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Wheat Grain Yield Response to N Application Evaluated through Canopy Reflectance

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Application of the appropriate N fertilizer rate for wheat production is needed to improve and sustain productivity. Different methods have been developed over time to estimate these needs. The objective of this work was to evaluate the relationship basal N rate at planting – NDVI (normalized difference vegetative index) by means of a spline regression to estimate further N needs of spring wheat. Experiments were established in two planting systems; permanent beds and conventional in solid stands. Three flat N rates (25, 50, and 75 kg N ha^{-1}, and 30, 60 and 90 kg Nha^{-1} for permanent beds and conventional planting, respectively) plus an unfertilized check plot were applied according to three N timing treatments (whole rate at planting or end of tillering, and split at planting and at the end of tillering). Before the application of N treatments at the end of tillering, plots were divided into two halves to apply variable N rates according to the first segment of the spline model. Results indicated that parameter estimates from the spline regression vary within each planting system. However, variable N rates estimated for each year and location were lower than flat N rates. In spite of those differential fertilizer rates, grain yield resulting for the application of variable N rates were similar to flat N rates. Pooled data analysis suggests that NDVI readings greater than 0.56 and 0.65 for permanent beds and conventional planting, respectively, the application of N fertilizer at the end of tillering can be excluded as grain yield will not be modified.

Keywords: wheat, N management, permanent beds, conventional-tilled beds, NDVI

Introduction

Nitrogen fertilizer recommendations for dryland wheat production in the high lands of Mexico have varied over time. Recently, it has been reported that the optimum rate to obtain adequate grain yields varies from 0 to 60 kg N ha^{-1} depending upon the environment (Limon-Ortega and Villaseñor-Mir 2006). This wide range suggests that alternate approaches to make more accurate recommendations are needed.

Researchers have shown that the N concentration of plants at early growth stages or soil N tests can be used to make more accurate N fertilizer recommendations. However, a common drawback of these methods is the effort required, cost, and the time delay from sampling until N test result is obtained. Alternatively, innovative technologies that use optical sensors to surmount those constrains by monitoring the crop to adjust in-season the N

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fertilizer requirements have been developed. One of those technologies is based upon the canopy reflectance that evaluates the NDVI. This sensor (GreenSeeker^{TM}, Ntech Industries, Inc.) has been thoroughly described by Raun et al. (2001). Canopy reflectance is determined by leaf surface properties, internal structure, and the concentration and distribution of biochemical components (Peñuelas and Filella 1998). Red (R;671 ± 6 nm) and near infra-red (NIR; 780 ± 6 nm) are often among the wavelengths of interest for indirect measurements of plan characteristics; R-reflected energy is absorbed by chlorophyll and NIR reflectance is sensitive to water content and leaf cell structure (Wood et al. 1999).

Studies have recently been performed to evaluate the grain yield response to variable-rate N applications according to sensor-based estimates of tiller density (Phillips et al. 2004). A similar approach indicates that models based on in-season estimates of grain yield potential at early growth stages, could be also an alternative for refining in-season fertilizer N requirements (Raun et al. 2001).

As additional innovation to improve the productivity of the cropping systems in the highlands, the planting system on permanent beds have been proposed as a form of conservation tillage method.

The objective of this work was to evaluate the relationship basal N rate at planting – NDVI collected during tillering by means of a spline regression to estimate further N needs of spring wheat. Measurements were collected in two planting systems; permanent beds and conventional planting in solid stands with tillage.

Materials and Methods

The experiment on permanent beds was performed in a single location (2280 masl, 19º 26’ N, 98º 53’ W) from 2006 to 2008. The experiment with conventional planting was established in 2006 in three representative locations (2490, 2747 and 2496 masl; 19º 31’ N, 98º 15’ W; 19º 29’ N, 98º 33’ W; and 19º 36’ N, 98º 29’ W, respectively, for Sites 1, 2 and 3) of the highlands of Mexico. Plots were planted to hard spring wheat cultivar Nahuatl F2000 at a rate of 100 kg ha^{-1}.

Treatments consisted in the application of three flat N rates (25, 50 and 75 kg N ha^{-1} for permanent beds, and 30, 60 and 90 kg N ha^{-1} for conventional planting) including an unfertilized check plot. Each N rate was composed of three N-timing treatments; whole rate at planting or at the end of tillering, and split at planting and the end of tillering. Plots were divided into two halves during tillering to apply in each one the flat and variable N rates at the end of this growth stage. Variable N rates were estimated according to the basal N rate at planting – NDVI relationship with a spline regression model defined by Eq. (1) and (2),

$$NDVI = a + bN \text{ if } N < K \tag{1}$$

$$NDVI = a + bN + c(N - K) \text{ if } N \geq K \tag{2}$$

where $NDVI$ is the sensor reading collected during tillering and N is the N rate (kg N ha^{-1}) applied at planting; a (intercept), b and c (linear coefficients), and K (knot, critical rate of fertilization, intersection of the two regression lines) are parameter estimates obtained by fitting the model to the data.

