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Use of Chlorophyll Meters to Assess In-Season Wheat Nitrogen Fertilizer Requirements in the Southern San Joaquin Valley

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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 plant nitrogen concentrations and subsequent in-season fertilizer recommendations. The transmittance/absorbance type meters gave the most accurate readings. Early in-season fertilizer recommendation would be to apply 40 kg nitrogen per hectare plus 15 kg nitrogen per hectare for each unit difference measured with the SPAD meter between the crop and reference area or 25 kg plus 13 kg per hectare for each unit difference measured with the CCM 200. Once the crop was sufficiently fertilized meter readings became inconclusive and were of no benefit for determining nitrogen status, silage yield and quality and grain yield and protein.

Keywords**—**Wheat, nitrogen fertilization, chlorophyll meter.

I. Introduction

THE Southern San Joaquin Valley in 2012 produced 660 thousand Mg of wheat grain valued at 194.1 million dollars on 96,000 hectares. Almost twice that 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 dairy waste 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 hectare. For optimum grain production, it is recommended that split nitrogen applications be made with a majority of the nitrogen applied prior to heading [1]. 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.

Pettygrove et al. [2] found that 50 percent of the variability in grain protein could be accounted for by flag leaf nitrogen concentration using transmittance/absorbance measurements made at growth stage Feekes 10.5. Murdock et al. [3] had correlation values between 0.88 and 0.95 for growth stage Feekes 6 meter reading versus yield for both reflectance and transmittance/absorbance measurement methods. Wright et al. [4] overall had a 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. [5] observed nitrogen use efficiencies of 61.3, 51.0 and 13.1 percent using sensor-based, soil minimum nitrogen management and traditional farmer practices, respectively. In an economic analysis, [6] determined that plant-sensing systems have the potential to increase profitability.

II. Materials and Methods

Plots were established each year from 2011 to 2013 in a different location at the University of California Cooperative Extension Kern Research Farm (KRF) on a Wasco sandy loam (coarse-loamy, mixed, nonacid, thermic Typic Torriorthent) soil and at the UC West Side Research and Extension Center (WSREC) on a Panoche clay loam (Fine-loamy, mixed, superactive, thermic Typic Haplocambid). A randomized complete block factorial design with three replications was used. Soil nitrogen level was tested before planting and after harvest. The expectation was that the WSREC location would provide moderate to low initial nitrogen plot area and the UCCE Kern location would provide very low initial nitrogen plot area. Soil nitrate was 20 to 25 kg N ha^{-1} each year at KRF. Pre-plant soil nitrate at WSREC ranged from 20 to 130 kg N ha^{-1} over the years. Plots were 1.5 meters by 7.7 meters. Wheat (*Triticum aestivum*) was drilled in rows 20 cm apart in December of each year at a rate of 3 million seeds per hectare. Irrigation was sufficient to not be a limiting factor and without leaching nitrates below the root zone. Treatments were

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nitrogen fertilizer applications of 0, 112, 224, and 336 kg nitrogen per hectare applied at planting only and the same rates at planting with additional nitrogen fertilizer at growth stage Feekes 5 to total 336 kg N per hectare. Nitrogen was applied as urea with a urease inhibitor. Plant nitrogen status was tested at Feekes 5 and 10 (tillering and flag leaf extension). Plant nitrogen measurements were made by transmittance/absorbance and reflectance meters, and wet chemistry at the UC Davis Analytical Lab.

The three instruments used to 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 4 cm to 12 cm 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 60 cm 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 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. Measurements shown in the tables and used in the calculations were made on the most recent fully expanded leaf at the midpoint between the leaf tip and collar. 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 931nm) thus the scale is different.

III. Results and Discussion

For common wheat at growth stage Feekes 5 there was no difference in the main effect of fertilizer rate for the CM 1000 meter readings at either 45 or 90 degree angles (Table I). Neither were there any CM 1000 measurement differences in 2011 or 2012 at either location (data not shown). There was a significant difference in the measured value with the SPAD and CCM 200 meters and whole plant N between the zero nitrogen treatment and any treatment that received nitrogen fertilizer, the exception is WSREC SPAD meter readings where there were no significant differences. Similar results were observed in the other years (data not shown). At the KRF site with very low pre-plant soil nitrate, the CCM 200 meter measurements were significantly different between N rates from 0 to 224 kg N ha^{-1}. This occurred only at this location where there was very little soil organic matter (< 1 mg g^{-1}) to contribute to the N pool. Whole plant N at growth stage Feekes 5 was significantly lower in the 0 N treatment than the 224 and 336 kg N treatments. All would be considered below the sufficiency range of 40 to 50 mg g^{-1} [7]. Dry matter also increased with increasing N rate at both locations.

