**Project Title:** Use of Chlorophyll Meters to Assess Nitrogen Fertilization Requirements for Optimum Wheat Grain and Silage Yield and Quality

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## Abstract

Nitrogen fertilizer is the most used and often the most mismanaged nutrient input. Nitrogen management has tremendous implications on crop productivity, quality and environmental stewardship. Sufficient nitrogen is needed to optimum yield and quality. Soil and in-season plant tissue testing for nitrogen status are a time consuming and expensive process. Real time sensing of plant nitrogen status can be a useful tool in managing nitrogen inputs. The objectives of this project were to assess the reliability of remotely sensed non-destructive plant nitrogen measurements compared to wet chemistry data from sampled plant tissue, develop in-season nitrogen recommendations based on remotely sensed data for improved nitrogen use efficiency and assess the potential for determining yield and quality from remotely sensed data. Very good correlations were observed between early-season remotely sensed crop nitrogen status and nitrogen concentrations and subsequent fertilizer recommendations. The SPAD meter gave the most accurate readings. Early season fertilizer recommendation would be to apply 45 pounds nitrogen per acre plus 14 pounds nitrogen per acre for each unit difference measured between the crop and reference area. Once the crop was sufficiently fertilized meter readings became inconclusive and were of no benefit for determining nitrogen status, silage yield and protein and grain yield and protein.

## Introduction and Objectives

The southern San Joaquin Valley in 2010 produced 666 thousand tons of wheat grain valued at 143.5 million dollars on 233,300 acres. Additional wheat acreage was harvested for silage. Nitrogen requirements for wheat production are well established. The nitrogen requirement can be accurately determining by knowing the available soil nitrogen and the amount of added nitrogen. Much of the wheat silage acreage is fertilized with manure and irrigated with lagoon water. However, an accurate and thorough measurement of nitrogen levels in manure and lagoon water is rarely conducted. The over application of nitrogen has the potential to dramatically impact ground water through leaching and surface water from runoff. The quality of wheat silage, as determined by nutritional value either as energy or protein percent decreases as the plant develops. For optimum nutrition, it is recommended that wheat silage be harvested between the boot and early heading. This timing however, does not produce the most tonnage nor the most energy or protein per acre. For optimum grain production, it is recommended that split nitrogen applications be made with a majority of the nitrogen applied prior to heading. Nitrogen applications after heading may improve grain protein to meet acceptable protein levels. The use of remote sensing to determine nitrogen status in the plant is a quick method for determining if any additional nitrogen is required to produce optimum yield and quality.

Petegrove, et al. found that fifty percent of the variability in grain protein could be accounted for by flag leaf nitrogen content using transmittance/absorbance measurements made at Feekes 10.5. Murdock, et al. had correlation values between 0.88 and 0.95 for Feekes 6 meter reading and yield for both reflectance and transmittance/absorbance measurement methods. Wright, et al. overall had lower correlation ($R^2$) values with hand held meters than Murdock, et al. but they were higher than those from satellite imagery. Li, et al. observed nitrogen use efficiencies of 61.3, 51.0 and 13.1 % using sensor-based, soil minimum nitrogen management and traditional farmer practices, respectively. In an economic analysis, Biemacher, et al. determined that plant-sensing systems have the potential to increase profitability.

## Materials and Methods

Plots were established at the UCCE Kern Research Farm and UC Westside REC. A randomized complete block factorial design with three replications was used. The WSREC location provided moderate to low initial nitrogen plot area and the UCCE Kern location provided very low initial nitrogen plot area. Plots were 5 feet by 25 feet. Irrigation was sufficient to not be a limiting factor. Treatments were nitrogen fertilizer application of 0, 100, 200, and 300 lbs. of nitrogen per acre applied at planting only and the same rates at planting with additional nitrogen fertilizer at growth stage Feekes 5 to total 300 lbs. N per acre. Soil nitrogen level was tested before planting and after harvest. Plant nitrogen status was tested at Feekes 3, 6 and 8 and 10 (tillering through flag leaf extension). Plant nitrogen measurements were made by reflectance, transmittance/absorbance, and wet chemistry at the UC Davis Analytical Lab.

