USING CHLOROPHYLL METER READINGS TO DETERMINE N APPLICATION RATES FOR CORN[1]

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Abstract

One method for refining nitrogen (N) application in corn is use of in-season crop sensing. To aid producers in making decisions regarding N rate adjustments, a calibrated relationship between sensor-derived information and expected N application need should be established. Nitrogen rate trials were conducted at multiple sites across Iowa in 2001-2003. Nitrogen was applied at or shortly after corn planting. Minolta SPAD chlorophyll meter (CM) readings were collected at the R1 growth stage from the ear leaf. The results show a statistically significant quadratic-plateau relationship between relative chlorophyll meter (RCM) values and differential from economic optimum N rate ($R^2 = 0.69$, $P < 0.001$). The regression fit resulted in a 0.97 RCM value at zero differential from economic optimum N. A related study in 2003 at six N rate by crop rotation sites showed RCM values at the V15 and R1 growth stages were similar. This indicates adequate time is available to collect readings after significant corn N uptake and before making in-season N adjustments. This relationship between RCM value and differential from economic optimum N rate could be used by producers to determine additional N need.

Introduction

Water quality impairment related to N continues to be an important issue in Iowa. Proposed Environmental Protection Agency surface water quality criteria and total maximum daily load planning have potential to dictate strict guidance for N inputs to corn. This focus could designate N use practices that require high levels of management and economic risk. Therefore, it is important to develop N management strategies that can refine N use while improving economic return to corn production.

Rate of application is an important N management factor in corn production related to increase in nitrate reaching surface and groundwater. Rate is also important in regard to economics of corn production. Application above crop need increases the pool of nitrate in soil remaining after crop harvest and thus nitrate for potential movement out of the soil profile. While attaining only the needed fertilizer N rate in a given year will not stop nitrate from leaving cornfields or necessarily achieve proposed water quality criteria, it can result in reduced residual soil nitrate (Andraski et al., 2000). Therefore, being able to assess corn N need differentially each season could improve corn N use efficiency and reduce nitrate susceptible to loss compared to application of a base agronomic rate each year.

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Monitoring the corn plant as a means to determine N status and seasonal N availability has advantages in that the plant integrates N supply over a period of time, and hence can reflect N supply as affected by weather, soil processing, and fertilization. It can also reflect spatial variation. The longer the corn plant grows, the larger the fraction of total N accumulated (Ritchie, et al., 1986). For example, approximately 50-65% is accumulated by the silking (R1) growth stage. Effect of N supply on corn N status and yield is not well reflected visually (by N stress) in small plants (Piekielek and Fox, 1992), but is better related late in the season (Vetsch and Randall, 2004; Fox et al., 2001; Piekielek et al., 1995; Binford and Blackmer, 1993). Also, excess N is not indicated visually by plant color. These are limitations to corn plant monitoring for determining N status, especially in dryland production, as the best time to closely determine crop N need may be after it is too late to apply and have N be accessible for plant uptake. The small corn N uptake early in the season also implies that small plants can only indicate severe N shortage and cannot differentiate total season N need, especially if available soil N plus preplant N is large (Scharf and Lory, 2002). A compromise is to monitor the crop during rapid growth and after considerable N uptake, but by the early reproductive growth stages. This still allows time for N to be effective if application is needed, and to limit potential yield loss because of delayed application (Scharf et al., 2002; Binder et al., 2000; Varvel et al., 1997a; Blackmer and Schepers, 1995; Peterson et al., 1993). However, if severe N stress develops unrecoverable yield loss may occur (Scharf et al., 2002; Binder et al., 2000; Varvel et al., 1997a; Blackmer and Schepers, 1995). The potential for irreversible yield loss can be reduced with application of preplant N, monitoring for development of plant N deficiency, and in-season applications timed before significant N stress occurs and while corn can still respond to the increased soil N pool from late vegetative growth through seed fill.

