Comparison of Late-Season Diagnostic Tests for Predicting Nitrogen Status of Corn

Richard H. Fox,* William P. Piekielek, and Kirsten E. Macneal

ABSTRACT

We compared six late-season diagnostic tests for determining N adequacy in corn (*Zea mays* L.) in a 3-yr study in Pennsylvania. The six tests were: (i) the NO_3^-–N concentration of stalk sections at black layer; (ii) the NO_3^-–N concentration of stalk sections at the one-fourth milk line growth stage (MLGS), which allows corn grown for silage to be tested; (iii) the chlorophyll meter (CM) test at the one-fourth MLGS; (iv) the relative CM test (normalized values) at the one-fourth MLGS; (v) a visual test based on the number of green leaves below and including the ear leaf at the one-fourth MLGS; and (vi) a relative visual test (normalized values at the one-fourth MLGS). We found that with a critical level of 250 mg kg^{-1} NO_3^-–N, the stalk NO_3^- test separated N-sufficient from N-deficient sites with approximately 93% accuracy when sampling was done at either the one-fourth MLGS or within several weeks after black-layer formation. It appears that the 250 mg kg^{-1} NO_3^-–N critical level can be used to accurately predict N adequacy for any sampling time between the one-fourth MLGS and a few weeks after black-layer formation. When drought-stressed fields were excluded or the CM readings normalized with a high-N reference plot in the field, the accuracy of the CM test at the one-fourth MLGS was approximately 92%. The visual test at the one-fourth MLGS was an accurate predictor of corn N status only when visual readings were normalized with a high-N reference plot. These results demonstrate that there are several late-season N tests that are suitable for making relatively accurate assessments of N sufficiency for corn silage and grain yields.

NITRATE CONTAMINATION of surface and ground water by agriculture continues to be of national concern in the USA in spite of concerted efforts by policymakers, researchers, and farm advisors to reduce levels of NO_3^- leaving agricultural fields (Burkhart and James, 1999). A recent survey of water quality in the USA (USGS, 1999) found that 3 of the 12 areas where more than 15% of the shallow ground-water wells contained greater than the EPA standard of 10 mg L^{-1} NO_3^- were in southeastern Pennsylvania. A survey in 1993 found that more than 50% of the private wells sampled in southeastern Pennsylvania had NO_3^- concentrations >10 mg L^{-1} NO_3^-–N and that the highest NO_3^- concentrations were in wells within 150 m of corn fields (Swistock et al., 1993).

The presidedress NO_3^- test (PSNT) and early season chlorophyll meter (CM) tests have been shown to produce accurate N fertilizer recommendations for corn on soils receiving manure or following legumes (Fox et al., 1989; Fox et al., 1992; Piekielek and Fox, 1992). However, even though these tests have been promoted in Pennsylvania (Beegle et al., 1990; Piekielek et al., 1997), their usage by farmers and farm advisors has been limited. Reasons given for this include: the narrow sampling-time window when farmers are often busy with other field work, difficulty of taking soil samples to 30 cm, purchase price of the CM, and the reluctance to establish high-N reference strips needed to obtain the relative readings required for accurate estimates with the early season CM test.

In an attempt to provide more convenient N management tools for farmers and crop consultants, we have been assessing end-of-season N tests. An accurate evaluation of the N status of a corn crop at the end of a growing season could help a producer or consultant make more informed decisions on quantifying N fertilizer recommendations for their corn fields in subsequent years. Binford et al. (1990, 1992) developed a corn stalk NO_3^- test taken at kernel black layer that accurately indicated whether N supply had been adequate for near-maximum yields. Hooker and Morris (1999) have recently shown that corn stalk NO_3^- concentration at silage harvest could also be used to indicate adequacy of N supply. However, the stalk NO_3^- tests are somewhat inconvenient and time consuming, requiring sample collection, drying, and grinding before a NO_3^- analysis. Binford and Blackmer (1993) found that a visual test relating the number of green leaves below the primary ear compared with the green leaf number in a high-N reference plot following silking was a reasonably accurate predictor of relative grain yield ($r^2 = 0.74$–0.80). Although simple and inexpensive, this visual test is somewhat inconvenient because it requires a reference plot. Piekielek et al. (1995) developed a late-season CM test of corn ear leaves taken at the kernel one-fourth milk line growth stage (MLGS) that was 93% accurate in separating N-sufficient from N-deficient sites. This test is a quick and easy on-site test, but it must be done in a fairly narrow time window near the one-fourth MLGS.

We initiated research to compare the accuracy of six late-season tests in estimating the adequacy of N supply for near-maximum corn yields. These tests were: (i) the NO_3^-–N concentration of stalk sections at black layer; (ii) the NO_3^-–N concentration of stalk sections at the one-fourth MLGS, which would allow corn grown for silage to be tested; (iii) the CM test at the one-fourth MLGS; (iv) the relative CM test (normalized values) at the one-fourth MLGS; (v) a visual test based on the number of green leaves below and including the ear leaf at the one-fourth MLGS; and (vi) a relative visual test (normalized values at the one-fourth MLGS).

Dep. of Agron., 116 ASI Building, Penn State Univ., University Park, PA 16802. Received 14 July 2000. *Corresponding author (rhf@psu.edu).

Published in Agron. J. 93:590–597 (2001).

Abbreviations: CM, chlorophyll meter; gl/p, green leaves per plant; MLGS, milk line growth stage.

