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 transmittance/absorbance type meters 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 with the SPAD meter between the crop and reference area or 35 pounds plus 11 pounds 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 protein and grain yield and protein.

Introduction and Objectives

The southern San Joaquin Valley in 2012 produced 728 thousand tons of wheat grain valued at 194.1 million dollars on 237,900 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 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. 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, 5 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 and were reported previously. Measurements in 2013 were made 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 931) thus the scale is different.

Results

For common wheat there was no difference in silage or grain yield or protein for treatments at West Side REC that received any nitrogen fertilizer 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. CCM 200 meter readings for the zero nitrogen rate treatment at planting were significantly lower than the other treatments (Table 2). That difference was not discernible with the SPAD meter. The initial soil nitrogen measurement was more than 120 lbs. per acre which limited the usefulness of this location.

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 reduced 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 in the at-planting only treatments. Plant nitrogen concentration at Feekes 5 increased with each increase in nitrogen rate (Table 4).

Similar results were observed for durum wheat at both locations. The zero nitrogen treatment at WSREC had lower flag leaf N concentration, yield and grain protein (Table 5). All other treatments were equivalent in meter readings, N content and yield (Table 6). At the Kern Research Farm significant differences were observed. All treatments that received 300 lbs. N per acre had equivalent yields except for the 0 nitrogen treatment at planting (Table 7). It followed the same pattern as with common wheat. Early season growth was stunted to the point where the plants never recovered once nitrogen fertilizer was applied. Positive responses were observed for each increase in nitrogen fertilizer application in N content, and yield. These differences were measureable with the SPAD and CCM 200 meters. The CM 1000 meter only had measureable differences between the 0 and 100 lb. N treatments (Table 8).

Very good correlations ($R^2 > 0.77$ to 0.96) were observed between readings from the CCM 200 and SPAD meters and the V5 nitrogen concentration for both common and durum wheat at the Kern location (Figures 1 & 2). There was no relationship between meter readings and flag leaf nitrogen concentrations (Figure 3).

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 SPAD and CCM 200 meters. That data was combined with data from the previous years to calculate recommended nitrogen fertilizer recommendations (Figures 4 & 5). There was very little separation in the meter readings at the West Side REC location.

Readings made with the CM 1000 did not vary with any of the treatments except for the zero nitrogen treatment in the Durum wheat study at the low initial N Kern Research Farm. There was excellent correlation between the nitrogen rate and meter reading difference for the SPAD and CCM 200 meters using the Kern site data and only the 100 lbs. N treatment data from WSREC (Figure 6).

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. 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 season nitrogen fertilizer recommendation 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:

$$N = 45 + 14D \qquad \text{using the SPAD meter}$$

$$N = 36 + 11D \qquad \text{using the CCM 200 meter}$$

N = Recommended Nitrogen Rate in lbs N/A

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

The nitrogen rate calculation based on data from one year only for durum wheat is:

N = 6 + 15D using the SPAD meter

N = 36 + 33D using the CCM 200 meter

N = Recommended Nitrogen Rate in lbs N/A

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

What didn't get accomplished

An additional meter (Opi-Sciences CCM 300) was purchased this year that is purported to measure chlorophyll content with greater accuracy. This instrument would be beneficial for work to be conducted for flag leaf measurements and late season nitrogen applications. Because it was on backorder I did not receive it in time to make any measurements this year. Steve Orloff used the 4 meters in work that he was conducting and was going to make some flag leaf measurements for me at IREC in conjunction with his work. He was not able to make those measurements for me. There was not any late season nitrogen application work conducted this year.