TABLE I
Effect of N Fertilizer on Plant N Concentration and Chlorophyll Meter Reading, 2013

N at planting	Growth Stage Feekes 5					Dry Matter
	CM 1000 45	CM 1000 90	SPAD	CCM 200	Whole Plant N	
-kg ha^{-1}-	--------- Meter Reading ---------				-mg g^{-1}-	-kg ha^{-1}-
			WSREC			
0	0.95	0.95	44.5	27.7	18.6	3725
112	0.96	0.94	43.7	31.2	28.8	5301
224	0.97	0.95	43.0	31.3	34.8	5344
336	0.96	0.95	44.6	32.6	36.6	6303
$LSD_{0.05}$	ns	ns	ns	1.6	10.1	355
			KRF			
0	0.93	0.92	37.5	17.9	20.0	3634
112	0.93	0.95	44.9	31.1	26.7	5344
224	0.93	0.93	46.7	39.9	32.4	5346
336	0.92	0.94	47.1	41.1	39.6	6304
$LSD_{0.05}$	ns	ns	1.7	1.5	11.6	1466

Good correlations of R^2 = 0.73 and 0.79 were observed between readings from the SPAD and CCM 200 meters, respectively, and the V5 whole plant nitrogen concentration averaged over years (Figs. 1 and 2). There was no relationship between CM 1000–45 or CM 1000–90 meter readings and V5 whole plant nitrogen concentrations (Fig. 3).

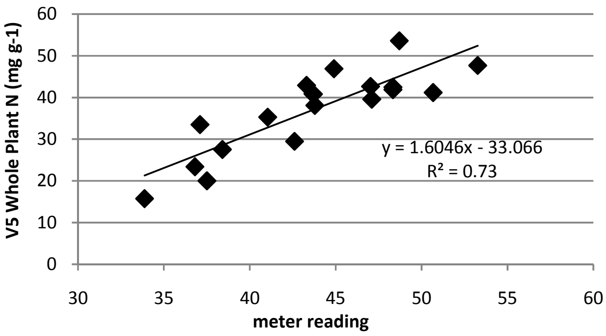

Fig. 1 V5 whole plant N versus SPAD meter reading

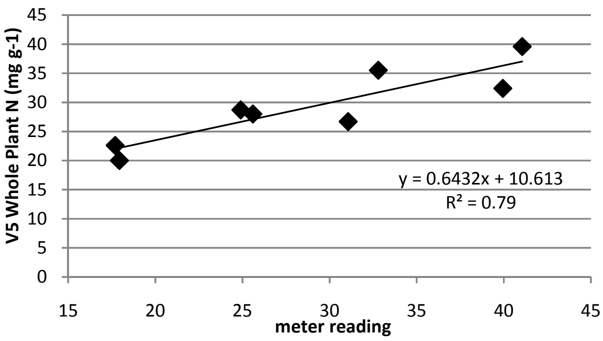

Fig. 2 V5 whole plant N versus CCM 200 meter reading

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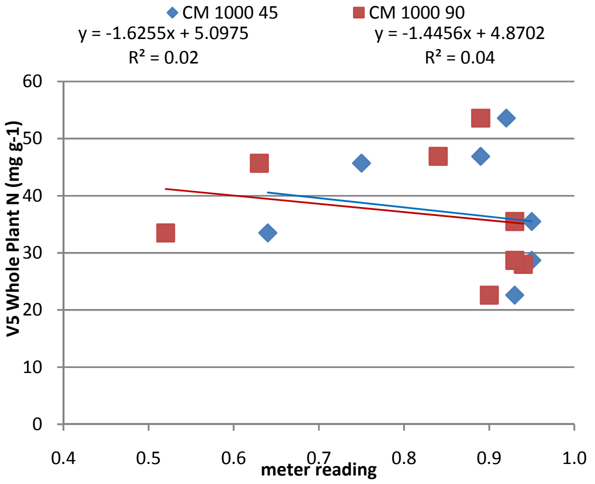

