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Wheat Characteristics under Varied Irrigation and Nitrogen

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Introduction

WHEAT IS AN IMPORTANT CROP in Idaho and Montana, with both states ranking in the top five in the United States in terms of production. Determining optimum water and nitrogen (N) requirements is critical to improve the yield and quality of wheat grown in arid and semiarid regions of the western United States.

Crop production in semiarid regions is highly dependent on supplemental irrigation. Efficient water management practices are vital to maintain crop production. N use efficiency (currently estimated at 30%–50%) must be improved to optimize wheat yields, reduce input costs, and minimize environmental impacts and human health concerns.

Plant uptake of water and N is fundamentally interactive. Soil-water scarcity limits the N uptake of plants, while excessive irrigation accelerates N loss. Insufficient or excessive N fertilizers result in low crop water-use efficiency. To improve profitability and minimize environmental impacts, the efficiency of both water and applied N should be enhanced.

The Soil Plant Analysis Development (SPAD) meter measures relative greenness and the Normalized Difference Vegetation Index (NDVI) meter measures crop health. These promising remote-sensing tools can be used to assess various crop responses to water and N availability, which facilitates the refining of water and N management practices in crop production.

Field Experiments

Studies were conducted at two locations in Idaho (University of Idaho Parma Research and Extension Center [PREC] and University of Idaho Aberdeen Research and Extension Center [AREC]) and one in Montana (Montana State University Northwestern Agricultural Research Center at Kalispell [NWARC]) in 2016 and 2017. Prior to planting, the top 60 cm soil samples were collected from each site and analyzed (see

Table 1 for a listing of soil characteristics for each site). Soft white spring ('Alturas'), hard white spring ('Dayn'), and hard red spring ('Egan') wheat were planted at a seeding rate of 3,900,000 seeds ha-¹ at the three locations. The size of the experimental plots was 3 × 6 m (18 m²) with 17.8 cm row spacing.

The experimental plots were arranged in a split-plot design with four replications in a 4 × 4 factorial setup. The main plot factor was moisture stress, N rate the subplot factor. The four levels of irrigation treatment included 0% (rainfed or no irrigation), 50% (low irrigation), 75% (medium irrigation), and 100% (high irrigation) crop evapotranspiration (ET_c). Crop ET_c was calculated using the equation, $ET_c = ET_0 \times K_c$, where ET_0 is a grass-based reference evapotranspiration obtained from the AgriMet Cooperative Agricultural Weather Network weather station located within 1 km from each experimental site and K_c a growth stage–specific crop coefficient. Experimental plots in Parma were irrigated using a subsurface drip irrigation system while those in Aberdeen and Kalispell were irrigated using a surface drip irrigation system. The four rates of N treatment included no fertilizer applied, low (68 kg N ha-¹), medium (224 kg N ha-¹), and high (280 kg N ha-¹). The high N treatment corresponds to the recommended rate of N in each state. The target rates of N represent the sum of soil residual N and added N as urea (46-0-0). Phosphorous and potassium were applied as monoammonium phosphate (MAP, 11-52-0) and potassium chloride (0-0-60), based on soil test results and the fertilizer guidelines of the University of Idaho and Montana State University. Herbicides, fungicides, and insecticides were applied as needed. At anthesis, the normalized difference vegetation index (NDVI) and chlorophyll content (as relative greenness) were measured using a GreenSeeker handheld crop sensor and SPAD meter, respectively. At maturity, grain protein content and yield components, such as number of spikes ha-¹, number of kernels per spike, and kernel weight, were measured. Experimental plots were harvested using a small plot combine to assess grain yield.

Data were analyzed using SAS 9.4 (Littell et al. 2006). Proc CORR was used to determine the Pearson correlation coefficients between yield and grain protein with the other measured parameters. Data were also analyzed using the GLIMMIX procedure to compare the least-square means and main effects and to assess interactions of the experimental factors. Year (Y) was treated as a fixed effect to determine the location (LOC) Y × irrigation (IR) × N association. Block (B) within a Y, IR × B within a Y, and N × B within the Y were considered as random effects. In the absence of the LOC × Y × IR × N, the data was combined for further analysis. Figures and linear regressions were generated using Excel (Microsoft, Redmond, WA).

Table 1. Characterization of top 60 cm soils in field sites at the University of Idaho Parma Research and Extension Center (PREC), University of Idaho Aberdeen Research and Extension Center (AREC), and Montana State University Northwestern Agricultural Research Center at Kalispell (NWARC), 2016 and 2017.

Location	Year	pH	OM (%)	Soil residual N (kg ha-¹)			P (mg kg-¹)	K (mg kg-¹)	Sulfate-S (mg kg-¹)
				Inorganic N	Mineralized from OM	Mineralized from preceding legume			
PREC	2016	8.0	1.9	100	0	n/a	98	319	30
	2017	8.1	2.1	65	0	n/a	59	283	33
AREC	2016	8.3	1.1	119	0	n/a	21	175	20
	2017	8.3	1.3	156	0	n/a	15	175	16
NWARC	2016	7.6	2.7	36.6	11.8	39.2	10	95	6
	2017	7.8	2.5	19.5	8.4	n/a	10	112	9

NOTE: OM = Organic Matter, P = phosphorous, K = potassium, S = sulfur, n/a = not applicable.