References

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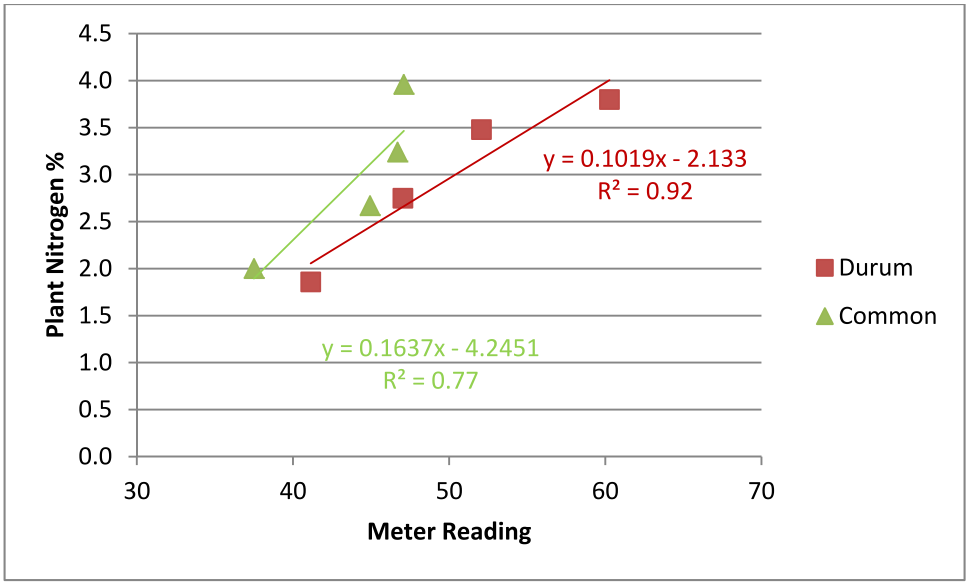

Figure 1. V5 Tissue Nitrogen Concentration versus SPAD Meter Reading, 2013.

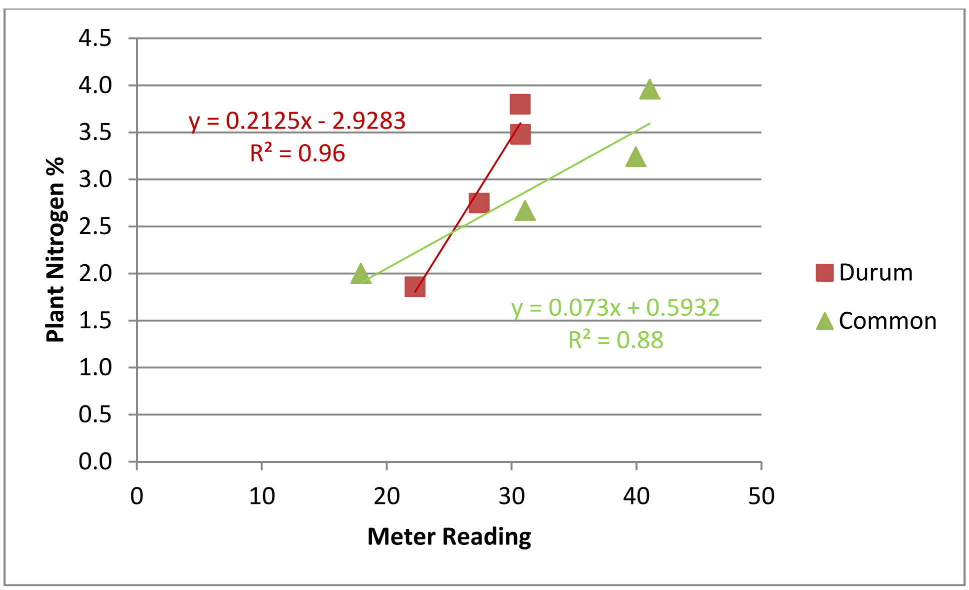

Figure 2. V5 Tissue Nitrogen Concentration versus CCM 200 Meter Readings, 2013.