MATERIALS AND METHODS

Forty-one corn N response experiments were conducted in central and southeastern Pennsylvania over three growing seasons: 1996, 1997, and 1998. Twenty N response experiments were in fields of cooperating farmers in Lebanon and Lancaster Counties in southeastern Pennsylvania. Fifteen N response experiments were located at the R.E. Larson Research Farm of the Pennsylvania State University in Centre County, and six were at the Southeast Research and Extension Center in Lancaster County. At each site, N fertilizer was applied at the time of planting at five rates (0, 50, 100, 150, and 200 kg N ha^{-1}) to three (3 exp.), four (32 exp.), or five (6 exp.) replications in a randomized complete block design. In six experiments, there were also treatments of 300 and 400 kg N ha^{-1}. Corn was planted in late April or May. Experiments on farmers' fields were planted and managed by the farmers except for N fertilizer rates. However, we ensured that nutrients other than N were adequate for maximum yield. The fields had a range of crop and manuring histories. Corn hybrids used had a range of stay-green ratings.

The late-season CM test was conducted as described in Piekielek et al. (1995). Minolta SPAD 502 CM readings were taken from primary ear leaves when kernels were in the one-fourth MLGS (milk line had moved one-fourth the distance from kernel exterior towards the base), 1 to 2 cm from the leaf edge at a point about three-fourths of the leaf length from the leaf base of five representative plants in each of the two center rows. Meter readings are reported as SPAD units. Relative CM readings (relative CM test) were calculated by dividing the average reading for the tested treatment by the average reading for the 200 kg N ha^{-1} treatment in the experiment.

For a late-season visual test, we counted the number of leaves that were *green* (<25% yellowed), including and below the ear leaf, on five representative plants from each of the center two rows in each plot at the one-fourth MLGS. We had hoped to eliminate the need for a high-N reference plot by limiting visual readings to a specific growth stage. Our visual test value is the average number of green leaves per plant (gl/p). Relative visual test values were calculated by dividing the average visual test values of treatments by the average test value of the 200 kg N ha^{-1} treatment in the appropriate experiment.

We followed the procedure of Binford et al. (1990, 1992) for the stalk NO_3^- test. Eight 20-cm stalk sections were cut 15 cm from the ground of each plot within a period of 1 to 3 wk after the corn kernels had formed a black layer. We also collected stalk samples at the one-fourth MLGS as a test for corn harvested as silage. Stalk sections were dried and ground, and the NO_3^- concentration was determined using a 2 *M* KCl extract and an autoanalyzer.

Grain yields were measured by hand-harvesting and weighing ears from 7 m of each of two center rows of each plot and determining the fraction of dry grain in the laboratory on six ears from each plot. Yields were expressed on the basis of 15.5 g kg^{-1} water content. The plateau grain yield for each experiment was determined with a quadratic-linear plateau yield-response model using a SAS-NLIN procedure (SAS Inst., 1982). If the data from an experiment did not fit the model, a plateau was estimated by averaging the grain yields from the high-N treatments that were not significantly different from one another. We did not include experiments in our database for this paper that had a reduction in grain yield due to drought stress of more than 35% of the expected yield potential. If there was not a grain yield response to N fertilizer in an experiment at the 0.10 probability level (*k*-ratio = 50) determined with a Waller *k* ratio *t*-test (SAS Inst., 1982), the relative grain yields for all treatments in that experiment were declared to be 1.0. In an N responsive experiment, if the grain yield for a treatment was significantly different than the plateau grain yield, the relative grain yield for that treatment was calculated by dividing the average grain yield of the treatment by the plateau grain yield for the experiment.

We used a modified Cate–Nelson graphic method (Cate and Nelson, 1965) to compare the various N tests in predicting N sufficiency for near-maximum yield. Average test values of the N treatments were plotted against the relative grain yields for the corresponding treatments (e.g., Fig. 1). We chose 0.93 relative grain yield as the horizontal critical level because we had observed that a treatment yield that was 93% or greater of the plateau field of the experiment was usually not significantly different from the plateau yield at the 0.10 probability level. The vertical (test) critical level was chosen to minimize errors or outliers. The upper left quadrant of the resulting graph contains the outlier treatments where the N test predicted that the treatment was N deficient, but in fact, the N treatment

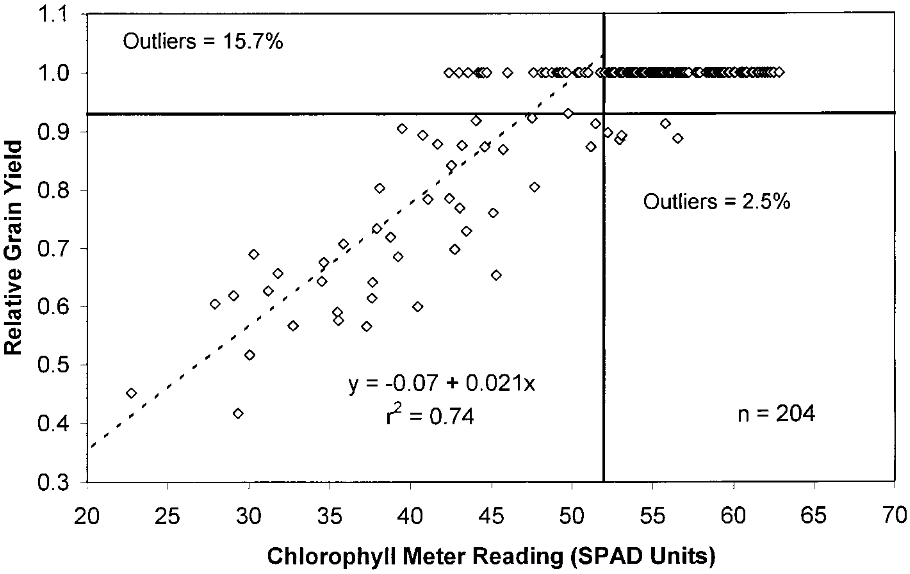

Fig. 1. A modified Cate–Nelson graphic analysis relating chlorophyll meter (CM) readings of corn ear leaves sampled at the one-fourth milk line growth stage (MLGS) with relative grain yield.

Table 1. Summary of Cate–Nelson Analyses.