Grain Yield and Yield Components

Grain yield was greater with a medium N rate plus high irrigation treatment, indicating that when plants are not water stressed, an optimal grain yield can be achieved even with an N level below the currently recommended level in each state (Table 2). Five out of six site years showed strong positive correlations between grain yield and irrigation treatment while none of the site years showed a correlation between grain yield and N treatment (Figures 1 and 2). The yield response specific to available moisture is illustrated in Figure 1 in which wheat yield is closely associated with irrigation. When site years were combined, yield showed the strongest response to low irrigation treatment, followed by a moderate response to the medium and high irrigation treatments. This reinforces yield similarity for the two higher water-application levels. N rate was not correlated with wheat yield at any of the site years (Table 2, Figure 2). The lack of response of yield to N fertilization could be due to relatively high residual soil N levels (especially at Aberdeen and Parma). Our findings agree with Bushong et al. (2014), who reported that wheat benefit from N application only when adequate soil moisture is available. Ul-Allah et al. (2018) also found that wheat performance was

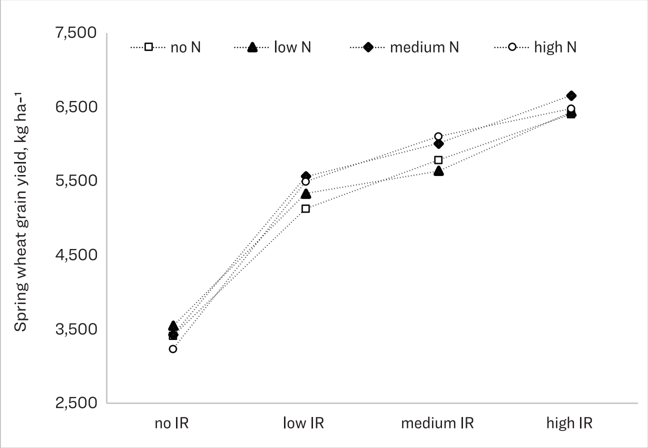

Figure 1. Average grain yield as affected by irrigation (IR) levels (0% [rainfed or no irrigation], 50% [low irrigation], 75% [medium irrigation], and 100% [high irrigation] crop evapotranspiration [ET$_c$]) at each N rate (no fertilizer applied, low [68 kg N ha^{-1}], medium [224 kg N ha^{-1}], and high [280 kg N ha^{-1}]).

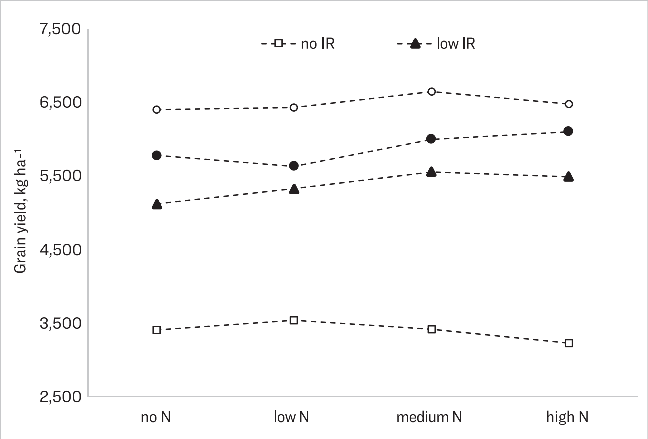

Figure 2. Average grain yield as affected by N rate (no fertilizer applied, low [68 kg N ha^{-1}], medium [224 kg N ha^{-1}], and high [280 kg N ha^{-1}]) at each irrigation (IR) level (0% [rainfed or no irrigation], 50% [low irrigation], 75% [medium irrigation], and 100% [high irrigation] crop evapotranspiration [ET$_c$]).

Table 2. Effects of irrigation (IR) levels (no, low, medium, and high) and N rates (no, low, medium, and high) on grain yield, grain protein, relative greenness (SPAD), and NDVI averaged across six site years.

