal (Binford et al., 1992). Research has been conducted to identify the adequacy of the concentration limits for each category within different production regions and environments. Brouder et al. (2000) showed that a nitrate N concentration of 1670 mg kg⁻¹ was adequate for separating sufficient vs. excessive N availability to corn produced in Indiana. Furthermore, the authors determined that the agronomic efficiency (yield increase per unit of N fertilizer added) reached 0% at CSNT concentrations of 2970 mg nitrate N kg⁻¹, recovering no grain yield return on applied fertilizer N.

Varvel et al. (1997) concluded that for a 3-yr study on irrigated corn in Nebraska, a CSNT concentration of 2000 mg nitrate N kg⁻¹ corresponded to the fertilizer-N rate that achieved maximum grain yield for both a continuous corn and corn-soybean (Glycine max L.) cropping system. Residual soil-N was low following N fertilizer rates at or below the N rate needed to maximize yield, but residual soil-N increased when additional fertilizer N was applied (Varvel et al., 1997), which emphasized the need to identify site-specific fertilizer-N rates. Nitrogen response trials in Pennsylvania concluded that a CSNT concentration of 250 mg nitrate N kg⁻¹ can distinguish between N deficient and adequate N availability to corn with a 93% accuracy (Fox et al., 2001). Hooker and Morris (1999) concluded that the optimal CSNT range of silage corn in Connecticut is 500 to 1000 mg nitrate N kg⁻¹ at the time of silage harvest. Previous studies (Binford et al., 1992; Blackmer and Mallarino, 1996; Varvel et al., 1997; Hooker and Morris, 1999; Brouder et al., 2000) have exhibited that slight variations in the corn stalk nitrate N concentration (ranging from 250 to 2000 mg nitrate N kg⁻¹), defined as optimal, exist for corn produced across the United States. There is potential that the optimal CSNT range could change over time as a result of research indicating steady increases in grain yield being observed over time and that modern corn hybrids have a 11% increase in N uptake at maturity compared to older hybrids (Ciampitti and Vyn, 2012). However, Mueller et al. (2017) concluded that there was little evidence of differences among modern hybrid responses to N fertilizer rate or timing for grain yield, biomass accumulation at maturity, or N content at maturity. Research by Wilhelm et al. (2005) found that corn hybrid did not have a significant influence on the nitrate N concentration of the corn stalk in an irrigated production system.

Tissue testing corn leaves has also been used to evaluate the nutrient status of corn plants in-season. Corn ELNC at the R1 growth stage have been shown to provide accurate in-season indications of the N status of corn. Blackmer et al. (1994) and Kovacs and Vyn (2017) showed a positive linear correlation between grain yield and ear-leaf N concentration (r² = 0.82 and 0.66, respectively) for corn in the Midwest. Research conducted in Arkansas by Rorie et al. (2011) also displayed a positive linear relationship between RGY and leaf N concentration at tasseling. The sufficiency range for ear-leaf N concentration at R1 is estimated to be 28 to 40 g N kg⁻¹ (Jones, 1967; Campbell, 2000). Cerrato and Blackmer (1991) concluded that a critical concentration of 21 g N kg⁻¹ could identify adequate N availability in Iowa when data was pooled from several different locations and was evaluated using a linear-plateau model. Several studies over multiple years in Illinois have specified that an ELNC of 30 g N kg⁻¹ can separate plants with adequate N from plants that are N deficient (Melsted et al., 1969).