Test	No. of treatments	Critical level	Outliers		
			Upper left	Lower right	Total
			%		
CM[†] at one-fourth MLGS[‡]: 1996–1998	204	52 SU[§]	15.7	2.5	18.2
CM at one-fourth MLGS: 1996–1998 (common sites)	189	52 SU	16.9	2.6	19.5
CM at one-fourth MLGS: 1996	88	52 SU	4.5	5.7	10.2
CM at one-fourth MLGS: 1997	53	52 SU	45.3	0.0	45.3
CM at one-fourth MLGS: 1998	63	52 SU	7.9	0.0	7.9
CM at one-fourth MLGS: 1989–1998, no drought	579	52 SU	5.2	2.1	7.3
CM at one-fourth MLGS: 1989–1998	702	52 SU	13.4	1.7	15.1
CM at one-fourth MLGS: 1989–1998	702	48 SU	2.7	4.6	7.3
Relative CM at one-fourth MLGS: 1996–1998	204	0.91	5.4	2.0	7.4
Relative CM at one-fourth MLGS: 1996–1998 (common sites)	189	0.91	5.3	2.1	7.4
Relative CM at one-fourth MLGS: 1996–1998	204	0.93	9.8	1.5	11.3
Relative CM at one-fourth MLGS: 1997	53	0.91	9.4	0.0	9.4
Visual: 1996–1998 (common sites)	189	2.2 gl/p[¶]	5.8	10.1	15.9
Visual: 1996–1998 (common sites)	189	3.6 gl/p	19.0	3.7	22.7
Relative visual: 1996–1998 (common sites)	189	0.73	3.7	3.7	7.4
Relative visual: 1997	48	0.73	2.1	8.3	10.4
Relative visual: 1997	48	0.83	8.3	2.1	10.4
Stalk NO$_3$–N; black layer: 1996–1998	209	250 mg kg^{-1}	5.3	1.9	7.2
Stalk NO$_3$–N; black layer: 1996–1998 (common sites)	189	250 mg kg^{-1}	4.8	2.1	6.9
Stalk NO$_3$–N; black layer: 1996–1998	209	700 mg kg^{-1}	12.0	0	12.0
Stalk NO$_3$–N; black layer: 1997	53	250 mg kg^{-1}	11.3	1.9	13.2
Stalk NO$_3$–N; one-fourth MLGS: 1996–1998	209	250 mg kg^{-1}	3.3	2.4	5.7
Stalk NO$_3$–N; one-fourth MLGS: 1996–1998 (common sites)	189	250 mg kg^{-1}	3.2	2.6	5.8
Stalk NO$_3$–N; one-fourth MLGS: 1996–1998	209	500 mg kg^{-1}	9.1	1.0	10.1

[†] CM, chlorophyll meter.
[‡] MLGS, milk line growth stage.
[§] SU, SPAD units.
[¶] gl/p, green leaves per plant at and below ear leaf.

was sufficient for near-maximum grain yield. The lower right quadrant contains outlier treatments where N sufficiency was predicted, but these treatments were actually N deficient. We selected a critical level for a test that minimized the total number of outliers but ensured that there were not more than 5% of the points in the lower right quadrant. We felt that for a test to be acceptable to growers, the probability of the test to predict N sufficiency, when in fact the treatment was deficient, should be low.

The visual rating tests could not be done on three sites (15 treatment averages) because of the effects of leaf disease on many of the leaves below the ear leaf. Neither the CM nor visual tests were done on one site (5 treatment averages) that had three different corn hybrids planted in the experiment. Cate–Nelson graphic analyses were done for all treatments that were tested and for a common data set of 189 treatments. Because there was little difference in the results of the two data sets (Table 1), we will only discuss the results for the total number of treatments available for each test.

RESULTS AND DISCUSSION

The growing season in 1996 had sufficient rainfall so that corn grain yields were not limited by moisture stress and maximum yields were close to the maximum values observed in the state (10–13 Mg ha^{-1}, depending on soil and region). In 1997, temperatures were cooler than average in the early and late part of the growing season. June and July were quite dry with a total of only 120 mm of rainfall at the Centre County Agronomy Research Farm for the 2 mo compared with the long-term average of 197 mm. This resulted in reduced vegetative growth and lower, more variable grain yields (max. yields of 7–10.5 Mg ha^{-1}) at some sites than in years with adequate rainfall. In 1998, rainfall was generally adequate to produce maximum yields of 10 to 13 Mg ha^{-1}, but there was late-season drought stress at some sites.

Late-Season Chlorophyll Meter Test

Piekielek et al. (1995) reported that a late-season CM test identified N-sufficient corn at the one-fourth MLGS with 92% accuracy using 52.0 SPAD units as a critical level. Using this critical level, the late-season CM test had an error rate of 18% for this study (Table 1 and Fig. 1). Error rates were 10 and 8% for 1996 and 1998 data, respectively, and 45% for 1997 sites. All of the outliers in the 1997 Cate–Nelson graph were in the upper left quadrant, treatments with average CM readings below the critical level but which were N sufficient for near-maximum yield. Most of the test error in 1997 was probably due to the effects of the mid- and late-season drought conditions. Severe midseason drought conditions in 1997 resulted in corn plants with small, thin ear leaves with lower-than-normal CM readings. In addition, late-season drought stress at some sites caused lower ear leaf chlorophyll levels at the one-fourth MLGS. Piekielek et al. (1995) had noted erroneous test predictions for 2 of the 93 experiments in their database that had lower-than-expected leaf CM readings due to effects of drought stress and severe leaf disease symptoms. The 1997 results from this study confirm this effect of drought on the accuracy of the CM test.