Fig. 3 V5 whole plant N versus CM 1000 meter reading

TABLE II
EFFECT OF N FERTILIZER ON YIELD AND PROTEIN, WSREC

N at planting	N at Feekes 5	Silage Yield	Flag Leaf N	Grain Yield	Grain Protein
----- kg ha^{-1} -----		-Mg ha^{-1}-	-mg g^{-1}-	- kg ha^{-1} -	- mg g^{-1}-
		2012			
0	336	50.0	43.1	7578	165
112	224	44.8	45.4	7235	150
224	112	52.2	44.6	7560	157
336	0	57.3	48.2	8064	178
0	0	35.4	38.4	5880	89
112	0	50.4	41.2	7187	123
224	0	47.0	42.1	6682	144
336	0	55.6	47.6	7242	146
$LSD_{0.05}$		3.0	7.1	885	82
		2013			
0	336	47.3	46.0	6527	148
112	224	52.6	44.3	6272	153
224	112	51.1	44.8	7039	145
336	0	54.7	42.3	6455	143
0	0	35.8	32.9	4779	125
112	0	50.4	37.2	6705	143
224	0	53.3	39.7	6763	151
336	0	55.1	41.6	6625	148
$LSD_{0.05}$		5.6	5.9	886	7

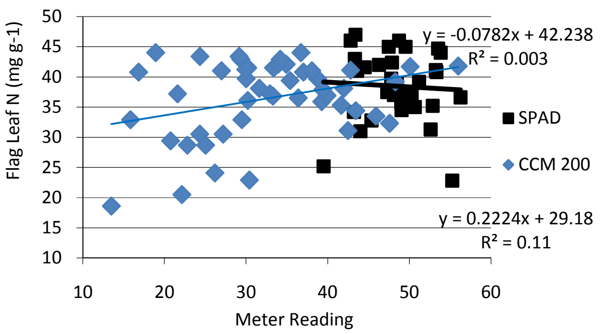

Fig. 4 Flag leaf nitrogen concentration versus meter readings

TABLE III
EFFECT OF N FERTILIZER ON YIELD AND PROTEIN, KRF

N at planting	N at Feekes 5	Silage Yield	Flag Leaf N	Grain Yield	Grain Protein
----- kg ha^{-1} -----		-Mg ha^{-1}-	-mg g^{-1}-	- kg ha^{-1} -	- mg g^{-1}-
		2012			
0	336	32.7	46.2	4107	179
112	224	50.8	46.6	6757	186
224	112	53.8	48.8	7149	192
336	0	58.0	43.8	7624	178
0	0	26.4	33.3	3360	151
112	0	39.2	37.7	4480	150
224	0	45.9	44.0	6085	157
336	0	50.2	44.4	7243	178
$LSD_{0.05}$		9.2	4.2	918	20
		2013			
0	336	40.8	39.2	5792	146
112	224	43.9	36.9	5768	146
224	112	42.6	40.8	5840	150
336	0	43.0	41.1	6241	155
0	0	26.7	25.2	2994	124
112	0	34.0	31.0	4113	137
224	0	35.6	35.0	5248	135
336	0	43.9	37.5	5776	147
$LSD_{0.05}$		7.2	6.2	981	5

Flag leaf nitrogen continued to increase with each increasing N application rate in all years. The response was greater at KRF where the initial soil nitrate was very low. All of the full rate fertilizer treatments, whither a single application or split application, had equivalent flag leaf N concentrations (Tables II, III). Flag leaf N concentrations in the full rate treatments were within the sufficiency range [7]. Calculated regression lines for any of the meter readings versus flag leaf N concentration did not reveal a strong relationship (Fig. 4).

There were no differences in SPAD measurements sampling on the upper or lower leaf surface and no interaction with different nitrogen concentrations (Table IV). There was a significant difference when measurements were made along the length of the leaf. Relative chlorophyll amounts increased as measurements were made from the leaf base to the leaf tip. It is recommended to sample mid-point on the leaf [8].

