2013-2014 Research Report to the California Wheat Commission

Calibrating In-field Diagnostic Tools to Improve Nitrogen Management for High Yield and High Protein Wheat in the Sacramento Valley

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Summary:

Growers of hard and durum wheat are paid not only for crop yield but also for grain protein content. These factors are inversely related and each is strongly influenced by the rate and timing of nitrogen (N) fertilization. The economic implications of this dynamic are clear: the quantity and timing of N fertilization should be optimized to produce the best combination of wheat yield and quality per dollar of N applied. In order to develop guidelines for optimum N management in the Sacramento Valley, the objectives of this research were to:

1) Establish multi-rate, split-application N fertilization trails on representative varieties of wheat in the Sacramento Valley region.
2) Measure the N status of the plant-soil environment at key phenological stages using both low-cost, in-field methods and established research methods.
3) Begin to develop decision support thresholds that relate the in-field diagnostic metrics to likely yield and protein responses under the various management scenarios enacted.

The goal of this work is to equip growers and crop consultants with a better understanding of the need for N at various stages of crop growth and, potentially, guidelines as to appropriate rates based on the use of in-field tests of the plant-soil environment. A multi-year research project is required to achieve this goal. This document reports on the research undertaken during the 2013-2014 season, which was partially funded by the California Wheat Commission and the CDFA FREP program.

Methods:

We established split rate N trials at two locations in the Sacramento Valley. The N rate and timing, water management, varieties, and planting and harvest dates for these trials are detailed in Table 1. Of note and importance to the interpretation of the results is that there were three water management scenarios between the two locations. At Field 1, located on the UC Davis research fields, the crop was irrigated to avoid any water stress. In addition, unless sufficient rainfall followed in-season applications of N, the field was irrigated to ensure that the applied N was fully available to the plant. Thus, potential N by water interactions were minimized at this site and it had high yield potential. In contrast, Field 2 was located at the Russell Ranch long term research facility. One of the two trials was located in a one-acre plot that received supplemental irrigation, while the other trial was located in a one-acre plot that received no supplemental irrigation. Given the below average rainfall during the 2013-2014 season, crops in both trials at Field 2 displayed water-deficiency symptoms at different points in the season. At Field 2, in-season applications of N were timed to precede rainfall events, and the applications were followed by rainfall of at least 0.4 inches within the subsequent 2 days. However, no irrigation accompanied these applications. In addition, weed control was not optimal at Field 2. Thus, there was an increased potential for interactions between applied N, water, and weeds, and an overall lower yield potential at Field 2 than at Field 1. As a result, with respect to Objective 1, this annual report will report the results from Field 1. Responses to N rate and timing at Field 1 were analyzed via ANOVA with mean separations ($P<0.05$) conducted via LSD.test in the agricolae package of R version 3.0.2.

Table 1. Management details of multi-rate, split-application N fertility trials for 2014-14 season.

Location	Irrigation	Fertility treatment	PREPLANT	TILLERING	BOOT	FLOWERING	TOTAL
			N fertilizer applied (lb/acre)				
Russell Ranch Cal Rojo Planted 11/2 Harvested 5/30	None	1	0	0	0	0	0
		2	25	0	0	0	25
		3	50	0	0	0	50
		4	75	75	0	0	150
		5	100	0	0	0	100
	Supplemental	1	0	0	0	0	0
		2	0	75	0	0	75
		3	0	37.5	37.5	37.5	75
		4	0	100	50	50	150
		5	0	150	0	0	150
		6	100	0	0	0	100
		7	100	37.5	0	0	137.5
		8	100	0	37.5	37.5	137.5
		9	100	37.5	37.5	37.5	175
		10	100	75	0	0	175
UCD Agronomy Patwin Planted 11/15 Harvested 6/9	Fully irrigated	1	0	0	0	0	0
		2	35	40	0	0	75
		3	50	50	0	0	100
		4	150	0	0	0	150
		5	120	0	0	30	150
		6	100	50	0	0	150
		7	70	40	40	0	150
		8	70	50	0	30	150
		9	0	70	50	30	150
		10	225	0	0	0	225
		11	185	0	0	40	225
		12	150	75	0	0	225
		13	110	60	55	0	225
		14	110	75	0	40	225
		15	0	110	75	40	225
		16	300	0	0	0	300
		17	250	0	0	50	300
		18	200	100	0	0	300
		19	150	75	75	0	300
		20	150	100	0	50	300
		21	0	150	100	50	300