Variable N rates applied at the end of tillering were estimated by solving Eq. [1] for *N*;

$$N = (NDVI - a) / b. \qquad [3]$$

Authors hypothesized that plots with a flat N rate or NDVI greater than *K* or NDVI estimated at $N = K$, respectively, did not need additional N application.

A single regression equation relating basal N rates and NDVI was derived for each location using PROC NLIN (SAS Inst. 1990). Slopes, intercepts, and critical N rates for the independent regressions were compared with an approximate F-test (Mead et al. 1993) to determine if a single relationship could be used across environments.

Results and Discussion

Results indicated that parameter estimates from the basal N rate – NDVI relationship for in-season N adjustment were different within each planting system (Table 1). The overall result suggests that there are not single regression estimates (*a* and *b* in Eq. 1) to manage N fertilizer in the highlands of Mexico. This is likely due to climatic and edaphic conditions that vary in time and space. However, average grain yield within each year and location was similar for both variable and flat N rates (Table 2). This suggests that the use of Eq. 3

Table 1. Approximate F-test for parameter estimates for two planting systems

Null hypothesis	DF†	RSS‡	Variance ratio
Approximate F-test for permanent beds			
1. Individual fit of estimates	118	0.3874	–
2. *a, b* and/or *C* does not vary	125	0.9101	–
(2 – 1) ($F_{7,125,99} = 2.79$)	7	0.5227	22.7**
3. *a* does not vary	120	0.3944	–
(3 – 1) ($F_{2,120,99} = 4.78$)	2	0.0070	1.07 NS±
4. *b* does not vary	121	0.3992	–
(4 – 1) ($F_{3,121,99} = 3.94$)	3	0.0118	1.20 NS
5. *C* does not vary	121	0.3887	–
(5 – 1) ($F_{3,121,99} = 3.94$)	3	0.0013	0.13 NS
Approximate F-test for conventional planting			
1. Individual fit of estimates	78	0.2405	–
2. *a, b* and/or *C* does not vary	86	0.7913	–
(2 – 1) ($F_{8,86,99} = 2.74$)	8	0.5508	22.3**
3. *a* does not vary	82	0.3996	–
(3 – 1) ($F_{4,82,99} = 3.56$)	4	0.1591	12.9**
4. *b* does not vary	81	0.3321	–
(4 – 1) ($F_{3,81,99} = 4.04$)	3	0.0916	9.90**
5. *C* does not vary	81	0.3278	–
(5 – 1) ($F_{3,81,99} = 4.04$)	3	0.0873	9.44**

† DF: degrees of freedom; ‡ RSS: residual sum of squares; ± NS: not significant at p = 0.01
** highly significant at P < 0.01.

is adequate for in-season N adjustments but requires the development of specific regression parameters for each year. Interestingly, NDVI readings were correlated with grain yield (r = 0.65) from permanent beds and heads per m^2 from conventional planting (r = 0.59), otherwise, correlation coefficients were lower (data not shown).

Table 2. Parameter estimates from the spline model (Eq. 1) and average grain yield for two planting systems

Year	Estimates for permanent beds				Grain yield (kg ha^{-1})	
	a	*b*	*K* (*kg N ha*$^{-1}$)	*NDVI* (at *N* = *K*)	Flat N rate	Variable N rate
2006	0.44	–0.0004	9.8	0.440	3078	2939
2007	0.50	0.0050	20.3	0.600	4032	4059
2008	0.46	0.0070	7.9	0.510	2729	2794
Location	Estimates for conventional planting				Grain yield (kg ha^{-1})	
Site 1	0.68	–0.0009	60.1	0.630	4423	4232
Site 2	0.70	0.0063	9.6	0.760	4190	4394
Site 3	0.50	0.0109	10.3	0.610	3957	4248

Planting system on permanent beds

The approximate F-test for this planting system showed significance but did not indicate which parameter was different (Table 1). The response to N application at planting (*b* parameter) was negative in 2006 when the amount of rainfall from planting to the end of tillering was 74 mm. Indeed, previous reports have indicated that dryland wheat production is highly dependent on rainfall after planting (Raun et al. 2002).

The highest average grain yield and intercept at 0 kg N ha^{-1} (*a* parameter) was measured in 2007 (Table 2, Fig. 1a) likely due to the relatively high residual soil N-NH_3 from the previous crop in 2006 (Table 3). According to Halvorson et al. (1999), the variation across years of N-NH_3 can be ascribed to many factors; two of them can be grain yield of the preceding crop and rainfall.