Many studies using the handheld Minolta SPAD 502 chlorophyll meter (CM) to assess corn plant N status have shown reliable indication of N stress and relationship to relative yield, especially with later season sensing (Vetsch and Randall, 2004; Fox et al., 2001; Bullock and Anderson, 1998; Varvel et al., 1997b; Blackmer et al., 1994; Jemison and Lytle, 1996; Waskom et al., 1996; Piekielek et al., 1995; Blackmer and Schepers, 1994; Piekielek and Fox, 1992; Wood et al., 1992). Estimation of sidedress N rate has not been reliable with early season corn plant sensing based on CM readings from small corn plants at V6-V7 stages (Zebarth et al., 2002; Scharf, 2001; Piekielek and Fox, 1992). However, Scharf and Lory (2002) were able to predict sidedress N rate from aerial photographs of corn color at the V6-V7 stage (after removal of background soil color), but only when no N was applied preplant. Piekielek et al (1995) did find good separation of N deficient from N sufficient treatments at late milk to mid-dent corn stages, linear correlation for responsive sites between CM readings and N that would have been needed to meet economic N rates, but poor correlation between CM readings and excess N fertilizer application.

For improvement in N use efficiency and environmental impacts, a sensing system should do more than indicate N stress. It should be sensitive to estimation of N rate adjustments across a range of plant-available N, and do so early enough for N application and plant response to applied N. The objective of this work was to evaluate the potential for Minolta SPAD 502 CM readings to estimate N rate need in corn based on N stress in mid-vegetative growth (V15) and beginning reproductive growth stage (R1).

Approach

Data for the evaluation was obtained from two multi-year studies. The first study, conducted from 2001-2003, was a series of forty-three on-farm sites across Iowa with corn following soybean where replicated plots of six N rates (0 to 200 lb N/acre in 40 lb increments) were applied shortly after planting as surface applied ammonium nitrate. Minolta SPAD 502 CM readings were taken from ear leaves at the R1 growth stage following the procedure outlined by Peterson et al. (1993). The second study was a series of six long-term N by crop rotation sites (LTN) at research farms across Iowa. The plots at these sites were fixed, with N rates (0 to 240 lb N/acre in 40 or 60 lb N/acre increments) applied to the same plots each year in corn-soybean and corn-corn rotations. The N was applied either spring preplant as incorporated urea or UAN solution (five sites), or sidedress as ammonium nitrate (one site). Chlorophyll meter readings at the R1 growth stage from the first year of N rate application in the corn-soybean rotation at these sites were included with the on-farm data (eight site-years). In 2003, CM readings were collected at four crop growth stages (V8, V15, R1, and R3) from these six sites following the procedure outlined by Peterson et al. (1993). Nitrogen rate applications at four of the sites were started in 1999, one in 2000, and one in 2001. Therefore, there was a one to four year history of N rate application prior to the 2003 year. Corn grain yields were measured at all sites and economic optimum N rate (10:1 corn:N price ratio) was determined for each site-year.

The highest applied N rate was used as an adequately N-fertilized reference to calculate relative chlorophyll meter (RCM) values. Prior research with the Minolta SPAD 502 CM and with remote imagery has shown that readings should be adjusted (normalized) to an adequately N-fertilized reference area (Peterson et al., 1993; Piekielek et al., 1995; Shanahan et al., 2001) to reduce effects on plant greenness other than from N deficiency stress (for example drought, diseases, hybrid differences, and other nutrients). The mean CM readings and calculated RCM values were associated with the differential in each applied N rate from the calculated economic optimum N for each site-year. These differentials were regressed against CM readings and RCM values to determine the potential for estimating corn N need.

Results

The relationship between CM readings and differential from economic optimum N (Fig. 1) was poor for both deficit N (N rate below zero differential from optimum N) and excess N (N rate above zero differential from optimum N). This is understandable because of variation in CM readings that occurred with different hybrids, growing seasons, and stress conditions across these sites. This variation in CM readings has been noted in previous research (Peterson et al., 1993; Piekielek et al., 1995; Shanahan et al., 2001).

The relationship between CM readings and differential from economic optimum N was improved when the readings were normalized (RCM) to the highest N rate at each site (Fig 2.). The amount of scatter was greatly diminished for both deficit and excess N. Regression analyses indicated a significant quadratic plateau equation for RCM values versus differential from optimum N (RCM value = $0.97 + 0.0059*ND - 0.00000499*ND^2$ for ND less than 59 lb N/acre, $R^2 = 0.69$, $P < 0.001$; where ND is the N rate differential from optimum N in lb N/acre). The RCM value where the regression crossed the optimum N rate (zero differential from optimum N) was at 0.97. This, along with the join point in the quadratic plateau regression at 59 lb N/acre, indicates the corn ear leaf at the R1 stage cannot express much loss of chlorophyll (little N stress) or productivity will be reduced. The 0.97 RCM value is slightly higher than the 0.95 RCM value recommended by Peterson et al. (1993) to trigger N application. The shape of the relationship between RCM value and N differential is similar to that found by Piekielek et al. (1995) between ear leaf CM readings and excess N fertilizer at the early dent growth stage.