As is demonstrated and discussed in the Results & Discussion section, the varying degrees of yield potential and soil water availability between Fields 1 and 2 provided a valuable opportunity to test the sensitivity of the in-field N diagnostic tools to heterogeneous growing environments. The suite of in-field tests we deployed is reported in Table 2. Of these, the colorimetric proximal sensing devices (AtLeaf; Greenseeker), which measured light reflectance from the leaves and canopy in the visible and near infrared spectrums, provided the most valuable information. As such, our calibration efforts have been concentrated on these measurements to date. The AtLeaf chlorophyll meter (Image A) is a SPAD proxy measuring reflectance from a leaf sample at 660nm and 940nm. At the various stages of potential N application (tillering, boot, and flowering) the AtLeaf index of 20 penultimate leaves was measured from selected N treatments. Likewise, the Greenseeker handheld NDVI meter (Image B) was used to measure reflectance 2-3 feet above the canopy during these crop growth stages. Soil and tissue samples were also taken at the various in-season sampling stages and will be useful in corroborating the measurements from the in-field tools. In addition, the additional plant-soil information collected may become more valuable as we add site-years to the dataset because it could serve to correct for between-site variability in base fertility. However, with respect to Objective 2 and 3, this annual report will focus on the potential for the AtLeaf and Greenseeker tools to indicate yield and protein responses to N fertilization and timing. This was analyzed via mixed, non-linear regression procedures (nlme package in R 3.0.2) where the meter reading for a given plot at a given stage was fit via a linear plateau model to N fertilizer applied at that stage, and also to the protein (AtLeaf) or protein yield (Greenseeker) result. The resulting thresholds were then applied via binary classification to the development dataset. The resulting median values and associated variables were subsequently plotted via boxplots.

Table 2. In-field diagnostic tests deployed at various stages of wheat development.

Crop stage	preplant		tillering		boot/flowering	
In-field Methods	Soil C	Solvita, POX-C				
	Soil N	nitrate	Soil N	nitrate	Soil N	nitrate
			Plant N	AtLeaf (SPAD proxy) Greenseeker (NDVI) Field Scout (DGCI) Leaf sap nitrate	Plant N	AtLeaf (SPAD proxy) Greenseeker (NDVI) Field Scout (DGCI)
			Yield Potential	LAI leaf dimensions	Yield Potential	leaf dimensions

For the data currently compiled, the flowering-stage metrics are most demonstrative of the potential value of the in-field tools and are therefore reported here. The same approaches are being used to analyze boot and tillering stage data collected in the Sacramento Valley. In addition, in-season measurements were taken at the Intermountain REC for the tillering, boot and flowering stages, and at Westside REC for the tillering stage. These data will be eventually incorporated into the eventual multi-year, multi-site analysis, but are not reported on here.

Image A. AtLeaf chlorophyll meter.

Image B. Greenseeker handheld NDVI meter.

Results & Discussion:

Yield, protein, protein yield and Nitrogen use efficiency responses to multi-rate, split-application N fertilization