The three instruments used to remotely sense plant nitrogen content use either reflectance or light transmittance/absorbance. The reflectance method uses ambient and reflected light in the 660 and 840 nm wavelengths to calculate a relative chlorophyll index. This instrument is the Spectrum® FieldScout® CM 1000 NDVI Meter. The hand held device can measure areas from 1.5 inch to 4.5 inch diameter. This is the same methodology that is incorporated in aerial or satellite imagery. "Normalized difference vegetation index" or NDVI measurements were made with the instrument about 2 feet above the crop canopy with a 45 or 90 degree angle to the canopy. Measurements from reflected light are abbreviated CM 1000 45 or CM 1000 90, respectively, for the different angles.

The transmittance/absorbance instruments were the Konica® Minolta® SPAD 502 Plus, and the Opti-Sciences® CCM-200. These meters are clamped on a leaf and utilize the 650 and 940 nm wavelengths and 653 and 931 nm wavelengths, respectively, to determine a relative chlorophyll index. Measurements were made at different locations on the plant leaf to determine the most representative spot in 2011 (Table 8). Measurements in 2012 were made at the midpoint between the leaf tip and collar as has been recommended by other research. The CM 1000 NDVI meter displays the NDVI calculation (-1.0 to 1.0). The SPAD meter readings are a relative index (-9.99 to 199.9) calculated from NDVI times a constant whereas the CCM meter readings are the ratio of readings (653 nm divided by 931) thus the scale is different.

## Results

There was no difference in silage or grain yield or protein for treatments at West Side REC that received 300 pounds of nitrogen fertilizer per acre whether at planting or at Feekes 5 (Table 1). The zero nitrogen treatment was significantly lower in yield and protein than the other at planting only nitrogen treatments which were not significantly different. CM 1000 readings were not significantly different at Feekes 5. SPAD and CCM 200 meter readings for the zero nitrogen rate treatment at planting were significantly lower than the other treatments (Table 2).

Silage and grain yield and grain protein were not significantly different at the Kern Research Farm for all treatments that received a total of 300 pounds nitrogen per acre except for the zero nitrogen treatment at planting (Table 3). Wheat growth and development was delayed and very little tillering occurred in this treatment due to the very low initial soil nitrogen. Silage and grain yield continued to increase with higher nitrogen rates. Plant nitrogen concentration at Feekes 5 increased with each increase in nitrogen rate (Table 4).

Very good correlations ($R^2$>0.83 & 0.98) were observed between meter readings from the CM 1000 and V5 nitrogen concentration at the Kern location for either observation angle (Figure 1). There were only small differences between readings at the West Side REC location although the correlations were good to very good. Varietal differences at the locations may have contributed to the difference in reading with comparable nitrogen concentration. The SPAD and CCM 200 meters also had very good correlations between the meter reading and V5 nitrogen concentration (Figure 2). Variety difference between the locations was again evident in the differences in meter readings.

The difference between the meter reading of the well fertilized treatment and the other treatments was calculated. Those differences had a good correlation at the Kern location for the CM 1000 at either measured angle (Figure 3). There was very little separation in the meter readings at the West Side REC location. Good correlations were observed for both the SPAD and CCM 200 meters at both locations (Figures 4 & 5).

Figure six includes 2011 and 2012 data. This generates more data points for calculating a recommended nitrogen fertilizer rate based on SPAD chlorophyll meter readings. Other multiyear data will be discussed after the completion of a third year of testing.

## Discussion, Conclusions and Recommendations

Early spring sampling of wheat plants can provide useful information on plant nitrogen status and the need for additional nitrogen fertilizer. The use of chlorophyll meters provides quick and accurate information needed for nitrogen fertilizer recommendations.

Generally grain yields were equivalent for all locations where total nitrogen applied was the same. Where irrigation is correctly managed or winter rains do not leach fall applied nitrogen fertilizer there is no difference in grain yield based on timing of fertilizer application.

SPAD meter measurements should be made mid leaf on the upper most fully exposed leaf for greatest consistency and accuracy. Plants and leaves that are not representative of the field, under stress or insect damaged should not be used. Following recommendations from other research, CM 1000 measurements were made between 10:00 am and 2:00 pm and without shadows on the crop or meter for maximum ambient light. CM 1000 measurements made early in the season should be made with the instrument at a 45 degree angle from the crop. Too much bare soil can be included in the measurements made at a 90 degree angle early in the season thereby making those measurements less reliable. The 90 degree angle CM 1000 late-season measurements were more precise than the 45 degree angle measurements.