Research studies in Missouri (25 site-years) have shown that N fertilization can be delayed until the V11 growth stage without resulting in an irreversible yield reduction, even when N deficiencies are present (Scharf et al., 2002). Their research also showed that delaying the addition of all N fertilizer until the R1 growth stage still resulted in a significant grain yield increase (>2.2 Mg ha⁻¹) and was economical to apply, however maximum yield could not be achieved. Binder et al. (2000) found that corn grain yield could be increased by N fertilizer applications as late as the R3 growth stage using an irrigated production system in Nebraska. Nitrogen fertilizer that is applied late in the growing season also has a high recovery efficiency (Roberts et al., 2016). Furrow-irrigated corn research trials in Arkansas have indicated that N fertilizer applied at V12 can have an improved fertilizer-N recovery efficiency compared with earlier N applications (Roberts et al., 2016). Furthermore, Ta and Weiland (1992) demonstrated that the later in the growing season N was taken up by the plant, the N was more likely to be directed to the developing kernel compared to other plant parts. Research by Binder et al. (2000) suggest the potential that when corn is identified as N-deficient at the R1 growth stage using an ear-leaf tissue sample, a rescue N fertilizer application can be applied and achieve a grain yield response in the mid-South.

Issues concerning the use of corn ear leaves as a general diagnostic tool in production agriculture include the inability to separate adequate from excessive N availability and sampling time sensitivity. Cerrato and Blackmer (1991) demonstrated that optimal and above-optimal N fertilizer rates can result in similar leaf N concentrations, highlighting that ELNC cannot distinguish between optimal and excessive N availability to corn. The nutrient concentration in a plant varies based on the growth stage and the sampled plant part, which emphasizes the importance of following test procedures to obtain accurate results (Jones et al., 1990).

The CSNT results cannot be used to make N fertilization adjustments to the current crop as a result of sample collection timing; however, CSNT results can improve the sustainability of N fertilization practices for subsequent corn crops following multiple years of collecting samples. Balkcom et al. (2003) reported that the CSNT can be used by corn producers to improve N management practices and reduce nitrate N loss from production fields. Utilization of best management practices and accurate fertilizer recommendations allow producers to optimize yields and maximize profit. The nitrate N concentration in the lower portion of the corn stalk is useful for determining the adequacy of a producer’s N fertilization program in the primary corn production regions of the United States.
States. Using only the CSNT to evaluate N availability could be problematic, since the test lacks the ability to differentiate between actual N availability and various N loss mechanisms when results are identified in the low category (Varvel et al., 1997). Therefore, using an ELNC and the CSNT together may have the potential to provide insight on the adequacy of an N-fertilizer program than one method alone. Limited research has been conducted to evaluate the ELNC and CSNT to evaluate N availability could be problematic, since the test lacks the ability to differentiate between actual N availability and various N loss mechanisms when results are identified in the low category (Varvel et al., 1997). Therefore, using an ELNC and the CSNT together may have the potential to provide insight on the adequacy of an N-fertilizer program than one method alone.

Table 1. Soil information, corn hybrid, N rate to achieve 95% relative grain yield (RGY), check-plot grain yield, and maximum (max) yield achieved at each site for the 24 corn N-response trials across Arkansas.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Corn hybrid</th>
<th>Check-plot grain yield</th>
<th>N rate to achieve 95% RGY</th>
<th>Max grain yield</th>
<th>Soil series</th>
<th>Soil classification</th>
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<td>1</td>
<td>P1690HR</td>
<td>3.7†</td>
<td>165</td>
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<tr>
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<tr>
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<td>123</td>
<td>16.3</td>
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</tr>
</tbody>
</table>

† Sites where ear-leaf tissue samples were not collected.
‡ SIL, silt loam; SL, sandy loam.  

‡ SIL, silt loam; SL, sandy loam.
check plot grain yield varied by 11.5 Mg ha\(^{-1}\) across all site-years (Table 1). Concurrently, the N rate needed to achieve 95% RGY had a range of 70 to 260 kg N ha\(^{-1}\), indicating that the study contained a wide variety of sites with both a high and low responsiveness to N fertilization. The relationship between ELNC at the R1 growth stage and percent RGY at maturity was characterized by a quadratic model (Fig. 1). This relationship \((r^2 = 0.79)\) between RGY and ELNC indicates that low concentrations of N in the ear-leaf are recovered from N-deficient plants that will not produce their maximum yield potential. A RGY of 95% was used to determine the lowest predicted ELNC that would produce near maximum grain yield. A 95% confidence interval was established around the ELNC that represented 95% RGY, ranging from 31 to 37 g N kg\(^{-1}\) contained in the ear-leaf. An ELNC of 30 g N kg\(^{-1}\) at the R1 growth stage is used to separate N limited from N adequate plants.