Prior to establishment of the 2013-14 wheat crop, Field 1 had been managed with the objective of depleting available soil N (two sudangrass crops and one wheat crop that had received no N fertilization). As a result, initial soil nitrate-N values were less than or equal to 1.5 ppm NO3-N in the first 8 feet of the soil profile. The combination of low available soil N and high yield potential resulted in strong yield and protein responses to N fertilization ($P<0.01$), with the control (zero N) resulting in 40%-60% of the maximum yield, protein and protein yield (Figure 1). For N rates split between preplant and tillering (the most common current management practice), yields increased up to 150 lb N acre^{1} (Figure 1a), protein yields increased up to 225 lb N acre^{1} (Figure 1c), and protein increase up to 300 lb N acre^{1} (Figure 1b). Among yield-maximizing rates, the 150 lb N acre^{1} treatment used N more efficiently than the 300 lb N acre^{1} treatment and was also trending higher in N use efficiency than the 225 lb N acre^{1} treatment (Figure 1d). It is important to note that the combination of higher than average yields and extreme soil N deficiency observed in this trial created conditions for N responses at rates higher than are typically used for wheat in the Sacramento Valley. Therefore, we should not necessarily conclude that the absolute rates reported here are advisable under normal management conditions. In addition, the results reported in Figure 1 are for N fertilizer split-applied preplant and at tillering. Yet, interactions were measured between the timing of N and the absolute N rate ($P<0.01$). As such, higher or lower N rates would be required, depending on the application timing. However, it does appear that rates in excess of 150 lb N acre^{1} may be advisable under some circumstances in order to meet yield and protein goals. As more site-years are added to this study, we will be able to discern absolute N requirements with increasing confidence.

Yield, protein, protein yield and N use efficiency outcomes were also affected ($P<0.01$) by the timing of N fertilization. Of note is that, for N rates ≤ 225 lb N acre^{1}, preplant N applications were least effective from yield, protein, protein yield and NUE perspectives (Figure 2). Indeed, treatments that received no N fertilization until tillering had the best protein, protein yield and NUE outcomes (Figure 2). This is a surprising result given that plants which had received no preplant fertilization appeared N-deficient both visually and according to the in-field plant and soil measurements taken at tillering. While the mechanism for this response is not yet clear, it is possible that the early-season deficiency combined with a sudden abundance of available nitrogen results in compensatory growth that builds yield components more efficiently than if a plant had received N fertilization preplant. In addition to tillering vs preplant differences, flowering applications resulted in higher protein than boot applications for N rates of 150 lb N acre^{1} but not for rates of N rates of 225 lb N acre^{1} (Figure 2b depicts combination of 150 and 225 lb N acre^{1} rates). Taken together, the results from the initial year of experimentation suggest that N fertilizer timing at tillering and flowering may produce the best productivity and efficiency outcomes. However, for growers, the logistical feasibility of these precise timings depends on water availability and fertilizer delivery options. In addition, these results must be cross-validated with the data collected at other sites and using other varieties.