Early season nitrogen fertilizer recommendation is as follows:

Apply the expected full nitrogen fertilizer rate on a reference area at least three weeks prior to sampling with actively growing plants. The reference area should be representative of the field and can be several small areas throughout the field or a strip through the field. At Feekes 5 to 6, compare the readings from the reference areas to readings from the remainder of the field. Because individual plants vary, at least 30 readings should be made throughout the field and reference area. The difference between the averages of the readings will give an indication of the need for additional nitrogen fertilizer.

The nitrogen rate calculation is:

$$N = 45 + 14D$$

N = Recommended Nitrogen Rate in lbs N/A

D = Difference in SPAD meter reading between measured crop and reference area

The additional plots that are not fully fertilized helped to determine optimum nitrogen fertilizer requirements and yield potential for the different soils and sites. The sites selected were a good representation of a range of soil types and yield potential. There were differences in the slope and intercept from each year. Combining the data increases the robustness of the recommendation equation. Additional measurement distance (size of area sampled) needs to be explored for the CM 1000 meter.

**References**

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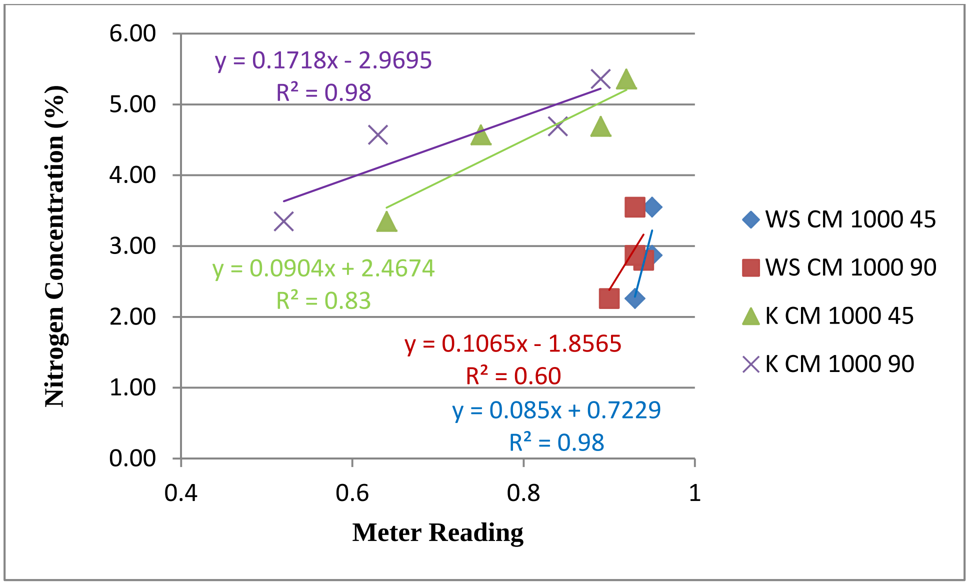


Figure 1. V5 Tissue Nitrogen Concentration versus NDVI Reading.