Our results are similar to what was observed by Melsted et al. (1969) who found a critical composition value for leaf N to be at 30 g N kg\(^{-1}\) to separate between N limiting and N adequate plants. Similarly, Bennett et al. (1953) concluded that an ELNC at the R1 growth stage of 28 g N kg\(^{-1}\), was identified as representing 95% of maximum yield. However, differences in the relationship between ELNC and RGY do exist between research conducted in the mid-South and upper Midwest. These differences are prevalent when tissue samples have an ELNC of 25 g N kg\(^{-1}\) or less. An ELNC of 15 g N kg\(^{-1}\) identified from research conducted in the upper Midwest (Cerrato and Blackmer, 1991; Schmidt et al., 2002) results in a RGY of about 60%, however in the current study (mid-South) an ELNC of 15 g N kg\(^{-1}\) would result in a RGY of approximately 20% (Fig. 1).

A potential reason for this observation is that mid-South corn might rely more on the translocation of N already contained within the plant during the grain fill period. Research has shown that in modern corn varieties, N acquired during reproductive growth contributes more to the grain N concentration than N acquired during vegetative growth compared to older corn hybrids (Ciampitti and Vyn, 2013). Furthermore, a study conducted by Six et al. (2002) highlighted the importance of temperature and tillage influence on organic matter content of soils. Corn in the upper Midwest may have the ability to recover a greater quantity of N from the soil to supply the kernels during the grain fill period (potentially greater plant available N

**RESULTS AND DISCUSSION**

**Ear-leaf Nitrogen Concentration**

Ear-leaf samples (only the leaf blade) were collected at random from the top ear of five prolific plants in the two center rows of each plot at the R1 growth stage (Ritchie et al., 1996). The ear-leaf is defined as the leaf that is developing at the same node as the ear. Ear-leaf samples were collected at 60°C until a constant weight was achieved, ground, and analyzed for N concentration by combustion (Elementar Rapid N 3, Elementar Americas, Inc., Mt. Laurel, NJ; Campbell, 1992).

**Corn Stalk Sampling**

Corn stalk samples were collected within 1 to 2 wk after the R6 growth stage (Ritchie et al., 1996) or kernel black layer formation (physiological maturity), from five random plants within the two center rows of each plot. Corn stalk samples were collected by cutting the lower portion of the corn stalk at 15 and 35 cm above the soil surface, and the dried leaf sheaths were removed from the resulting 20 cm segment of corn stalk (Binford et al., 1992). Following collection, samples were dried at 60°C until a constant weight was achieved and ground to pass a 1-mm screen. Corn stalk nitrate N was extracted by shaking a 0.5-g subsample of ground tissue with 30 mL of 2 mol L\(^{-1}\) KCl for 30 min. The extracted solution was filtered (Whatman No. 4, qualitative filter papers) and analyzed for nitrate N colorimetrically (Mulvaney, 1996) using a SKALAR Segmented Flow Auto Analyzer (San System, Brenda, Netherlands). Extracts were refrigerated after extraction for storage prior to the nitrate N analysis.

