IN-FIELD PLANT MONITORING AS A TOOL FOR N MANAGEMENT IN SMALL GRAINS

Mark Lundy, Steve Wright, Steve Orloff, Robert Hutmacher[1]

ABSTRACT

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 crop developmental stages using low-cost, in-field methods; and 3) develop decision support thresholds that relate the in-field diagnostic measurements to likely yield and protein responses. The results to date demonstrate that 1) split-applications improve yield, protein and N use efficiency outcomes with applications of N at tillering being more valuable in terms of N use efficiency than pre-plant applications; 2) late-season applications can boost grain protein content if the crop has sufficient protein yield potential; and 3) in-field diagnostic tools can indicate whether the crop is likely to respond to an in-season N top-dress.

INTRODUCTION

Nitrogen management is a key determinant of the productivity, profitability and sustainability of hard and durum classes of wheat produced in California. Wheat growers are paid not only for a crop's yield but also for its protein content, factors that are often inversely related and influenced by cultivar selection, moisture availability, and N fertilizer management (Chen et al., 2011; Souza et al., 2004). Since achieving both high yields and high protein percentages has significant economic consequences for wheat producers, high rates of N fertilization early in the season can be attractive to growers due to the reduced cost of application associated with the pre-season forms of N (Orloff and Wright, 2011). However, increasing yield via high rates of N fertilization early in the season may result in reduced grain protein content because average root zone N levels and plant uptake may have declined by booting and beyond. Additionally, very high early rates of N fertilization may cause excessive vegetative growth and lodging and introduce the possibility of losses to the environment through pathways such as nitrate leaching (Di and Cameron, 2002).

For these reasons, many growers split N applications, applying a portion pre-plant or during earlier vegetative growth stages, and a second portion between boot through post-flowering

[1] M. Lundy (melundy@ucanr.edu), Farm Advisor, UC Cooperative Extension; S. Wright (sdwright@ucanr.edu), Farm Advisor, UC Cooperative Extension; R. Hutmacher (rbhutmacher@ucdavis.edu), UC Cooperative Extension Specialist, UC Davis Plant Sci. Dept. and Director, UC West Side REC; S. Orloff (sborloff@ucanr.edu), Farm Advisor, UC Cooperative Extension. **In**: Proceedings, 2014 California Alfalfa, Forage, and Grain Symposium, Long Beach, CA, 10-12 December, 2014. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other Alfalfa Symposium Proceedings.)

(Orloff and Wright, 2011). Relative to applying all the N pre-plant through tillering, N applications from booting onward boost available N during the grain filling period when grain protein levels are more likely to be impacted (Brown et al., 2005; Jones and Olson-Rutz, 2012; Nakano et al., 2010). Prior research indicates that late-season (post-boot stage) applications in the range of 20-60 pounds of N per acre can increase grain protein content (Orloff and Wright, 2011; Nakano et al., 2010). However, strong interactions exist between cultivars, environmental conditions and N management. This makes it difficult to develop consistent N management information that cuts across years, varieties and regions. Therefore, more work is needed to assess the response of wheat to in-season N application rates that is specific to the various agro-ecological regions where wheat is grown in California, including in the Sacramento Valley.

Additionally, research is needed to calibrate in-field tools that might be used to assess the site-specific plant-soil N status at various points in the crop cycle and determine whether and how much N should be applied to optimize yield and protein content. There are several recent examples of work that has assessed plant N status via flag leaf N content at heading (Brown et al., 2005; Lopez-Bellido et al., 2004), SPAD readings at various growth stages (Lopez-Bellido et al., 2004; Nakano et al., 2010), or proxies for yield potential taken at specified growth stages (Nakano et al., 2010). Pre-plant and in-season soil N have also been used as a guide for the N status of the system and resulting N management in wheat and other crops (Abad et al., 2004). With recently developed instrumentation to measure proxies of plant and soil N at a relatively low cost [eg. SPAD proxy (Atleaf); handheld NDVI meter (Greenseeker)], it may be possible that coupled or multivariate measurements of soil/plant status taken at specified growth stages could provide unique insight as to the plant-soil N status, protein yield potential, and likelihood of protein response to N application. If properly calibrated, these devices may be able to provide decision support thresholds specific to particular crop growth stages that indicate the need for N fertilization.