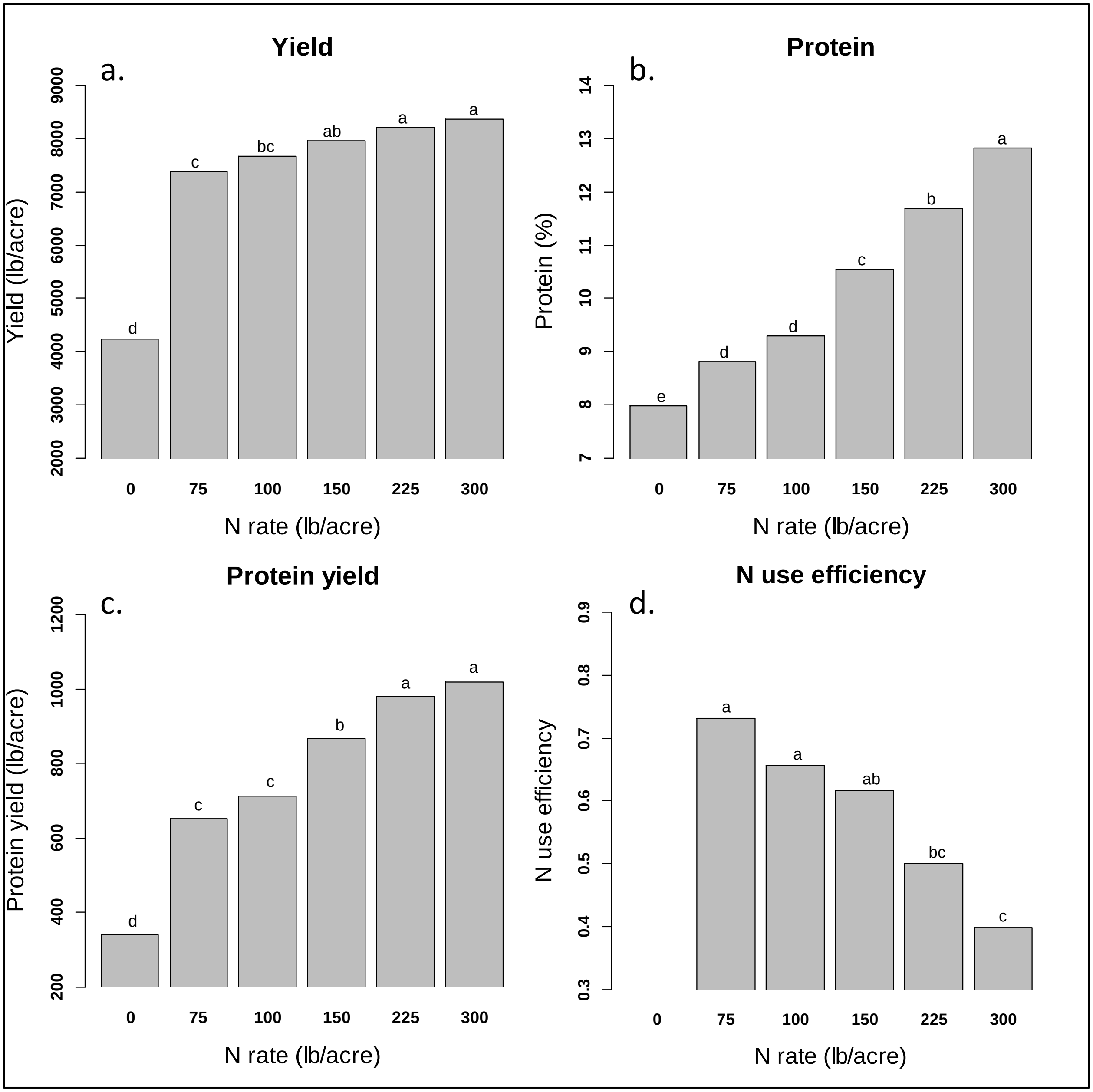

Figure 1. Yield, protein, protein yield and N use efficiency as a result of variations in N fertilizer rates in the preplant-tillering split rate treatment in Field 1.