We combined the data used in the Piekielek et al. (1995) paper with this study and unpublished data from experiments in 1993 to 1995 to form a database of 702 treatment averages over a 10-yr period. Of those treatments, 579 were from experiments that were not significantly affected by drought stress or leaf disease. A Cate–

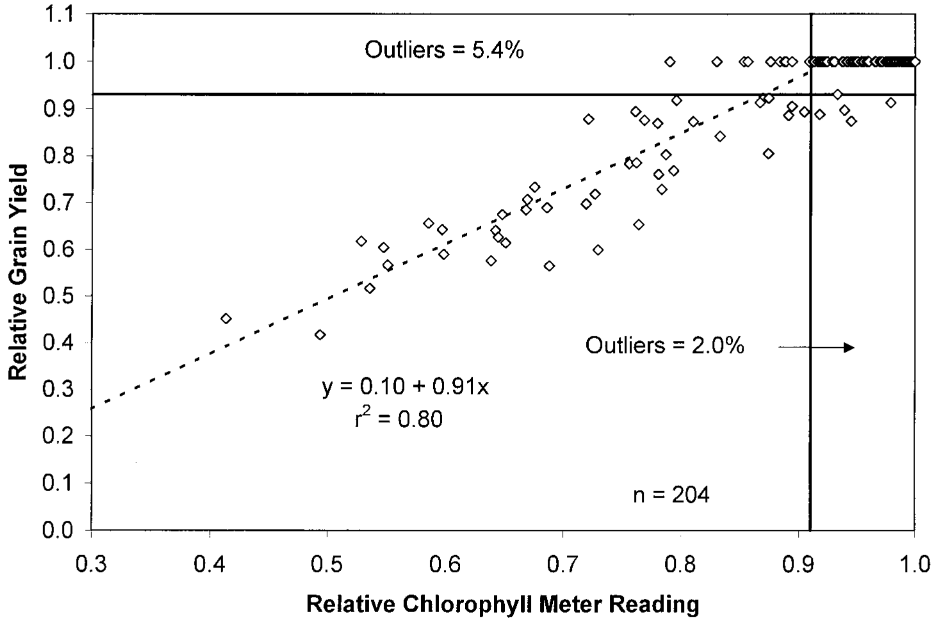

Fig. 2. A modified Cate–Nelson graphic analysis relating relative chlorophyll meter (CM) readings of corn ear leaves sampled at the one-fourth milk line growth stage (MLGS) with relative grain yield.

Nelson graphic analysis of this database with a critical level of 52.0 SPAD units resulted in a test error rate of 7.3% with only 2.1% error in the lower right quadrant (Table 1). Lowering the critical level to 51.0 SPAD units reduced the overall error rate to 6% but noticeably increased the probability of lower-right quadrant error. Only 1 of 19 treatments with CM readings between 52.0 and 52.9 were N deficient while 5 of 17 treatments with readings between 51.0 and 51.9 were N deficient. Considering that we are placing more emphasis on minimizing lower-right quadrant error and that we are accepting 93% relative grain yield as N sufficient, using 52.0 SPAD units may be a better critical level.

A Cate–Nelson graphic analysis of all of the 702 treatment averages illustrates how drought stress introduces uncertainty into the choice of a *best* critical level for the CM test. Using a critical level of 52.0 SPAD units results in a test error rate of 15.1% with 13.4% of treatments as outliers in the upper left quadrant (Table 1). Many of these outliers are N-sufficient treatments with leaf chlorophyll levels reduced by drought stress. Lowering the critical level to 48.0 SPAD units will reduce overall error rate to 7.3% but at a cost of increasing lower-right quadrant error to 4.6% compared with 2.7% for upper left quadrant error.

It would be difficult to easily quantify the degree of drought stress present in a field to determine which CM reading critical level to use. We included drought-stressed fields in this study where grain yield was not reduced by more than about one-third. Early or midseason drought caused smaller plants and ear leaves, and late-season drought led to leaf rolling, duller leaf surfaces, or dried leaves. With these drought-affected sites included, we found that 97.5% of the treatments with ear leaf CM readings of 52.0 SPAD units or greater were N sufficient while 91.6% of treatments with readings <48.0 SPAD units were N deficient. It was mainly in the range of 48.0 to 51.9 SPAD units where drought affected leaf CM readings and the accuracy of the test. In this range, 21% of treatments were N deficient and 79% were N sufficient. We suggest that when the CM test is used on fields that are drought stressed, the higher level of inaccuracy should be recognized when a reading is ≥48.0 but <52.0 SPAD units.

Relative Late-Season Chlorophyll Meter Test

Using relative CM readings is a procedure to try to minimize the effects of factors other than N fertility on the readings. For instance, it has been shown that by using relative meter readings, a late-season CM test could be done over a range of sampling times using the same test critical level (Piekielek et al., 1995). For all experiments over the 3 yr of this project, we found that with a critical level of 0.91, relative CM readings at the one-fourth MLGS predicted N sufficiency with an error rate of only 7.4% (Table 1 and Fig. 2). We found that the originally proposed critical level of 0.93 for this database gave an error rate of 11.3% with only a slight reduction in lower-right quadrant error while increasing upper left quadrant error from 5.4 to 9.8% (Table 1). With a critical level of 0.91 for 1997 data, the test error rate was only 9.4%, indicating that by using relative meter readings, the effect of drought stress on the accuracy of the test was minimized. Despite the accuracy of this test over a range of environmental conditions and sampling times, most growers or consultants would probably not wish to establish and maintain a high-N reference plot in each field tested.