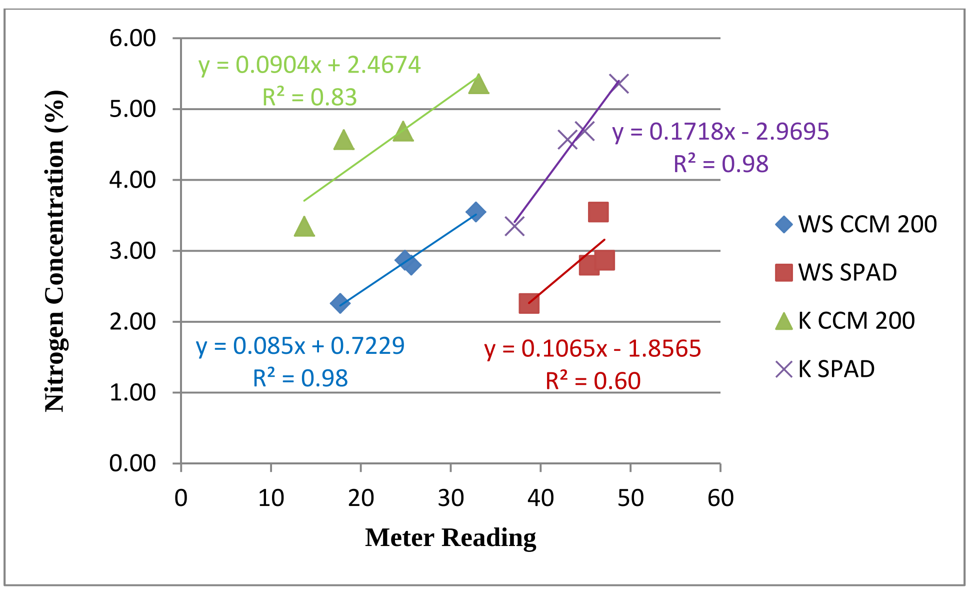


Figure 2. V5 Tissue Nitrogen Concentration versus SPAD and CCM 200 Meter Readings.

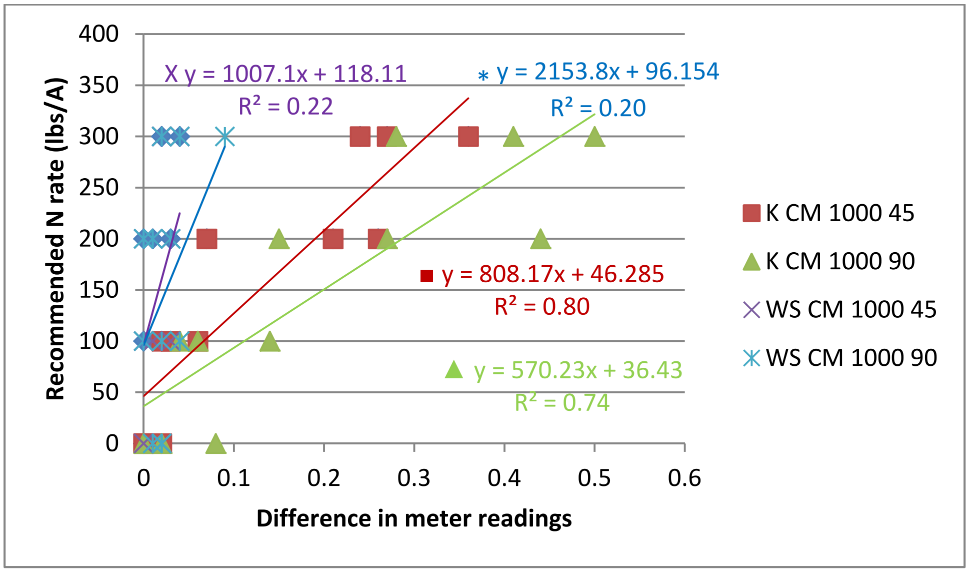


Figure 3. Recommended Nitrogen Rate versus NDVI Differential.

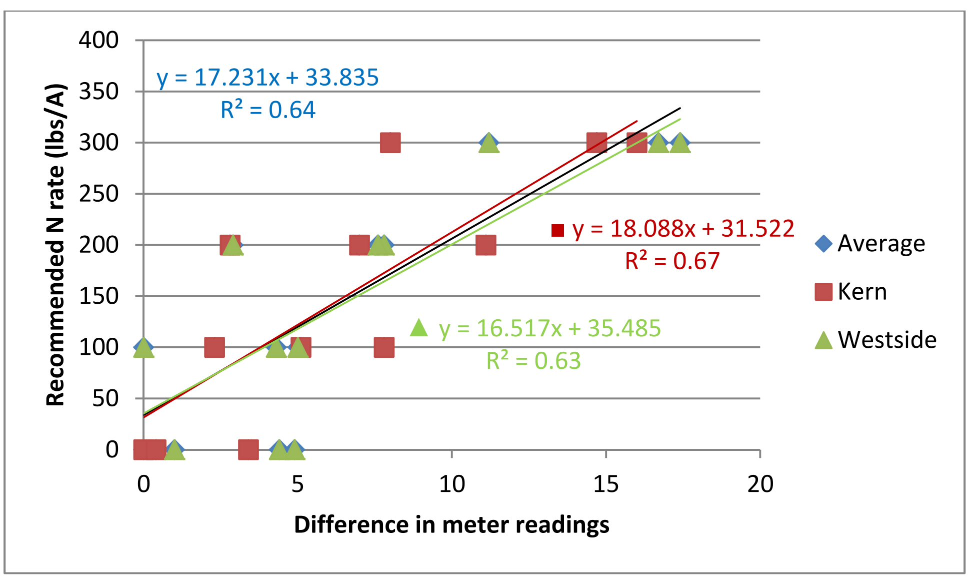


Figure 4. Recommended Nitrogen Rate versus SPAD Differential.