Several observations can be made from the relationship between RCM value and N rate differential from optimum N (Fig. 2). One, SPAD RCM values do not indicate excess N rate. Two, SPAD RCM values indicate N stress and N stress severity. Three, SPAD CM readings, when normalized to a well N-fertilized reference (non-N deficient), reduces variability in the relationship with yield and applied N, however variability still exits. Four, there is only small separation in RCM values from slightly N deficient corn to corn with adequate and excess N. This may limit the potential to discern and address small N rate needs, which could limit ability to fine-tune the last increments of needed N. Five, despite the significant regression fit. the scatter in data when N rate is deficit may limit potential to discern small N rate changes. However, considering the wide range is hybrids, soils, and climatic seasons contained in this large dataset, the strength in the relationship between RCM value and differential N is quite good, and perhaps surpasses other testing methods in ability to estimate N rate need when supply is short.

Time for data collection and N application, in addition to adequate time for crop response to applied N, can constrain in-season N application systems in dryland corn production. Therefore, having CM readings related to N stress and needed N from vegetative stages would be helpful. Fig. 3 shows that the average RCM values collected at the V15 and R1 stages were similar for corn following soybean. As the season progressed, the RCM values decreased. Since the sites where these readings were collected had a history of no N application on the control plots for some years, N deficiency was measured even at the early V8 growth stage. At V8, RCM values were not as differentiating between deficit N and adequate to excess N as for the other sampling dates. If one assumes that RCM values between approximately V15 and R1 remain consistent, then the regression relationship between RCM values and differential from optimum N developed from readings at R1 could be used to estimate N application need between V15 to R1. This window could then allow time for N application and crop response.

Crop rotation can impact both leaf chlorophyll and response to N. Fig. 4 shows the relationship between average RCM values and differential from optimum N for both the soybean-corn and continuous corn rotations in 2003 when readings were collected at V15 and R1 growth stages. The relationship is similar; however, because of greater N need in the continuous corn and lower resultant RCM values, the deficit in N was greater for continuous corn. One could use the regression relationship developed with the corn-soybean rotation for continuous corn, but refinement may be needed as the RCM values for both rotations at equivalent deficit N was not exact and overall covered a wider N differential range. This should be evaluated further.

Summary

As shown in previous research, Minolta SPAD 502 RCM values reflected corn N deficiency stress level, but did not differentiate between adequate and excess N. With corn following soybean, average RCM values were the same when collected at V15 and R1 growth stages. This early- to mid-season sensing can provide time for collecting data and making in-season N application adjustments. Relative chlorophyll meter values from corn following soybean and continuous corn indicated similar relationship to N rate differential from optimum N, but further work should clarify if the same N estimation can be used in both rotations. The results show a statistically significant quadratic-plateau relationship between RCM values and differential from economic optimum N rate. The regression fit resulted in a 0.97 RCM value at zero differential from economic optimum N. This relationship between RCM value and differential from economic optimum N could be used by producers to determine additional N needed for in-season application and as a method to adjust application rates for specific field and season differences. However, to determine this adjustment, corn must be showing N stress and known non-N limiting reference areas need to be present.