Visual Rating Test

The lowest total error rate for the visual test was 15.9% with a critical level of 2.2 gl/p at and below the ear leaf, but the error rate of the lower right quadrant

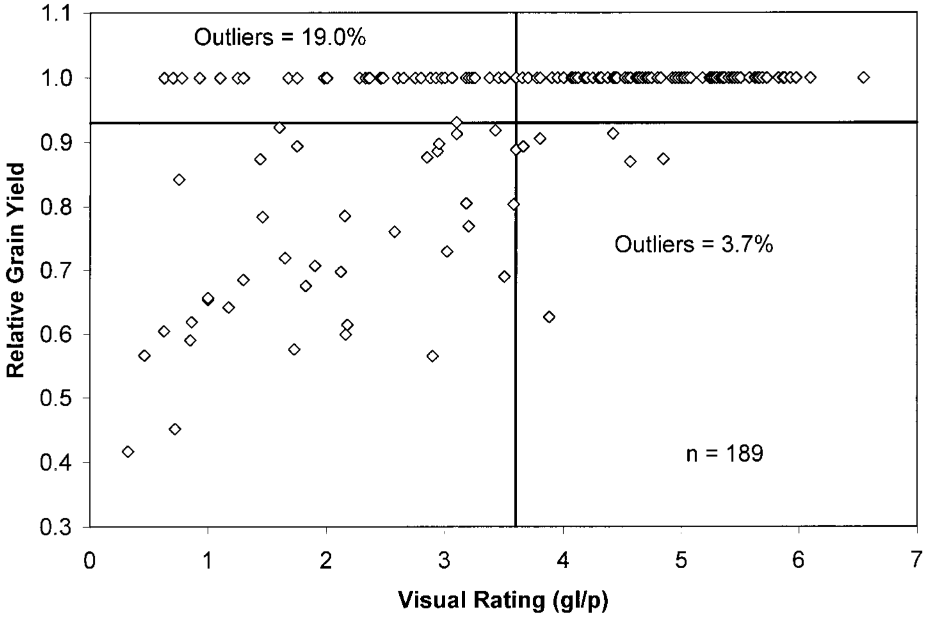

Fig. 3. A modified Cate–Nelson graphic analysis relating visual ratings of corn ear leaves sampled at the one-fourth milk line growth stage (MLGS) with relative grain yield.

was 10.1% (Table 1). The critical level had to be raised to 3.6 gl/p to have the error rate of the lower right quadrant be lower than 5%, which resulted in a total error rate of 22.7% (Table 1 and Fig. 3). This test appeared to be markedly affected by not only drought stress, but also by stay-green rating, high plant populations, and disease. Our data did show that this type of visual rating might have some use as a limited method for identifying N-sufficient fields. For instance, in this study, 95.7% of 70 treatments with a visual rating of 4.0 gl/p or higher were N sufficient. However, many (53.6%) of the 69 treatments with a visual rating <4.0 gl/p were also N sufficient. A different late-season test would have been needed for an accurate assessment of these treatments.

Relative Visual Rating Test

As with the CM test, normalizing visual ratings seemed to remove much of the error caused by factors other than N fertility. A relative visual rating of 0.73 resulted in a total error rate of only 7.4% with 3.7% in the lower right quadrant (Table 1 and Fig. 4). For 1997 treatments only, the error rate was 10.4% with 8.3% of the outliers in the lower right quadrant. A relative visual rating of 0.83 would be a better critical level for 1997 data and would result in only 2.1% of the error in the lower right quadrant. This may indicate that normalizing visual ratings did not remove all of the drought stress effect. For their visual test, Binford and Blackmer (1993) used adjusted leaf rating, which is the leaf rating of the treatment in question subtracted from the highest leaf rating attained in the experiment. A Cate-Nelson graphic analysis of our visual rating adjusted in this way resulted in 21.2% error. As with the relative CM test, the necessity for a reference plot in each field is a shortcoming of the test.

Black-Layer Stalk Nitrate Test

We found that using Binford et al.'s (1990) original stalk NO_3^- concentration at maturity critical level of 250 mg kg^{-1} NO_3^-–N resulted in a very low error rate of only 7.2% with only 1.9% of the samples in the lower right quadrant (Table 1 and Fig. 5). By using a critical limit of 700 mg kg^{-1} NO_3^-–N to determine adequacy of N availability as suggested in Binford et al.'s later paper (1992), the error rate increased to 12.0% (Table 1). Thus, in this study, using our method of calculating grain yield response, the more accurate stalk NO_3^- concentration at black-layer critical level for predicting response to N was 250 mg kg^{-1} NO_3^-–N. The error rate for sites from the drought year of 1997 was 13.2%, indicating that this test worked relatively well even under these conditions.

One-Fourth Milk Line Stalk Nitrate Test

Using a critical level of 250 mg kg^{-1} NO_3^-–N for stalk NO_3^- concentrations at the one-fourth MLGS resulted in a very low total error rate of only 5.7% in predicting N adequacy (Table 1) with only 2.4% of the treatments being in the lower right quadrant (Fig. 6). Hooker and Morris (1999) recently reported that a stalk NO_3^- concentration of 500 mg kg^{-1} NO_3^-–N at the corn silage stage resulted in an error rate in predicting N adequacy of only 6.1% using the Cate–Nelson method. At the one-fourth MLGS, corn plants have approximately 37% dry matter (Ganoe and Roth, 1992), which is within the 29 to 42% dry matter in the silage harvested in the Hooker and Morris study. By using their critical level of 500 mg kg^{-1} NO_3^-–N, the prediction of N adequacy error rate rose to 10.1% in our study.