**Statistical Analysis**

The treatment structure for all statistical analysis was a randomized complete block design with four replications. Means for corn stalk nitrate N concentration, ELNC, and RGY were calculated by averaging the replicates for each site-year. Nonlinear regression (Proc NLIN) using SAS 9.4 (SAS Institute, Inc., Cary NC) was used to fit a quadratic model with plateau (QP) to regress corn stalk nitrate N concentration versus percent RGY using means for each treatment within a site-year to determine an estimated join point at which RGY was near-maximum and corn stalk nitrate N concentration plateaued. Nonlinear regression using SAS 9.4 was also used to fit an ordinary least squares quadratic model to evaluate percent RGY versus ELNC. Nitrogen rates required to achieve 95% RGY were determined for each site-year using the profiler function in JMP PRO 13.0 (SAS Institute, Inc., Cary NC) on the fitted nonlinear regression model. The difference between the N fertilizer rate applied for each treatment and N fertilizer rate needed to achieve 95% RGY for each site (differential from N rate to achieve 95% RGY) was calculated by subtracting the applied N fertilizer rate for each treatment from the N rate needed to achieve 95% RGY of the site the fertilizer was applied for all site-years. Linear regression using JMP PRO 13.0 was used to analyze the relationship between nitrate N concentration in the stalk and differential from N rate to achieve 95% RGY for treatments that had a mean nitrate N concentration in the stalk of greater than 170 mg kg\(^{-1}\) (identified by the QP regression).
concentrations in the soil associated with higher levels of soil organic matter and less tillage). This would suggest that more N is required to be contained in the ear-leaf (and the above ground tissue of the corn plant) during early reproductive growth in the mid-South to obtain a similar RGY as in the upper Midwest.

Research conducted in Arkansas, Missouri, and Nebraska has shown that mid-season (V10 to R2) N fertilizer applications to corn can result in a significant yield increase (Binder et al., 2000; Scharf et al., 2002; Roberts et al., 2016). This indicates that producers can potentially apply a rescue N application to N-deficient corn at the R1 growth stage and still obtain a significant grain yield increase from the added N fertilizer. Research conducted by Pan et al. (2017) showed that post-silking N applications not only increase grain yield, but can also increase dry matter production and root development. Ear-leaf N concentration can be used in a mid-South corn production system to identify N-deficient corn plants (≤30 g N kg⁻¹) to potentially trigger a rescue fertilizer application at the R1 growth stage. However, issues with identifying over-fertilization of N to corn are not resolved using the ELNC at the R1 growth stage. The visual relationship between corn stalk nitrate N concentration and ELNC illustrates that corn plants recover elevated concentrations of nitrate N in the corn stalk from plants with an ELNC of ≥30 g N kg⁻¹ (Fig. 2). This observation supports research conducted by Viets et al. (1954) who indicated that a leaf N content of 28 g N kg⁻¹ at R1 represented the N rate that maximized grain yield, their research further indicated that ear-leaves with 22 to 28 g N kg⁻¹ N showed no symptoms of N deficiency but failed to produce maximum yield. Our results demonstrate that mid-South corn producers collecting ear-leaf tissue samples can be confident that N was not limiting grain yield with a 31 g N kg⁻¹ N content or greater at the R1 growth stage.

**Corn Stalk Nitrate Concentration**

When evaluating the relationship between the CSNT and RGY across all site-years (Fig. 3), nitrate N started to accumulate in the corn stalk once near-maximum grain yield was achieved. Binford et al. (1990) also identified a sharp break between nitrate N concentrations in the corn stalk that was considered sufficient and insufficient to achieve near-maximum grain yield. Treatments that resulted in a RGY less than 90%, usually resulted in a mean corn stalk nitrate N concentration of less than 50 mg nitrate N kg⁻¹. These results support the conclusions of Friedrich et al. (1979) who reported that excess available N during the grain-fill period resulted in nitrate N accumulation in the lower portion of the corn stalk; when N is deficient or unavailable, nitrate N stored in the lower portion of the corn stalk will be depleted during the grain-fill period.

There was a two-phase relationship (Fig. 4 and 5) between N fertilizer rate and corn stalk nitrate N concentration that was consistent with research reported by Binford et al. (1990, 1992). When the fertilizer-N rate was less than the rate needed to achieve near-maximum grain yield, increasing the N rate increased grain yield without increasing corn stalk nitrate N concentration. However, N rates above the predicted N rate needed to achieve near-maximum grain yield resulted in nitrate N accumulation in the corn stalk without increasing grain yield. These results show the predicted N rate needed to achieve 95% RGY was either at or near the point at which additional N fertilizer resulted in nitrate N accumulation in the corn stalk (Fig. 4
and 5). This relationship also predicted that corn stalk nitrate N concentrations tended to be less than 50 mg nitrate N kg\(^{-1}\) when fertilizer-N application rates were less than the fertilizer-N rate needed to achieve 95% RGY. Fields that are fertilized using standard N fertilizer recommendation and have high residual N availability have potential to result in greater CSNT values than fields with less residual N availability (Fig. 4 and 5). This highlights the importance of determining site-specific N fertilizer recommendations. The accumulation of corn stalk nitrate N concentration as N rate increased typically displayed a visually linear increase and reached as high as 9500 mg nitrate N kg\(^{-1}\) (Fig. 4 and 5).