Therefore, 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 crop growth stages using low-cost, in-field methods; and 3) to develop and validate metrics that relate the in-field diagnostic measurements to likely yield and protein responses under the various management scenarios enacted.

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. Both of the trials in Field 2 had lower yield potential due to a weed competition and suboptimal water availability.

Table 1. Management details of multi-rate, split-application N fertility trials for 2013-14 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	0	75
		4	0	100	50	0	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	0	137.5
		9	100	37.5	37.5	0	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 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. 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 and reported in

Table 2 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.

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

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

Yield, protein, protein yield and N use efficiency outcomes were affected by the timing of N fertilization ($P<0.01$) (Figure 1). Of note is that, for N rates ≤ 225 lb N acre^{-1}, pre-plant N applications were least effective from yield, protein, protein yield and NUE perspectives. Indeed, treatments that received no N fertilization until tillering had the best protein, protein yield and NUE outcomes (Figure 1). This is a surprising result given that plants which had received no pre-plant 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 entirely 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 pre-plant. In addition to tillering vs pre-plant 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 1b depicts a 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.

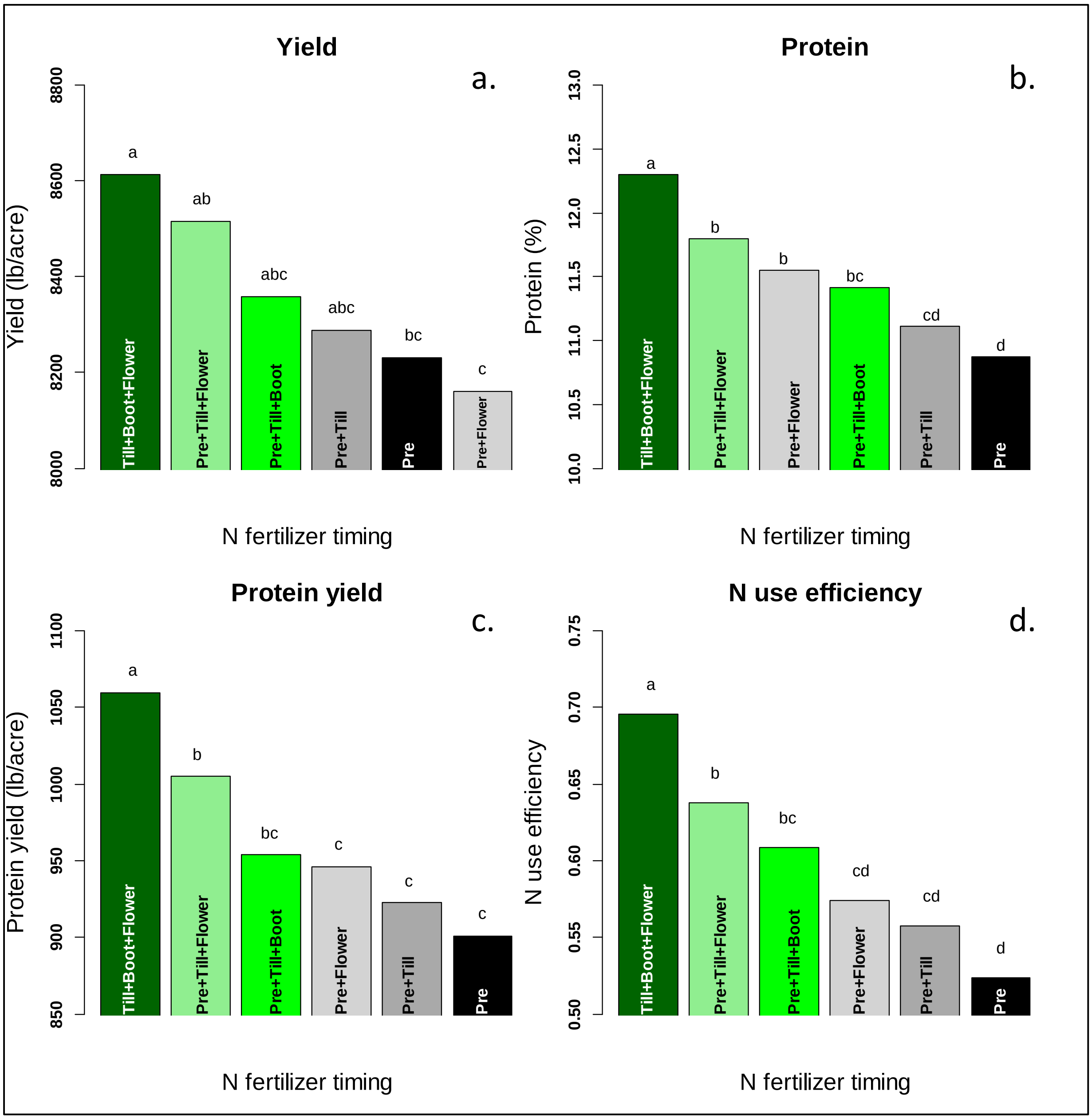

Figure 1. Yield, protein, protein yield and N use efficiency as a result of variations in N fertilizer timing for 150 lb N $acre^{-1}$ and 225 lb N $acre^{-1}$ treatments in Field 1.

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