For common wheat there was no difference in silage or grain yield or protein for any treatment each year at WSREC that received any nitrogen fertilizer at planting or at Feekes 5 (Table II). The zero nitrogen treatment was significantly lower in yield and protein than the other at planting only nitrogen treatments which were not significantly different.

Silage and grain yield increased with increasing N fertilizer rate in the at-planting only treatments at the Kern Research Farm. All treatments that received a total of 336 kg nitrogen per hectare were not significantly different (Table III). Wheat growth and development was reduced and very little tillering occurred in the 0 N treatment due to the very low initial soil nitrogen. The lack of development prior to Feekes 5 limited the potential for yield as shown in the 2012 yield.

TABLE IV
EFFECT OF SAMPLING LOCATION ON SPAD METER READING

Leaf Position	Nitrogen Concentration	Meter Reading
Upper Surface		41.0
Lower Surface		41.6
$LSD_{0.05}$		ns
	Low N	26.7
	Medium N	46.9
	High N	50.4
$LSD_{0.05}$		2.5
Upper Surface	Low N	25.9
	Medium N	47.5
	High N	49.7
Lower Surface	Low N	27.4
	Medium N	46.3
	High N	51.1
$LSD_{0.05}$		ns
Near Base		39.6
Mid Leaf		41.7
Near Tip		45.3
$LSD_{0.10}$		4.3

To calculate the recommended in-season N fertilizer rate, the difference between the meter reading of the well fertilized treatment and the other treatments was calculated. A regression line was calculated for the difference in meter reading and the recommended N rate. There is good correlation for each meter (Figs. 5 and 6).

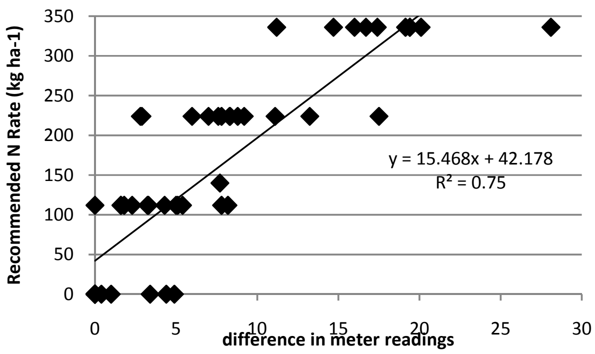

Fig. 5 Recommended nitrogen rate for common wheat versus SPAD difference

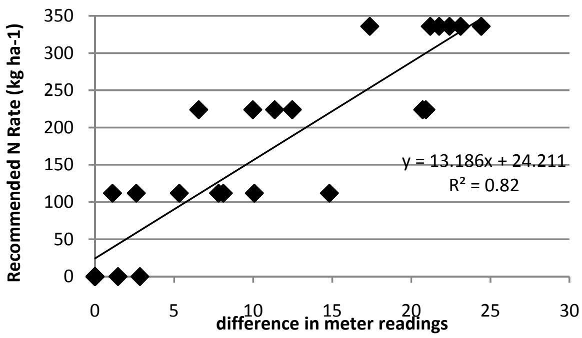

Fig. 6 Recommended nitrogen rate for common wheat versus CCM 200 difference

IV. CONCLUSIONS

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. The exception was in the very low initial fertility sandy soil at the Kern Research Farm. There was less growth and tillering prior to V5 fertilizer application than the other treatments. The wheat plants were always smaller and exhibited different development timing.

Early in-season nitrogen fertilizer recommendation for common wheat in the Southern San Joaquin Valley is as follows:

Apply the expected full nitrogen fertilizer rate on a reference area with actively growing plants at least three weeks prior to sampling. 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. SPAD and CCM 200 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. 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 for common wheat is:

$$N = 40 + 15D \quad \text{using the SPAD meter} \quad (1)$$

$$N = 25 + 13D \quad \text{using the CCM 200 meter} \quad (2)$$

where: N = Recommended Nitrogen Rate in kg N ha^{-1}; D = Difference in meter reading between measured crop and reference area.

As an example, if the average meter reading between the fertilizer reference sites and the field with the SPAD meter was 10, then the recommendation nitrogen fertilizer rate would be 40 + (15 * 10) for a total of 190 kg N ha^{-1}.

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