A QP relationship was used to characterize the relationship between RGY and corn stalk nitrate N values (Fig. 6). The QP model predicted that RGY plateaued at 97% when the corn stalk nitrate N concentration was 170 mg nitrate N kg\(^{-1}\) to separate N-deficient from N-sufficient sites. Therefore, the low category of the CSNT would encompass nitrate N concentrations <170 mg nitrate N kg\(^{-1}\). These results are in general agreement with research by Fox et al. (2001) who found a critical corn stalk nitrate N level of 250 mg nitrate N kg\(^{-1}\) can separate N deficient from N adequate corn. The range of corn stalk nitrate N concentrations identified as being optimal in the current study was determined to be from 170 to 1000 mg nitrate N kg\(^{-1}\) to ensure adequate N availability to maximize yield potential. The lower limit of the sufficient range was set at 170 mg nitrate N kg\(^{-1}\) in accordance with the estimated join point using the QP model. The upper limit of the optimal corn stalk nitrate N concentration range was set at 1000 mg nitrate N kg\(^{-1}\), determined by identifying the corn stalk nitrate N concentration recovered within 10% of the N rate predicted to achieve 95% RGY for each individual site-year (data not shown). The corn stalk nitrate N concentration recovered within 10% of the N rate predicted to achieve 95% RGY for each site-year resulted in a CSNT value <1000 mg nitrate N kg\(^{-1}\) for twenty-one out of twenty-four (88%) site-years. A CSNT concentration within the optimal range (170 to 1000 mg nitrate N kg\(^{-1}\)) would suggest that adequate N was available to the corn crop. However, the predicted N rate needed to achieve 95% RGY, 18 out of 24 sites resulted in a CSNT nitrate N concentration of <50 mg nitrate N kg\(^{-1}\) for an actual applied N rate nearest the predicted N rate needed to achieve 95% RGY identified for each site (Fig. 4 and 5).

The CSNT values above 1000 mg nitrate N kg\(^{-1}\) would suggest that N availability exceeded the amount needed to maximize yield, representing the excessive category. The relationship between the nitrate N concentration contained in the corn stalk and differential from N rate to achieve 95% RGY is presented in Fig. 7. This relationship can be used to estimate the amount of excessive N applied beyond the N rate needed to produce near maximum yield. This figure shows that nitrate N does not accumulate until N fertilizer is applied in excess of the predicted rate needed to produce 95% RGY. Linear regression was used to evaluate the relationship \((r^2 = 0.55)\) using treatment means with a CSNT value greater than 170 mg nitrate N kg\(^{-1}\) representing the lower limit of the optimal range. For each kg N ha\(^{-1}\) applied beyond the rate needed to produce near-maximum grain yield, the nitrate N concentration in the corn stalk increases by 24 mg kg\(^{-1}\). When CSNT values are consistently in the excessive category (>1000 mg nitrate N kg\(^{-1}\)), this data can potentially be used to help estimate how much N fertilizer was over applied and help producers identify a potential N reduction when sequential corn will be grown in the same field.
Fig. 5. Relationship between season total N rate applied and mean corn stalk nitrate N concentration at maturity for sites thirteen through twenty-four. Vertical line in the graph indicates the N rate to achieve 95% relative grain yield (RGY) for each site-year.