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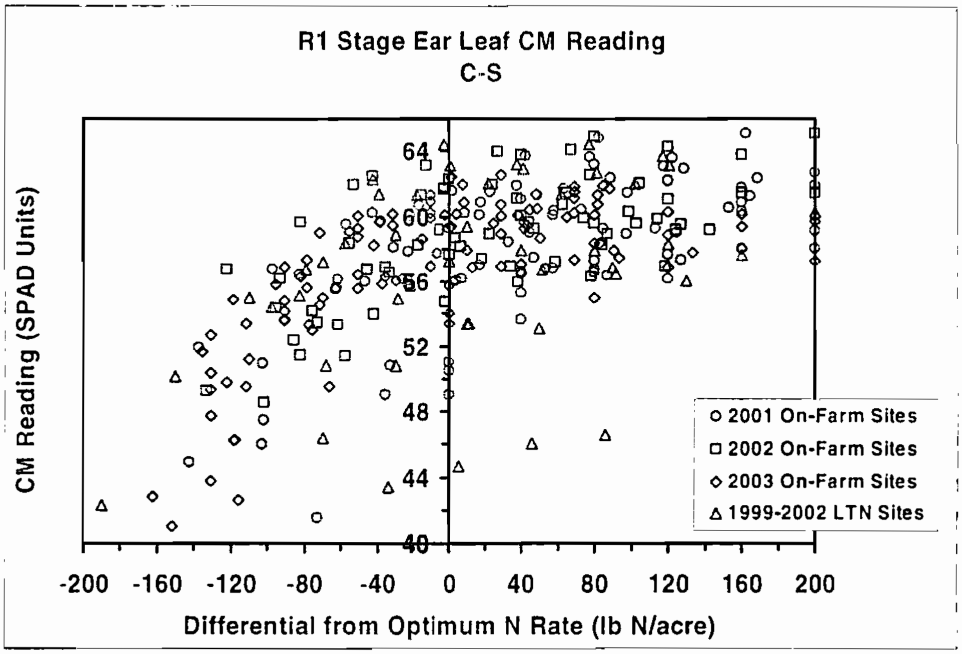

Figure 1. Chlorophyll meter readings as related to N rate differential from optimum N, corn following soybean at 51 site-years (n=306).

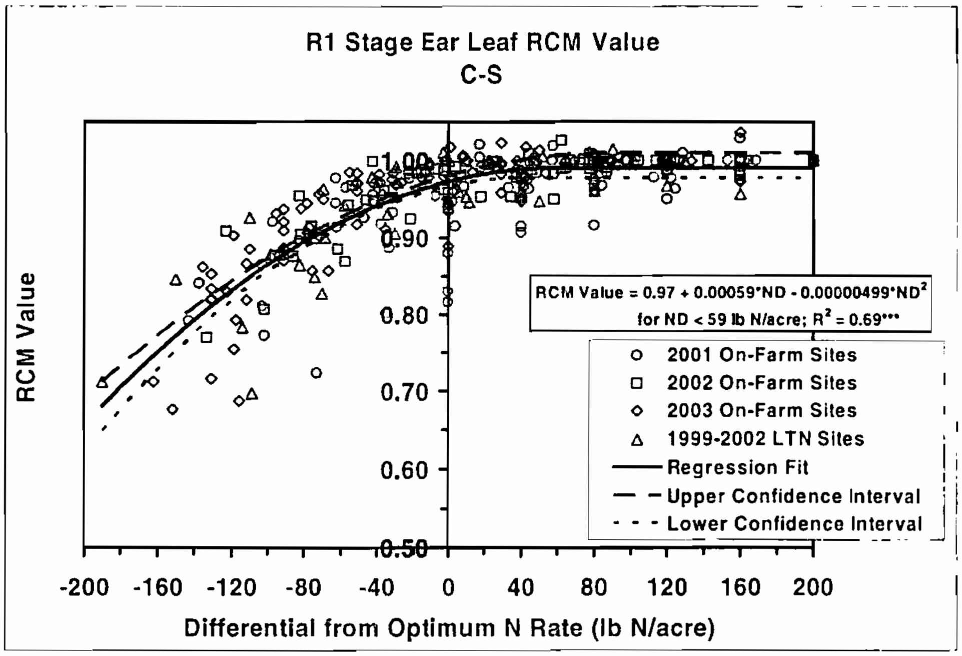

Figure 2. Relative chlorophyll meter values as related to N rate differential from optimum N, corn following soybean at 51 site-years (n = 306). The abbreviation ND in the equation is the N differential from the optimum N rate, lb N/acre.