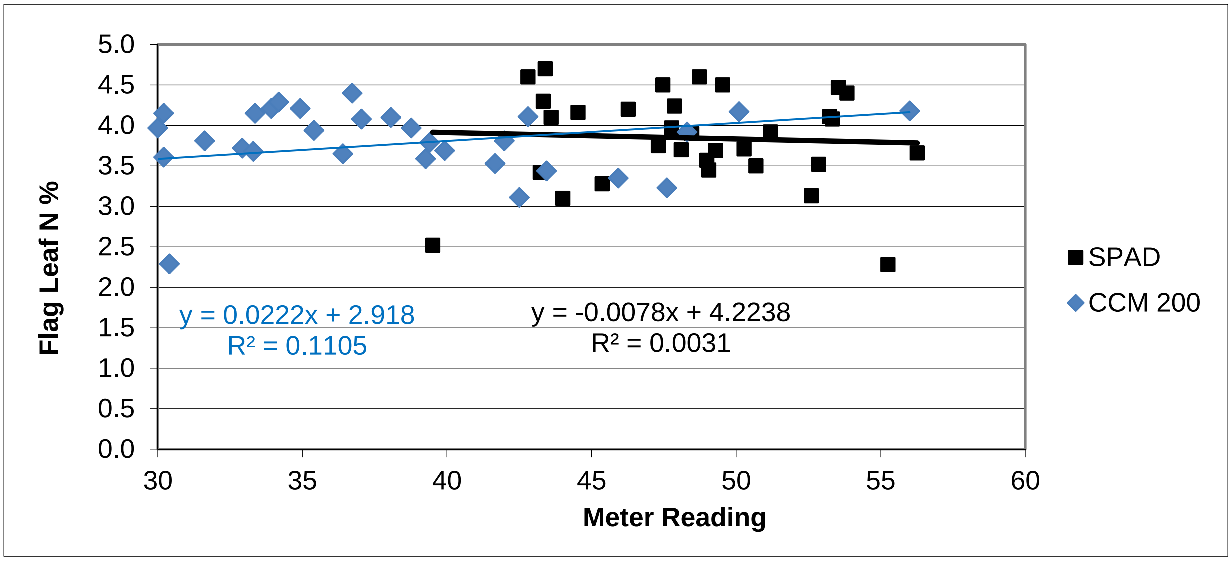

Figure 3. Flag Leaf Nitrogen Concentration versus Meter Readings.

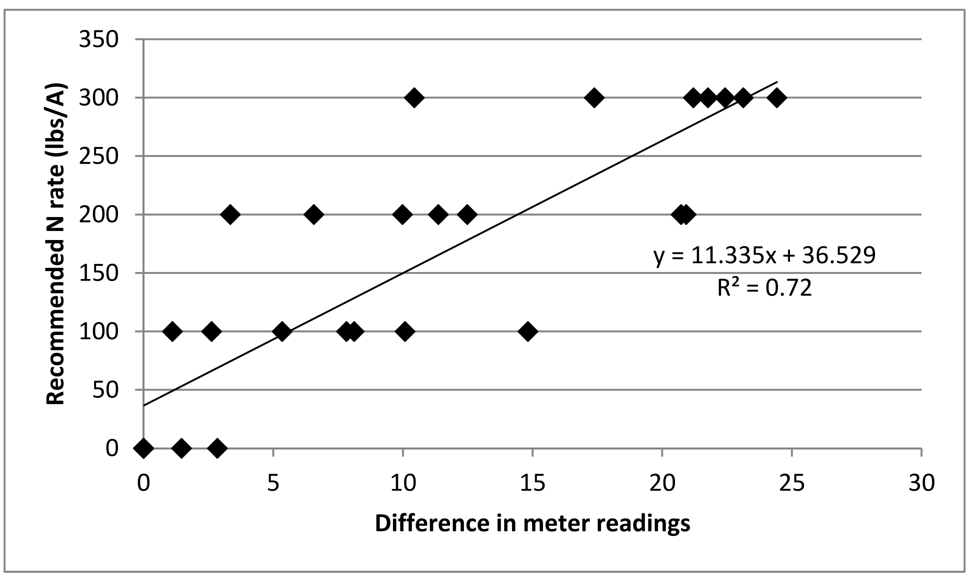

Figure 4. Recommended Nitrogen Rate for Common Wheat versus CCM 200 Differential.