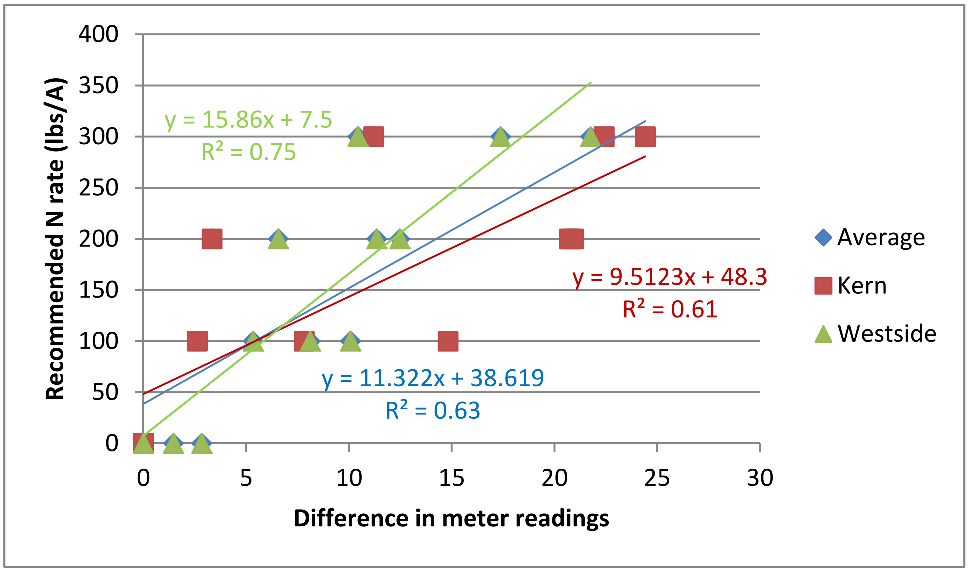


Figure 5. Recommended Nitrogen Rate versus CCM 200 Differential.

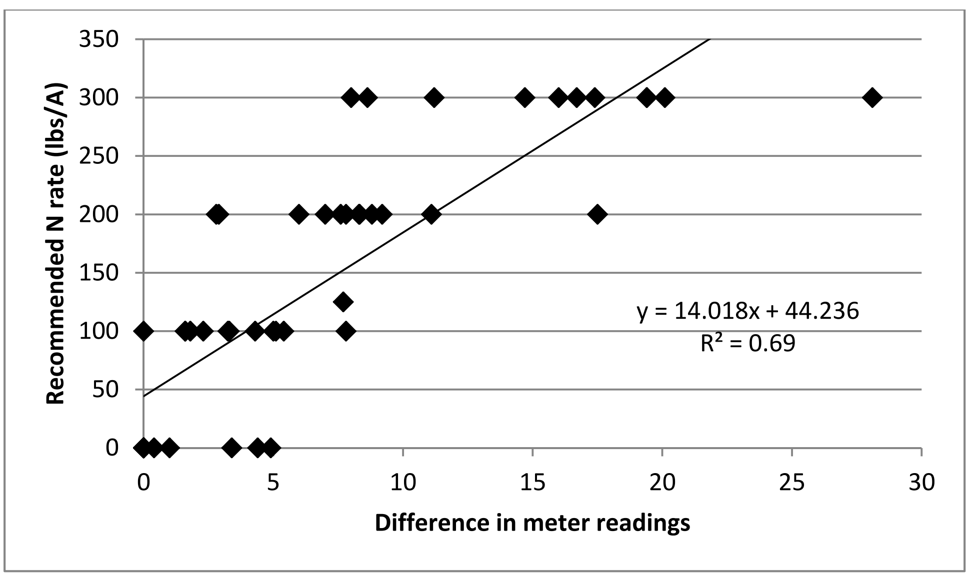


Figure 6. Recommended Nitrogen Rate versus SPAD Differential.