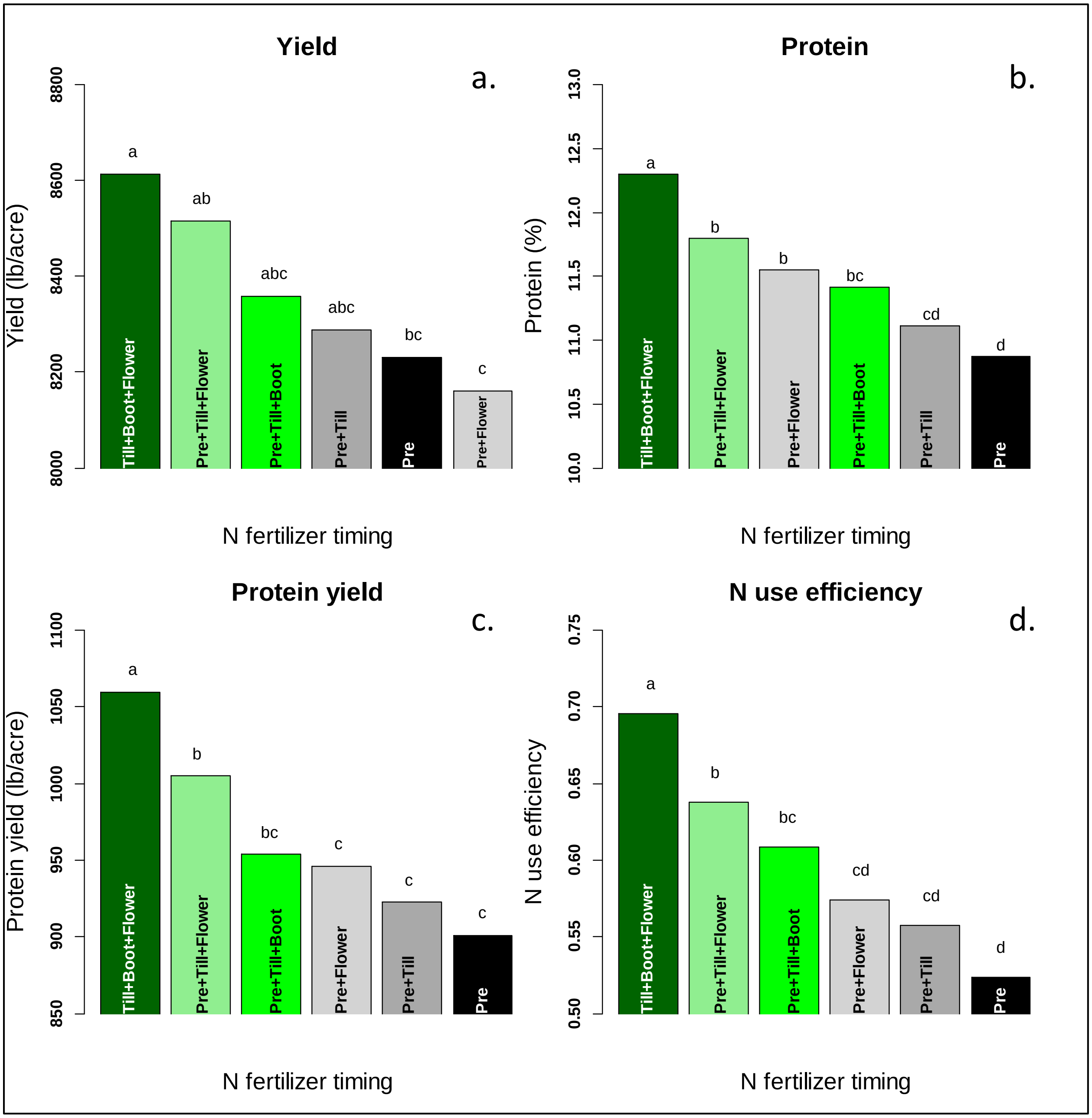

Figure 2. Yield, protein, protein yield and N use efficiency as a result of variations in N fertilizer timing for 150 lb N acre^{-1} and 225 lb N acre^{-1} treatments in Field 1.

Greenseeker NDVI and AtLeaf chlorophyll index as predictors of protein & protein yield outcomes

The AtLeaf chlorophyll meter and the Greenseeker handheld NDVI meter provided distinct and complementary information about the N status of the crop. When regressed against the applied N rate, the AtLeaf index was a more sensitive indicator of leaf N status. This can be observed by noting the higher average leaf chlorophyll index in the unirrigated vs supplementally-irrigated wheat in Field 2 (Figure 3c). Here, the wheat in the unirrigated plot had less yield potential due to relatively greater water stress. As a result, for an equivalent N rate (100 lb N acre^{-1}, for example) we would expect the tissue N to be more concentrated. Indeed, in Field 2 the AtLeaf index was higher for unirrigated than irrigated plots at 100 lb N acre^{-1} and overall ($P<0.05$) at both boot and flowering stages. Although the laboratory tissue results have not been completed, we expect them to correlate closely with the AtLeaf meter readings as has been shown previously with this device and the SPAD chlorophyll meter.