Variable N rates estimated through the use of Eq. [3] varied between 0 and 33 kg N ha^{-1} (Fig. 1c). In spite of the limitations to develop a single regression estimates, one might sur-

Table 3. Soil chemical properties from check plots (0 N) at post-harvest for each year and location

Year	Permanent beds					
	pH (0.01M)	OM (g kg^{-1})	N-$N0_3$ (mg kg^{-1})	N-NH_4 (mg kg^{-1})	$P_{available}$ (mg kg^{-1})	$K_{exchangeable}$ (mg kg^{-1})
2006	6.9	2.2	26	9	57	532
2007	6.5	2.4	22	19	33	493
2008	6.9	1.7	31	13	31	666
Location	Conventional planting					
Site 1	8.2	2.3	12	8	104	820
Site 2	6.8	2.0	2	7	65	204
Site 3	7.2	1.3	2	8	5	136

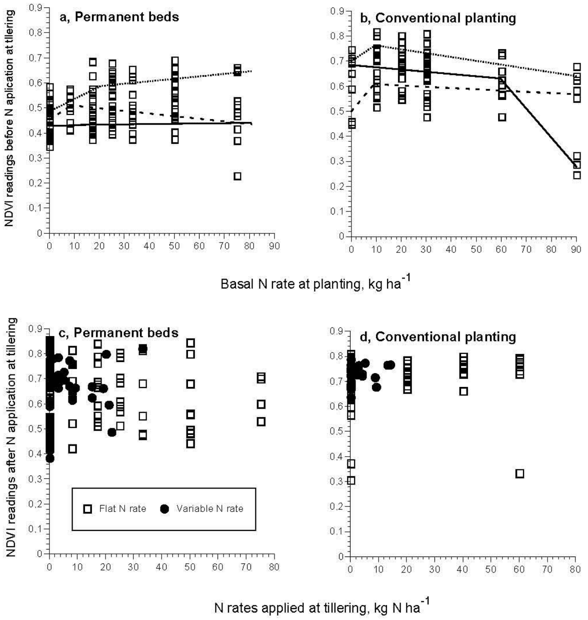

Figure 1a, b, c, d. Response to N fertilizer rates applied at planting (a, b) and tillering (c, d) evaluated with NDVI readings

mise that the N application at planting providing a minimum NDVI reading of 0.555 (roughly estimated at $N = K$) during tillering may suffice the crop needs. In this study, plots that showed NDVI readings equal or higher than 0.555 produced comparable grain yields to flat N rate, except for two outliers (Fig. 2a). Concomitantly, only 14 percent of those plots required an additional N application (1 to 7 kg N ha^{-1}).

Conventional planting system

The approximate F-test indicates that estimated parameters were different across locations (Table 1). Response to N application (*b* parameter) was negative for Site 1 (Table 2, Fig. 1b). This can be attributed the relatively high amount of soil OM and N-NH_3 (Table 3). Contrastingly, the highest N response was measured in Site 3 where soil OM and NH_3 were the lowest.

Variable N rates estimated during tillering through Eq. [3] were lower than 14 kg N ha^{-1} (Fig. 1d). Final wheat grain yield from both flat and variable N rate were similar (Table 2).

An average NDVI reading of 0.65 (at $N = K$) or greater collected during tillering suggests that the basal N applied at planting is enough to suffice crop needs. In this study, 35 percent of the plots that surpassed this NDVI threshold required additional N fertilizer. The average response of grain yield to the total N rate according to flat and variable N rates is shown in Fig. 2b.

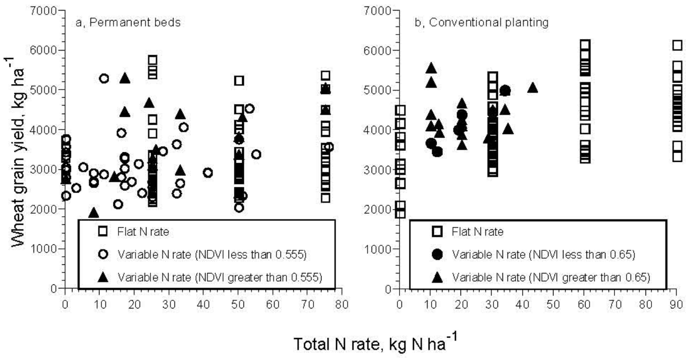

Figure 2a, b. Wheat grain yield response to flat and variable N rate applications. Variable N rates are indicated according to $N = K$

Conclusions

Development of new approaches to improve the N fertilizer management for dryland wheat production is critical for growers. One alternative is the canopy reflectance evaluated with a remote sensor that estimates NDVI. Readings should be collected during early growth stages to make in-season adjustments to correct N deficiencies.

This study showed that to make in-season N adjustments with variable N rates, NDVI readings collected during tillering should be lower than a maximum that depends upon the planting system. However, the variability among regression estimates hinders to make generalized N fertilizer recommendations for each system. As a general rule of thumb, if additional N is needed at the end of tillering, the planting system on permanent beds and conventional planting require a maximum of 33 and 14 kg N ha^{-1}, respectively.

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