Table 1. West Side REC

| lbs N at planting | lbs N at Fekes 5 | Silage Yield | Flag Leaf N | Grain Yield | Grain Protein |
|---|---|---|---|---|---|
| | | - Tons/A - | -- % -- | -- lbs/A -- | -- % -- |
| 0 | 300 | 22.3 | 4.31 | 6766 | 14.5 |
| 100 | 200 | 21.0 | 4.54 | 6460 | 14.0 |
| 200 | 100 | 23.3 | 4.46 | 6750 | 14.7 |
| 300 | 0 | 24.6 | 4.82 | 7200 | 15.8 |
| 0 | 0 | 15.8 | 3.84 | 5250 | 8.9 |
| 100 | 0 | 22.5 | 4.12 | 6417 | 12.3 |
| 200 | 0 | 21.0 | 4.21 | 5966 | 14.4 |
| 300 | 0 | 24.8 | 4.76 | 6466 | 14.6 |
| $LSD_{0.05}$ † | | 4.1 | 0.21 | 915 | 3.0 |
| CV%†† | | 13.4 | 7.1 | 7.6 | 8.2 |

† Least Significant Difference

††Coefficient of Variation.

Table 2. West Side REC

| | | Growth Stage Feekes 5 | | | | |
|---|---|---|---|---|---|---|
| lbs N at planting | lbs N at Fekes 5 | CM 1000 45 | CM 1000 90 | SPAD | CCM 200 | N content |
| | | | | | | % |
| 0 | 300 | 0.93 | 0.90 | 38.7 | 17.7 | 3.26 |
| 100 | 200 | 0.94 | 0.94 | 45.4 | 25.6 | 3.98 |
| 200 | 100 | 0.95 | 0.93 | 47.1 | 24.9 | 3.87 |
| 300 | 0 | 0.95 | 0.93 | 46.4 | 32.8 | 4.55 |
| $LSD_{0.05}$ | | ns†† | ns | 4.4 | 6.1 | 0.98 |
| CV%‡ | | 1.55 | 2.53 | 12.2 | 12.9 | 6.3 |

‡Not Significantly Different.

Table 3. Kern Research Farm

| lbs N at planting | lbs N at Fekes 5 | Silage Yield | Flag Leaf N | Grain Yield | Grain Protein |
|---|---|---|---|---|---|
| | | - Tons/A - | -- % -- | -- lbs/A -- | -- % -- |
| 0 | 300 | 14.6 | 4.62 | 3667 | 16.9 |
| 100 | 200 | 22.7 | 4.66 | 6033 | 17.6 |
| 200 | 100 | 24.0 | 4.88 | 6383 | 18.2 |
| 300 | 0 | 25.9 | 4.38 | 6807 | 16.8 |
| 0 | 0 | 11.8 | 3.33 | 3000 | 15.1 |
| 100 | 0 | 17.5 | 3.77 | 4000 | 15.0 |
| 200 | 0 | 20.5 | 4.40 | 5433 | 15.7 |
| 300 | 0 | 22.4 | 4.44 | 6467 | 17.8 |
| $LSD_{0.05}$ | | 4.1 | 0.42 | 820 | 2.0 |
| CV% | | 9.3 | 7.0 | 9.0 | 6.6 |

Table 4. Kern Research Farm

| | Growth Stage Feekes 5 | | | | |
|---|---|---|---|---|---|
| lbs N at planting | CM 1000 45 | CM 1000 90 | SPAD | CCM 200 | N content |
| | | | | | % |
| 0 | 0.64 | 0.52 | 37.1 | 13.7 | 3.35 |
| 100 | 0.75 | 0.63 | 43.0 | 18.1 | 4.57 |
| 200 | 0.89 | 0.84 | 44.9 | 24.7 | 4.69 |
| 300 | 0.92 | 0.89 | 48.7 | 33.1 | 5.36 |
| $LSD_{0.05}$ | 0.22 | 0.21 | 2.6 | 5.1 | 1.01 |
| CV% | 5.4 | 7.7 | 7.4 | 10.3 | 6.8 |