The linear correlation between stalk NO_3^- concentrations at the one-fourth MLGS and the stalk NO_3^- concentrations at black layer had an r^2 of 0.95, and the regression line had a slope of 0.96. There appeared to

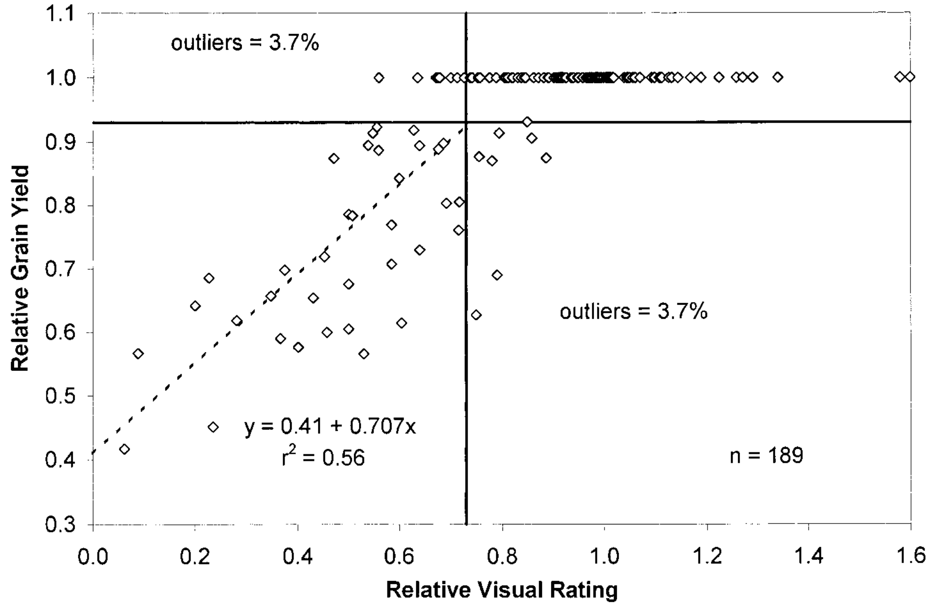

Fig. 4. A modified Cate–Nelson graphic analysis relating relative visual ratings of corn ear leaves sampled at the one-fourth milk line growth stage (MLGS) with relative grain yield.

be no trend in change of stalk NO_3^- concentration between the two sampling times. Of 209 treatments, only 33 showed a statistically significant (0.05 probability level) difference in stalk NO_3^- concentration between sampling times. The stalk NO_3^- concentration increased for 20 of these treatments and decreased for the other 13 treatments. Although we did no other samplings between our one-fourth MLGS and black-layer sampling times, our data suggests that sampling in this intervening time would have produced overall results very similar to both of the times that we did test. Although Binford et al. (1990) found that the NO_3^- concentration at black layer was slightly higher than it was during the 3 wk after black layer, their data do not indicate that the critical level would be different at black layer than for 3 wk after black layer. Thus, the sample window for the stalk NO_3^- test could be from one-fourth MLGS until 3 wk after black-layer formation using the same critical level of 250 mg kg^{-1} NO_3^-–N. Such a large sample window would be a major advantage of the stalk NO_3^- test.

Predicting Relative Yield with Late-Season Nitrogen Tests

The stalk NO_3^- tests are accurate in predicting whether the N status was sufficient for near-maximum yield, but they are not very useful for predicting the degree of N deficiency. However, based on observations by Binford et al. (1992) and Hooker and Morris (1999), it ap-

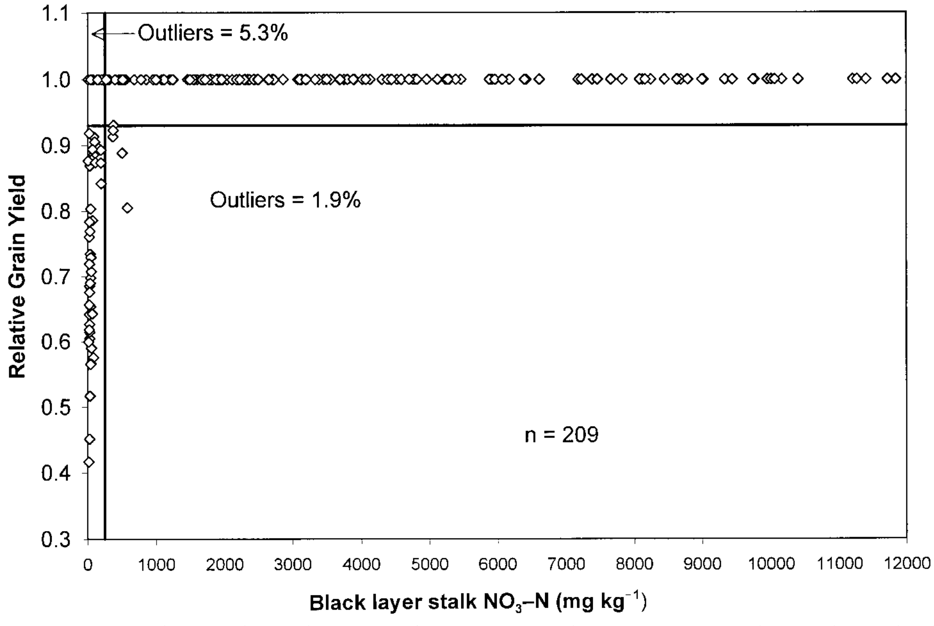

Fig. 5. A modified Cate–Nelson graphic analysis relating stalk NO_3^-–N concentration at black layer with relative grain yield.