The Greenseeker NDVI and AtLeaf chlorophyll index provided distinct and complementary information about the N status of the crop. The Greenseeker NDVI readings taken at boot and flowering were good predictors of the yield potential of the crop, but were not as sensitive to the N concentration in the leaves as the AtLeaf measurement. The average AtLeaf chlorophyll index reading of the penultimate leaves was closely correlated to the tissue N concentration of those leaves and served as a good predictor of the eventual protein content of the grain. For each of these meters, thresholds that indicated N saturation (AtLeaf) or high vs low protein yield potential (Greenseeker) were developed from the data collected at the field level. These thresholds could eventually be used as decision support tools for growers or managers trying to decide whether or not to apply an in-season application of N.

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 (AtLeaf giving an indication of current plant N status; Greenseeker giving an indication about whether there is a sufficient sink for a topdress). For example, the 'L L' combination in Figure 2 indicates plots where both Greenseeker and AtLeaf readings were below the threshold values at flowering, 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 relative to no N top-dress (L L N) because the future demand for additional N was insufficient. 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 and the N concentration in the leaves was low. 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 2). In combination, the two meter thresholds appear to more accurately predict protein responses in this intermediate protein range than either meter threshold on its

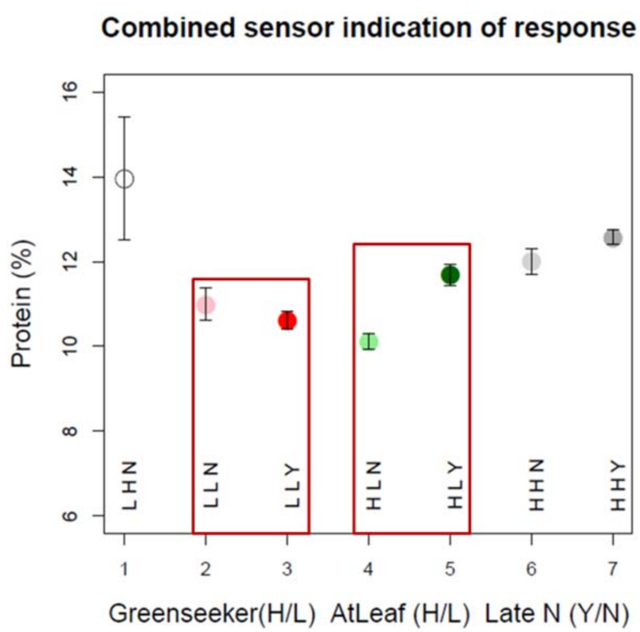

Figure 1. In-field flowering measurements sorted by their relationship to thresholds [high (H) or low (L)] as well as whether (Y) or not (N) a flowering top-dress of N was applied.

own. Using these tools and the associated thresholds a grower could learn, in real-time, whether an N top-dress at flowering would likely add protein or be wasted.

CONCLUSION

From a practical perspective, split applications of N in wheat give the grower flexibility to respond to in-season conditions and the real-time N demand of the crop. Applying the majority of N at tillering and later will likely result in the best N use efficiency, and applications from boot to flowering will increase the protein content of high-yielding crops. In addition, the use of in-field sensing devices alongside appropriately calibrated thresholds may be able to produce real-time information as to the likelihood of an N response 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. 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.