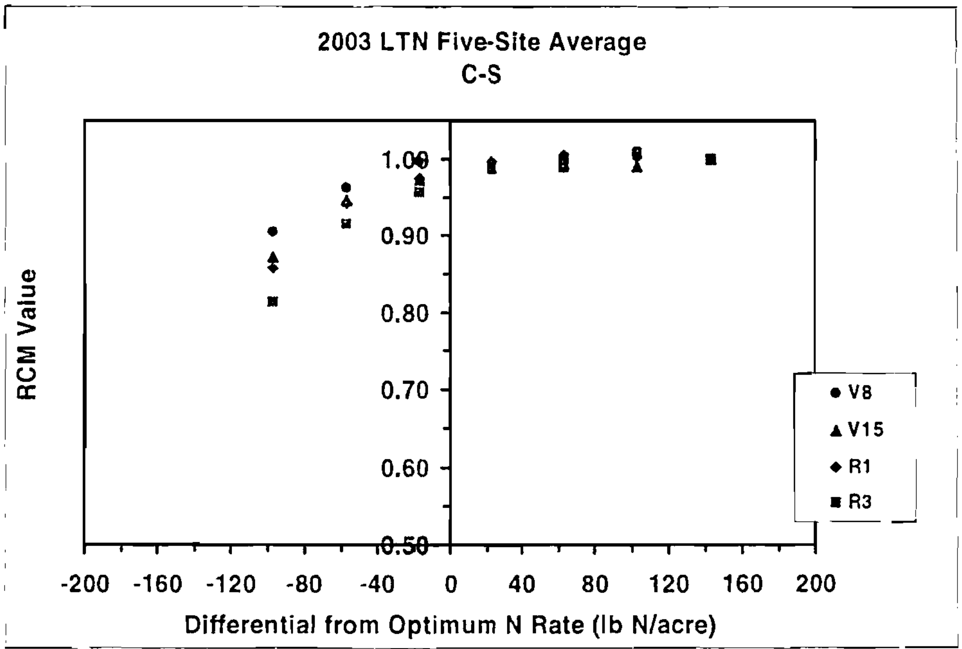

Figure 3. Average relative chlorophyll meter values as related to N rate differential from optimum N at four corn growth stages, corn following soybean.

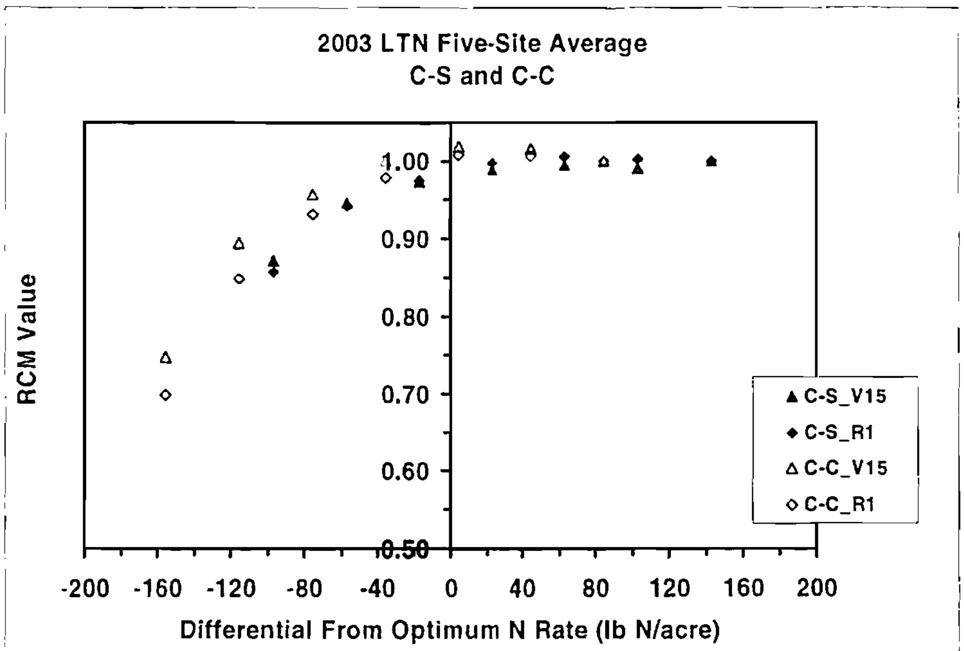

Figure 4. Average relative chlorophyll meter values as related to N rate differential from optimum N at two corn growth stages, corn following soybean and corn following corn.

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