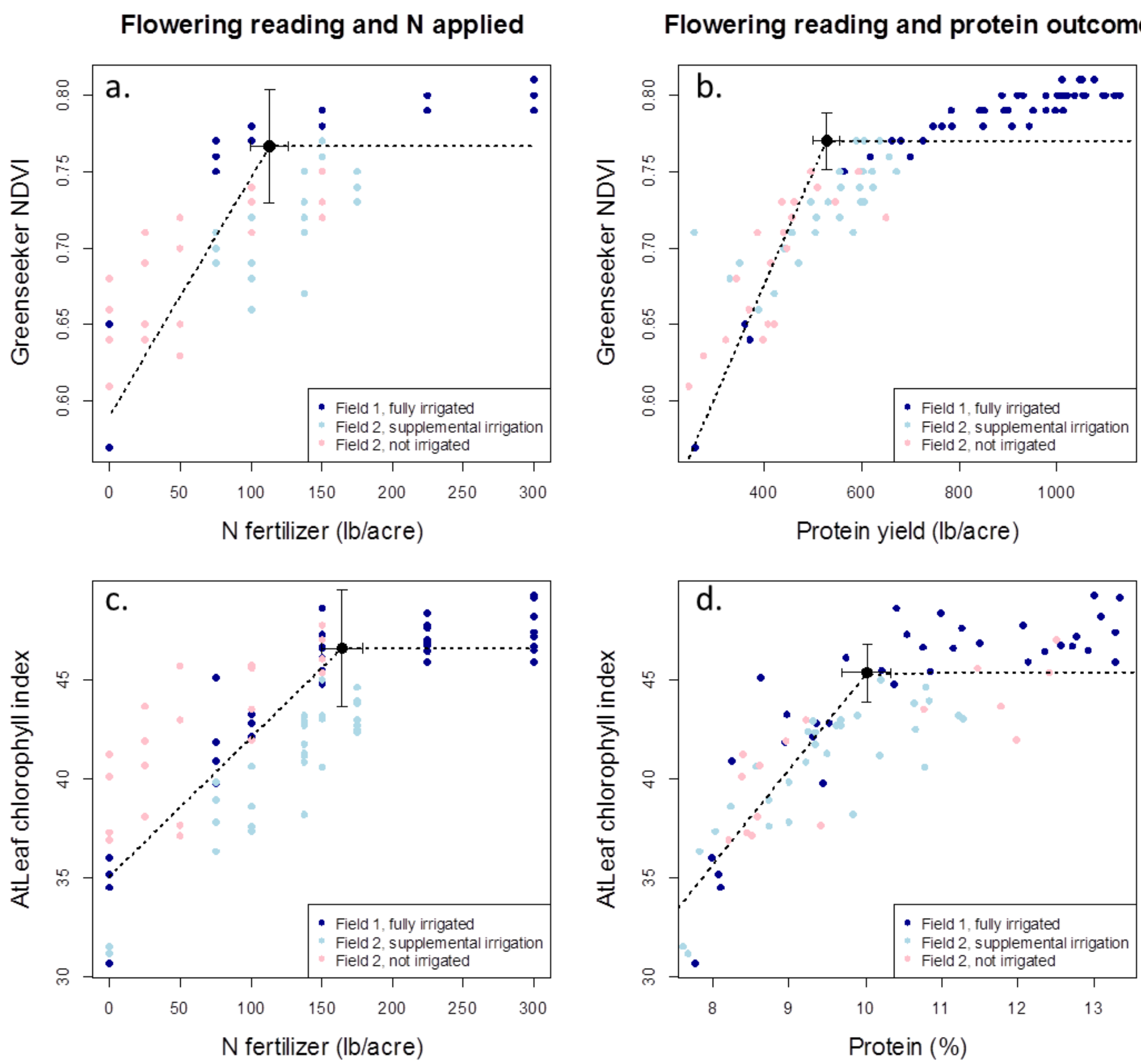

Figure 3. Linear plateau threshold models applied to Greenseeker NDVI and AtLeaf chlorophyll index measurements taken at the flowering stage of development for plots that did not receive a subsequent application of N. Measurements were made at two fields and under three water management scenarios.