Fig. 6. Relationship between relative grain yield (RGY) and corn stalk nitrate N concentration at maturity, using treatment means with a nitrate N concentration less than 2000 mg kg\(^{-1}\) and a RGY greater than 70%. The axis were adjusted to provide a more clearly visual depiction of the join point.

Fig. 7. Relationship between the mean nitrate N concentration in the corn stalk and the difference in the N fertilizer rate applied from the N fertilizer rate needed to achieve 95% relative grain yield (RGY). Positive values indicate amount of applied N fertilizer greater than the rate needed to achieve 95% RGY, negative values indicate N fertilizer rate applied less than the N rate needed to achieve 95% RGY, and zero is at the N rate needed to achieve 95% RGY for each site-year (\(n = 144\)).
Using both ELNC and CSNT samples can provide a more thorough assessment of the adequacy of N availability than either test alone. The grain yield potential and history of the field should be considered before making changes in N fertilizer rates for fields identified in either the low or excessive CSNT categories. Corn stalk N test values <170 mg nitrate N kg⁻¹ suggest that N availability was limiting corn grain yield, increasing the N fertilization rate could have resulted in an increase in grain yield. However, maximum grain yield can be achieved even when CSNT values are in the low category, potentially identified using previous grain yield and ELNC. The optimal category of the CSNT ranges from 170 to 1000 mg nitrate N kg⁻¹, indicating that adequate N was available to the crop to produce near maximum yield. A CSNT value of >1000 mg nitrate N kg⁻¹ would suggest that excess N was available to the corn crop, with a high probability that if less N was available to the crop near-maximum grain yield would still be maintained. Our results are relatively consistent with research conducted in other regions of the country that indicate >2000 mg kg⁻¹ of nitrate N in the corn stalk represent the excessive category (Binford et al., 1992; Blackmer and Mallarino, 1996; Brouder et al., 2000). Further research is needed to evaluate the variability in the CSNT within a field to subsequently identify how many corn stalk samples need to be collected for a specific area to produce accurate results. Additionally, future work should assess early-season (vegetative growth) N management tools to develop a holistic evaluation of the N status of corn throughout the growing season.

**CONCLUSION**

Both the ELNC content and corn stalk nitrate N concentration in the lower portion of the corn stalk has demonstrated the ability to identify the N status of a mid-South corn production system. The novelty of this research is that (i) corn stalk nitrate N accumulates near the N rate needed to achieve 95% RGY, (ii) provides insight into how much N fertilizer rate can be reduced when CSNT values are in the excessive category, and (iii) a critical concentration of 30 g N kg⁻¹ was determined to differentiate between N deficient and N adequate plants at the R1 growth stage for mid-South corn production systems. A range in CSNT value between 170 and 1000 mg nitrate N kg⁻¹ represents the optimal category, suggesting adequate N availability to produce near-maximum yields. The CSNT increases by 24 mg nitrate N kg⁻¹ for every kg N ha⁻¹ applied beyond the rate needed to achieve 95% RGY, enlightening producers on an estimate of the quantity of N fertilizer to be reduced when CSNT values are in the excessive category. The ELNC and CSNT should be used together when CSNT results are identified in the low category to ensure that N availability is limiting and not environmental factors. Maximum corn grain yield can still be achieved even when CSNT values are identified in the low category, ELNC and previous yield potential of the field can be used to identify these situations. The CSNT has the potential to distinguish between inadequate, optimal, and excessive N fertilization, with the potential to improved profitability by producers.

Differences in the N rate to achieve 95% RGY (89.5 to 260.7 kg N ha⁻¹) and check plot grain yield (0.7 to 12.2 Mg ha⁻¹) across Arkansas highlight the importance of developing a soil nitrogen test to determine site-specific season-total N fertilizer recommendations for corn. Using both the CSNT and ELNC will give mid-South corn producers the ability to gauge the adequacy of their N management program throughout the growing season, to provide insight on the efficiency of their N management. These N management tools can help producers fine-tune N management programs on a field-by-field basis to improve production, profitability, and nitrogen use efficiency within a furrow-irrigated corn production system.

**REFERENCES**


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