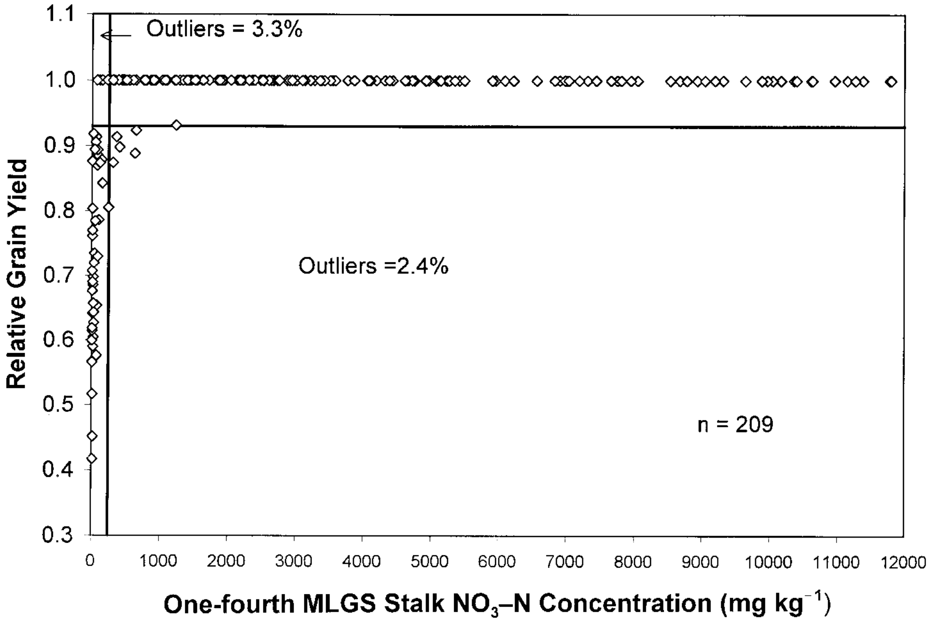

Fig. 6. A modified Cate–Nelson graphic analysis relating stalk NO_3^-–N concentration at the one-fourth milk line growth stage (MLGS) with relative grain yield.

pears that stalk NO_3^-–N concentrations >2000 mg kg^{-1} at either the one-fourth MLGS or black-layer sampling times indicate that there was more N available than needed for maximum corn yields, and it is likely that there would be potentially polluting levels of NO_3^- in soils following harvest.

Both the CM reading and relative CM reading of the ear leaf at one-fourth MLGS of treatments with values less than the critical level were linearly correlated with relative yield (r^2 = 0.75 and 0.80, respectively; Fig. 1 and 2). Thus, for fields with CM readings <52.0 SPAD units or relative readings <0.91, one could estimate how much yield had been lost by inadequate N supply. Previous research (Schepers et al., 1992; Piekielek et al., 1995) has shown that the CM is not a very good quantitative indicator of the degree of excess N available to the corn plant.

Although the relationship is not as strong as with the CM readings, the relative visual test values are also linearly correlated with relative grain yields for readings below 0.73 (r^2 = 0.56; Fig. 4). The visual rating was very poorly correlated with relative yield in the treatments with less than the critical level of 3.6 gl/p (r^2 = 0.16).

SUMMARY AND CONCLUSIONS

Results from this research indicate that the stalk NO_3^- test is an excellent indicator of corn N status when sampling is done at either the one-fourth MLGS or within several weeks after black-layer formation. A critical level of 250 mg kg^{-1} NO_3^-–N separates N-sufficient from N-deficient sites with approximately 93% accuracy. The real advantages of the test are the wide window of sampling dates and its accuracy even when the crop is affected by stress factors like drought. The time required to sample and the need for laboratory analysis are the disadvantages of this test compared with using a CM test. The CM reading at one-fourth MLGS is also an accurate test of N sufficiency with accuracy slightly >91% if drought-stressed fields are not included. The main advantage of this test is that it gives on-site results and is even faster than the visual test. Disadvantages of the CM test include the difficulty in consistently determining the one-fourth MLGS and the narrow sampling-time window. The relative or normalized CM readings (compared with a high-N reference plot) are more accurate (91–93% accurate) than the readings themselves when drought-stressed sites were included, but they require reference plots that farmers are reluctant to establish. We have previously shown that relative CM readings with one critical level can accurately predict N status over a range of sampling times. The visual test of number of green leaves at and below the ear leaf at the one-fourth MLGS is not an accurate predictor of N adequacy. However, this test could be used as a *screening* tool. Fields with a gl/p rating of 4.0 or higher would be accurately identified as N sufficient, but fields with lower ratings would need to be tested with another method to determine N adequacy.

We can only speculate about the best procedures for using these late-season N tests for field-scale application. We have done no research assessing plant-to-plant variability or determining minimum sample size for accurate results. All of these tests can indicate some level of luxury N consumption. This is especially true of the stalk NO_3^- test where our critical level was 250 mg kg^{-1} NO_3^-–N, and sample concentrations from very high-N sites were >10 000 mg kg^{-1} NO_3^-–N. In a field with both N deficient and sufficient areas, it is possible that the average N test reading could be above the critical level while the average yield for the field would be less than optimum. This potential type of error might be addressed by using a higher critical level than we determined with research size plots or by subsampling the field, especially where field variability is suspected. Subsampling a field would be easy with the CM test but somewhat more inconvenient with the stalk NO_3^- test. These late-season tests can be practical diagnostic tools, but their usefulness and accuracy will ultimately depend on the experience and expertise of the user.

REFERENCES

Beegle, D.B., R.H. Fox, and G.W. Roth. 1990. Nitrogen soil test for corn in Pennsylvania. Agron. Facts 17 (Revised ed.). Penn State College of Agric. Coop. Ext.

Binford, G.D., and A.M. Blackmer. 1993. Visually rating the nitrogen status of corn. J. Prod. Agric. 6:41–46.

Binford, G.D., A.M. Blackmer, and N.M. El-Hout. 1990. Tissue test for excess nitrogen during corn production. Agron. J. 82:124–129.

Binford, G.D., A.M. Blackmer, and B.G. Meese. 1992. Optimal concentration of nitrate in cornstalks at maturity. Agron. J. 84:881–887.

Burkhart, M.R., and D.E. James. 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. J. Environ. Qual. 28: 850–859.

Cate, R.B., Jr., and L.A. Nelson. 1965. A rapid method for correlation of soil test analyses with plant response data. Tech. Bull. 1. Int. Soil Testing Ser. North Carolina State Univ., Raleigh.