The relative tissue N concentration is a useful indicator of the present N status of the plant. However, since the tissue concentration changes over time, the plant N status provides only part of the overall picture of crop N demand. In order to determine whether or not to apply N fertilizer at a given point in the season, it is equally important to be able to predict future N demand. Although the Greenseeker handheld NDVI provided a less precise answer regarding the concentration of a given leaf, it provided a more integrated picture of the canopy N status. For example, for equivalent N rates, the NDVI readings in Field 1 were consistently higher than the NDVI readings in Field 2 (Figure 3a). As mentioned in the Methods section the crops in Field 2 had water, weed and other management-related issues that limited yield potential relative to Field 1. The Greenseeker NDVI was able to indicate these differences at both boot and flowering. As a result, the Greenseeker NDVI appears to be a better indicator of the overall protein yield potential than the AtLeaf index. The regressions of Greenseeker NDVI and protein yield (Figure 3b) and AtLeaf chlorophyll index and protein concentration (Figure 3d) support the conclusions about the relative sensitivity and precision of these in-field instruments.

The thresholds developed via linear plateau models indicate the meter readings beyond which protein yield (Figure 3b) or protein concentration (Figure 3d) responses are not expected at the flowering stage. Since the meters appear to provide distinct information about the concentration of and overall demand for N, these thresholds may be most informative when used in combination. For example, the 'L L' combination in Figure 4 indicates plots where both Greenseeker and AtLeaf readings were below the threshold values, meaning that both the relative tissue N concentration and relative protein yield potential were low. In this scenario, the flowering application of N (L L Y) did not increase protein concentration because the future demand for additional N was insufficient (Figure 4c). In contrast, the 'H L' combination indicated that the Greenseeker reading was higher than the threshold and the AtLeaf reading was lower than the threshold. In this scenario, there was likely enough relative yield potential for the crop to respond to additional N during grain filling. Therefore, plots that received a flowering application of N (H L Y) resulted in higher protein than plots that did not (H L N) (Figure 4c). In combination, the two meters thresholds appear to more accurately predict protein responses in this intermediate protein range than either meter threshold was able to on its own.

From a practical perspective, the combined use of these in-field sensing devices alongside appropriately calibrated thresholds may be able to produce actionable, in-season N management recommendations for California wheat growers. However, these conclusions should be considered tentative at this stage given the quantity of data and the fact that the results partially describe the same data from which the thresholds were derived. Additionally, there is a strong possibility for the thresholds to vary according to cultivar and climate. To account for these potential interactions, data was collected during the 2013-14 season at both the Intermountain and Westside RECs for different cultivars than those measured in the Sacramento Valley. However, this data has not yet been incorporated into the analysis reported here. Therefore, further analysis of the 2013-14 data and further data collection in 2014-15 will be required in order improve our confidence in these conclusions.