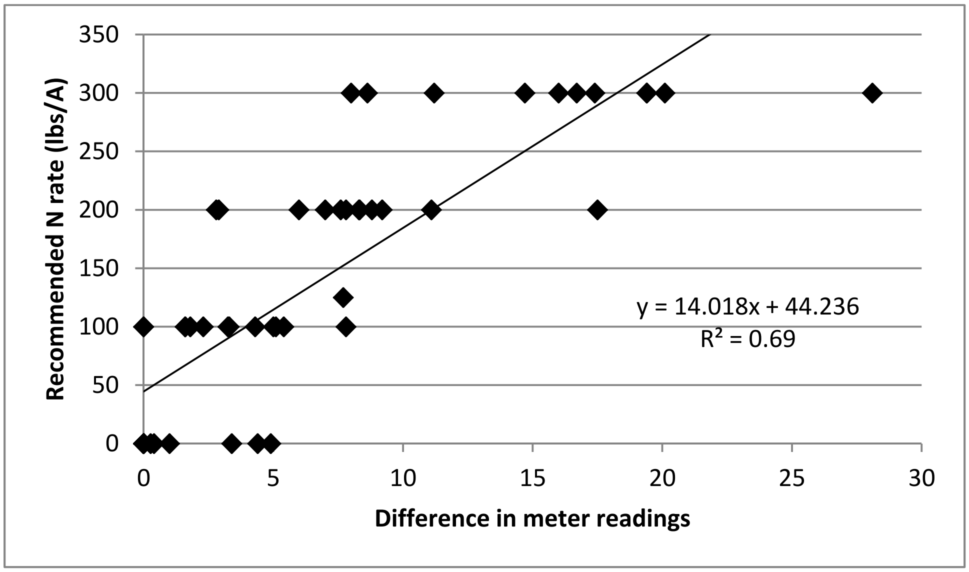

Figure 5. Recommended Nitrogen Rate for Common Wheat versus SPAD Differential.

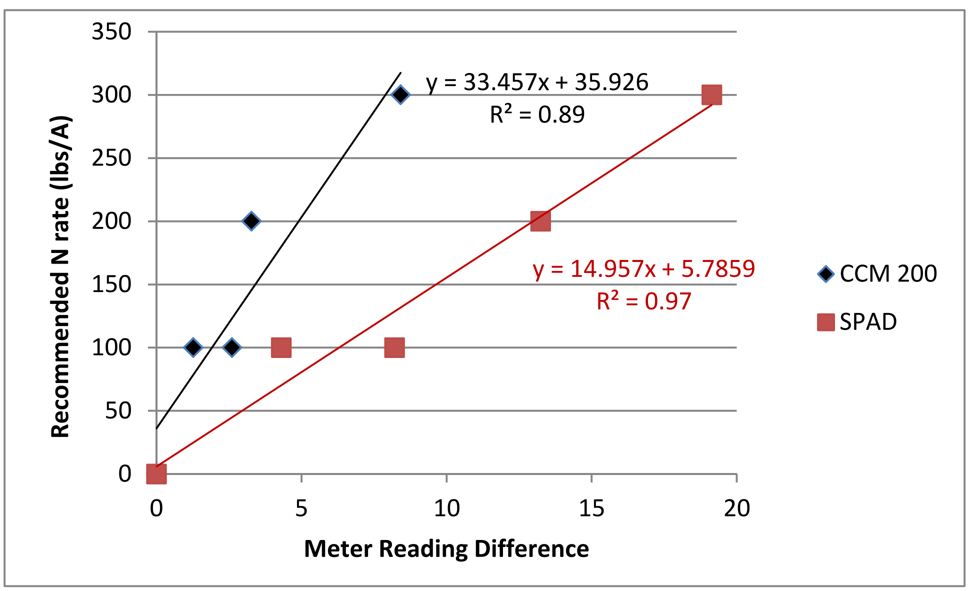

Figure 6. Recommended Nitrogen Rate for Durum Wheat versus Meter Reading Differential.

Table 1. West Side REC, Common Wheat

lbs N at planting	lbs N at Fekes 5	Silage Yield	Flag Leaf N	Grain Yield	Grain Protein
		- Tons/A -	-- % --	-- lbs/A --	-- % --
0	300	21.1	4.60	5828	14.8
100	200	23.5	4.43	5600	15.3
200	100	22.8	4.48	6285	14..5
300	0	24.4	4.23	5763	14.3
0	0	16.0	3.29	4267	12.5
100	0	22.5	3.72	5987	14.3
200	0	23.8	3.97	6038	15.1
300	0	24.6	4.16	5915	14.8
$LSD_{0.05}$ †		2.5	0.59	791	0.7