Fox, R.H., J.J. Meisinger, J.T. Sims, and W.P. Piekielek. 1992. Predicting N fertilizer needs for corn in humid regions: Advances in the Mid-Atlantic states. p. 43–56. *In* B.R. Bock and K.R. Kelley (ed.) Predicting N fertilizer needs for corn in humid regions. Natl. Fert. Environ. Res. Cent., TVA, Muscle Shoals, AL.

Fox, R.H., G.W. Roth, K.V. Iversen, and W.P. Piekielek. 1989. Soil and tissue nitrate tests compared for predicting soil nitrogen availability to corn. Agron. J. 81:971–974.

Ganoe, K.H., and G.W. Roth. 1992. Kernel milk line as a harvest indicator for corn silage in Pennsylvania. J. Prod. Agric. 5:519–523.

Hooker, B.A., and T.F. Morris. 1999. End-of-season corn stalk test for excess nitrogen in silage corn. J. Prod. Agric. 12:282–288.

Piekielek, W.P., and R.H. Fox. 1992. Use of a chlorophyll meter to predict sidedress N requirements for maize. Agron. J. 84:59–65.

Piekielek, W.P., R.H. Fox, J.D. Toth, and K.E. Macneal. 1995. Use of a chlorophyll meter at the early dent stage of corn to evaluate N sufficiency. Agron. J. 87:403–408.

Piekielek, W.P., D. Lingenfelter, D. Beegle, and R.H. Fox. 1997. The early season chlorophyll meter test for corn. Agron. Facts 53. Penn State College of Agric. Coop. Ext.

SAS Institute. 1982. SAS user's guide. 4th ed. SAS Inst., Cary, NC.

Schepers, J.S., D.D. Francis, M. Vigel, and F.E. Below. 1992. Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. Commun. Soil Sci. Plant Anal. 23:17–20.

Swistock, B.R., W.E. Sharpe, and P.D. Robillard. 1993. A survey of lead, nitrate, and radon contamination of private individual water systems in Pennsylvania. J. Environ. Health 55:6–12.

U.S. Geological Survey (USGS). 1999. The quality of our nation's waters—nutrients and pesticides. Circ. 1225.

Row Spacing, Plant Density, and Nitrogen Effects on Corn Silage

William J. Cox* and Debbie J. R. Cherney

ABSTRACT

Dairy producers in the northeastern USA who grow corn (*Zea mays* L.) forage in narrow rows plant at 125 000 plants ha^{-1} and fertilize at 225 kg N ha^{-1} because they believe narrow-row corn yields best at high plant densities and N rates. We evaluated corn in 1996 and 1997 at two row spacings (0.38 and 0.76 m), two harvest densities (80 000 and 116 000 plants ha^{-1}), and six N rates (0, 50, 100, 150, 200, and 250 kg ha^{-1}) to determine if row spacing × plant density × N rate interactions existed for dry matter (DM) and calculated milk yields. No interactions existed for DM yield, forage quality characteristics, and milk yields. Corn had greater DM and milk yields at 0.38- (20.3 and 16.1 Mg ha^{-1}, respectively) vs. 0.76-m spacing (18.9 and 15.2 Mg ha^{-1}, respectively). Dry matter and milk yields had quadratic-plus-plateau responses to N rates with maximum yields (20.6 and 17.1 Mg ha^{-1}, respectively) at an N rate of 150 kg ha^{-1}. Nitrogen accumulation at harvest, which had a row spacing × N rate interaction, had a linear response to N rates at 0.38-m spacing and a quadratic response at 0.76-m spacing. Dairy farmers in the northeastern USA can produce corn silage at similar plant densities and N fertility, regardless of row spacing. Dairy producers who have excess animal waste could apply slightly more N to narrow-row corn silage because it accumulates more N at harvest.

SOME LARGE DAIRY PRODUCERS in the northeastern USA produce corn silage under narrow rows (Cox et al., 1998). These producers, who have reported 3 to 4 Mg ha^{-1} yield responses to narrow rows, plant corn at about 125 000 plants ha^{-1} and apply about 225 kg N ha^{-1} because they believe that corn silage responds best to narrow rows under high plant densities and high N rates (Deibel, 1997). Consequently, these producers apply more animal waste, which is often in excess on their farms, to narrow-row corn. Barbieri et al. (2000), however, reported a greater grain yield response to narrow rows under N deficient conditions rather than high N conditions. Cox et al. (1998) also reported that corn silage yields do not have a row spacing × plant density interaction and that optimum plant densities for silage yields are the same at 0.38- and 0.76-m row spacing. Research is needed on the response of narrow-row corn silage under high plant densities to N rates.

Rutger and Crowder (1967) evaluated three hybrids in New York at 0.46- and 0.92-m spacing and 86 500 plants ha^{-1} and reported that row spacing did not affect corn silage yields. Bryant and Blaser (1968), however, reported that one hybrid yielded best at 0.36-m row spacing and 99 000 plants ha^{-1} and another hybrid yielded best at 0.76-m row spacing and 74 000 plants ha^{-1} in Virginia. More recently, Roth (1996) reported a 9% increase in corn silage yield at 0.38- vs. 0.76-m row spacing in Pennsylvania. Cox et al. (1998), however, reported only a 4% advantage for corn silage yield at 0.38- vs. 0.76-m row spacing in New York with no row spacing × plant density interaction. Cox et al. (1998) also reported that corn silage quality decreased as plant densities increased, so corn in narrow rows had optimum plant densi-

---

W.J. Cox, Dep. of Crop and Soil Sci.; and D.J.R. Cherney, Dep. of Animal Sci., Cornell Univ., Ithaca, NY 14853. Received 19 May 2000. *Corresponding author (wjc3@cornell.edu).

Published in Agron. J. 93:597–602 (2001).

Abbreviations: CP, crude protein; DM, dry matter; HI, harvest index; IVTD, in vitro true digestibility; LAI, leaf area index; NDF, neutral-detergent fiber.