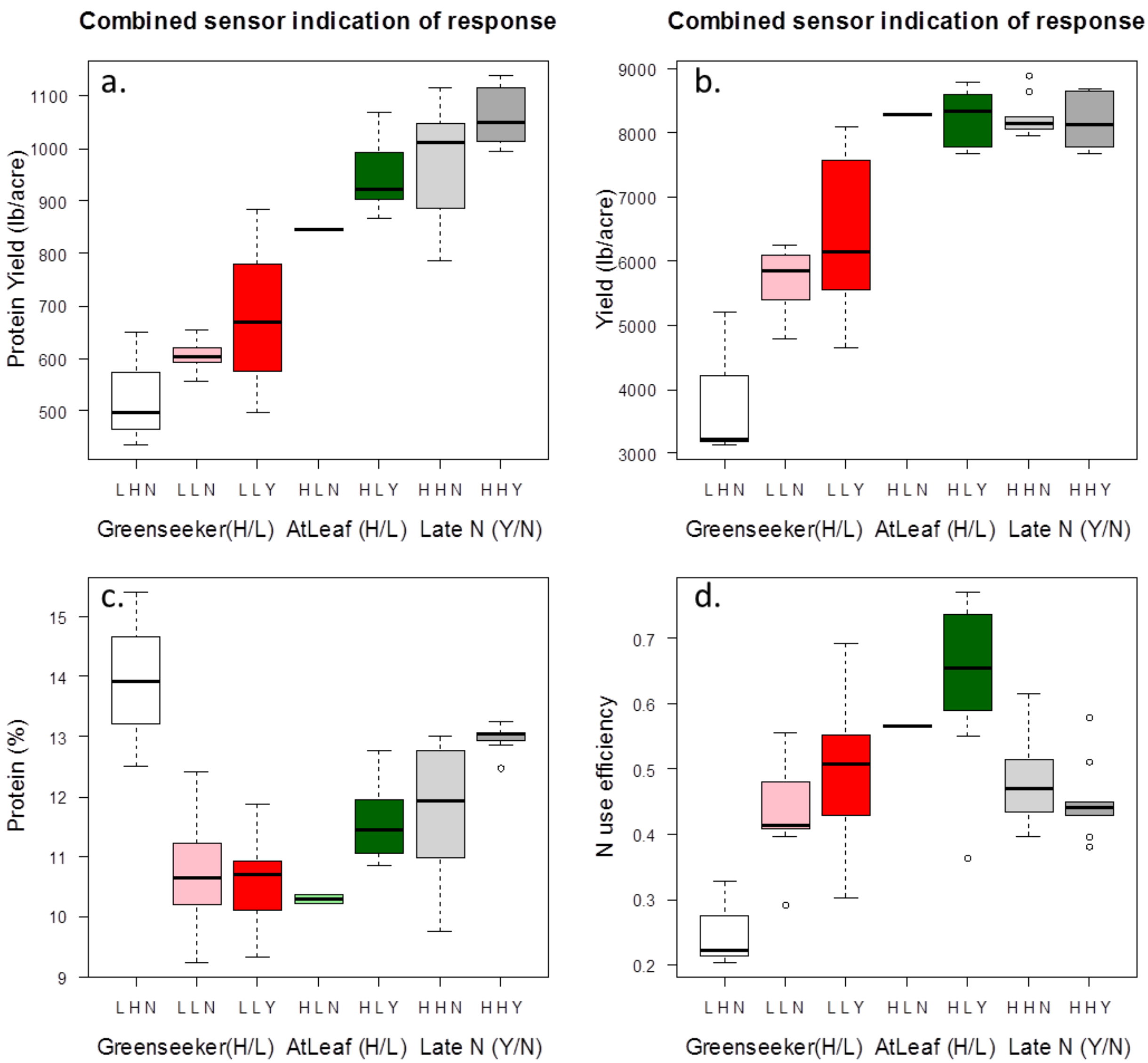

Figure 4. Boxplots of protein yield, yield, protein concentration and N use efficiency as determined by binary classification for combinations of Greenseeker and AtLeaf values above (H) or below (L) threshold values reported in Figure 3b and 3d that either did (Y) or did not (N) receive a flowering application of N.

Budget summary

Budget for 2013-14 California Wheat Commission Grant

Title: Calibrating In-field Diagnostic Tools to Improve Nitrogen Management for High Yield and High Protein Wheat in the Sacramento Valley

PI: Mark Lundy

Category	Projected ($)	Actual ($)	Pending ($)	Description/Notes
Field Supplies and Equipment	2000			fertilizers; certified seed; stakes, flags, bags, misc supplies
		2183.71		
Services	500			Deep core soil sampling to 8' on subset of plots
		0		*charged to another account to offset additional lab charges*
Plant and Soil Analysis	4610			analytical lab fees (soil and plant N)
		2659.4	3192.8	*additional sampling at Intermountain REC, which was beyond scope of proposed costs; AN Lab fees increased approximately 20%*
		5852.2		
Analytical Supplies	1000			one-time use analytical tests/tools
		948.15		*remaining inventory will be used in 2014-15 work*
Analytical Equipment	2000			reusable measurement devices
		1125.94		*partial costs; remainder charged to different account to offset additional laboratory costs*
Total	**10110**	6917.2 +	3192.8 =	**10110**