† Least Significant Difference

Table 2. West Side REC, Common Wheat

	Growth Stage Feekes 5					
lbs N at planting	CM 1000 45	CM 1000 90	SPAD	CCM 200	N content	DM
					%	lbs/A
0	0.95	0.95	44.5	27.7	2.00	3326
100	0.96	0.94	43.7	31.2	2.67	4733
200	0.97	0.95	43.0	31.3	3.24	4771
300	0.96	0.95	44.6	32.6	3.96	5628
$LSD_{0.05}$	ns	ns	ns	1.6	1.16	317

Table 3. Kern Research Farm, Common Wheat

lbs N at planting	lbs N at Fekes 5	Silage Yield	Flag Leaf N	Grain Yield	Grain Protein
		- Tons/A -	-- % --	-- lbs/A --	-- % --
0	300	18.2	3.92	5171	14.6
100	200	19.6	3.69	5150	14.6
200	100	19.0	4.08	5214	15.0
300	0	19.2	4.11	5572	15.5
0	0	11.9	2.52	2673	12.4
100	0	15.2	3.10	3672	13.7
200	0	15.9	3.50	4686	13.5
300	0	19.6	3.75	5157	14.7
$LSD_{0.05}$		3.2	0.62	876	0.5

Table 4. Kern Research Farm, Common Wheat

	Growth Stage Feekes 5					
lbs N at planting	CM 1000 45	CM 1000 90	SPAD	CCM 200	N content	DM
					%	lbs/A
0	0.93	0.92	37.5	17.9	2.00	3326
100	0.93	0.95	44.9	31.1	2.67	4772
200	0.93	0.93	46.7	39.9	3.24	4773
300	0.92	0.94	47.1	41.1	3.96	5629
$LSD_{0.05}$	ns	ns	1.7	1.5	1.16	1309

Table 5. West Side REC, Durum Wheat

lbs N at planting	lbs N at Fekes 5	Silage Yield	Flag Leaf N	Grain Yield	Grain Protein
		- Tons/A -	-- % --	-- lbs/A --	-- % --
0	300	22.4	4.71	5335	14.6
100	200	21.6	4.51	5703	15.0
200	100	23.8	4.60	5802	15.2
300	0	23.7	4.11	5657	15.3
0	0	17.1	3.91	4697	11.3
100	0	22.5	4.19	5818	13.7
200	0	25.4	4.28	5948	15.5
300	0	24.0	4.49	6002	15.9
$LSD_{0.05}$[†]		2.9	0.33[††]	780	1.2

[†] Least Significant Difference

[††]$LSD_{0.10}$

Table 6. West Side REC, Durum Wheat

	Growth Stage Feekes 5					
lbs N at planting	CM 1000 45	CM 1000 90	SPAD	CCM 200	N content	DM
					- % -	- lbs/A -
0	0.96	0.96	46.8	24.4	3.47	5117
100	0.96	0.97	51.1	27.0	3.80	5449
200	0.97	0.96	52.6	27.4	3.93	5629
300	0.97	0.96	50.8	30.1	3.71	5117
$LSD_{0.05}$	ns	ns	2.4	1.4	ns	ns

Table 7. Kern Research Farm, Durum Wheat

lbs N at planting	lbs N at Fekes 5	Silage Yield	Flag Leaf N	Grain Yield	Grain Protein
		- Tons/A -	-- % --	-- lbs/A --	-- % --
0	300	19.8	3.42	4890	14.2
100	200	20.5	3.57	5227	14.6
200	100	23.1	3.71	5650	13.9
300	0	22.2	3.50	5537	14.0
0	0	9.9	2.28	3412	12.3
100	0	11.9	3.13	3637	13.3
200	0	19.6	3.52	5045	13.7
300	0	20.7	3.66	5351	14.4
$LSD_{0.05}$		3.0	0.65	576	0.9

Table 8. Kern Research Farm, Durum Wheat

	Growth Stage Feekes 5					
lbs N at planting	CM 1000 45	CM 1000 90	SPAD	CCM 200	N content	DM
					- % -	- lbs/A -
0	0.91	0.85	41.1	22.3	1.86	3237
100	0.97	0.96	47.0	27.4	2.75	4349
200	0.96	0.97	52.1	30.7	3.48	5371
300	0.96	0.96	60.3	30.7	3.80	5373
$LSD_{0.05}$	0.055	0.060	1.9	1.6	0.79	860