Treatment	Grain yield (kg ha^{-1})	Grain protein (%)	SPAD	NDVI
No N-no IR	3,410 d	13.5 abc	32.6 d	0.38 g
Low N-no IR	3,542 d	14.4 a	33.7 cd	0.44 fg
Medium N-no IR	3,416 d	14.7 a	36.5 abcd	0.46 efg
High N-no IR	3,226 d	14.2 ab	35.1 bcd	0.47 ef
No N-low IR	5,119 c	11.4 d	37.8 abcd	0.49 def
Low N-low IR	5,327 c	12.1 cd	40.7 abcd	0.57 bcd
Medium N-low IR	5,557 bc	12.9 abcd	41.3 abcd	0.62 abc
High N-low IR	5,490 bc	12.5 bcd	40.6 abcd	0.58 abc
No N-medium IR	5,777 abc	12.0 cd	39.9 abcd	0.53 cde
Low N-medium IR	5,632 abc	12.8 abcd	38.3 abcd	0.57 bcd
Medium N-medium IR	6,001 abc	12.5 bcd	41.8 abc	0.64 ab
High N-medium IR	6,102 abc	12.2 cd	41.5 abcd	0.64 ab
No N-high IR	6,401 abc	11.2 d	42.9 abcd	0.60 abc
Low N-high IR	6,431 abc	12.6 bcd	40.6 ab	0.63 ab
Medium N-high IR	6,650 a	12.0 cd	40.3 abcd	0.66 a
High N-high IR	6,477 abc	13.2 abcd	44.6 a	0.67 a

NOTE: Means sharing the same letters are not statistically significant at 0.05 probability level.

affected by irrigation and N application, as well as genotype, with respect to grain yield and water use efficiency.

At all site years, a moderate correlation was observed between grain yield and the number of kernels per spike. In four out of six site years, a strong positive correlation was observed between grain yield and the number of spikes ha^{-1}. At three out of six site years, grain yield was positively correlated with kernel weight (data not shown). The differences in the relationship between grain yield and yield components among three locations could be due to varietal differences.

Grain Protein and Grain Yield/Grain Protein Relationship

Grain protein was mostly negatively correlated with irrigation treatment due to the inverse grain yield to protein relationship (Table 2). At the Montana location, grain protein was positively correlated with N rate in both years but in the Idaho locations, a significant correlation between grain protein and N rate was not observed (data not shown). Under rainfed conditions, relatively higher grain protein values were observed, with low and medium N rates. This was anticipated, as N fertilizer in combination with minimal water facilitates N concentration in wheat grain.

Grain yield and grain protein content typically possessed a negative correlation due to an inverse yield/grain protein relationship. At lower grain protein values (~11%–13%), yield was relatively stable. However, at higher grain protein values (>13%), yield decreased notably (Figure 3).

In-Season Sensor Measurements (SPAD and NDVI)

The relative greenness (SPAD) increased with increased irrigation, but a clear pattern was not observed with N rates (Table 2). However, NDVI increased when both irrigation and N fertilization increased. Notably, in response to N treatment, NDVI plateaued at a medium N rate, indicating NDVI saturation at a high N rate (Table 2, Figures 4 and 5). A strong positive correlation was observed between SPAD and NDVI. In addition, the SPAD and NDVI values showed a strong positive correlation

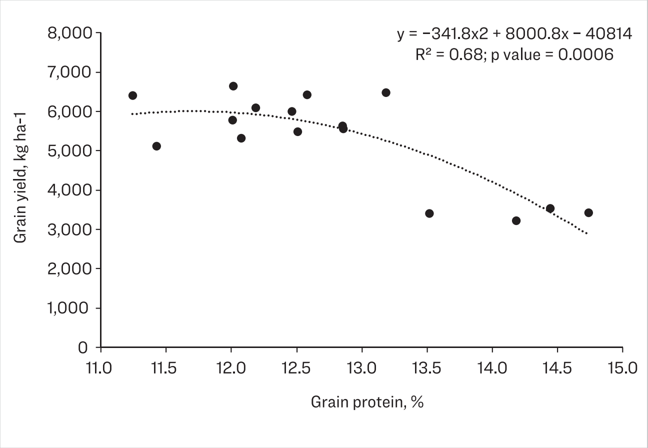

Figure 3. The relationship between grain yield and grain protein content across six site years.

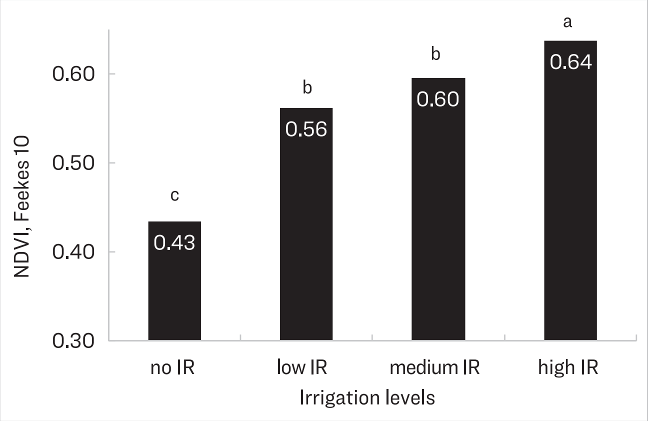

Figure 4. Effects of irrigation (IR) levels (0% [rainfed or no irrigation], 50% [low irrigation], 75% [medium irrigation], and 100% [high irrigation] crop evapotranspiration [ETc]) on NDVI when averaged over N rates (no fertilizer applied, low [68 kg N ha^{-1}], medium [224 kg N ha^{-1}], and high [280 kg N ha^{-1}]).

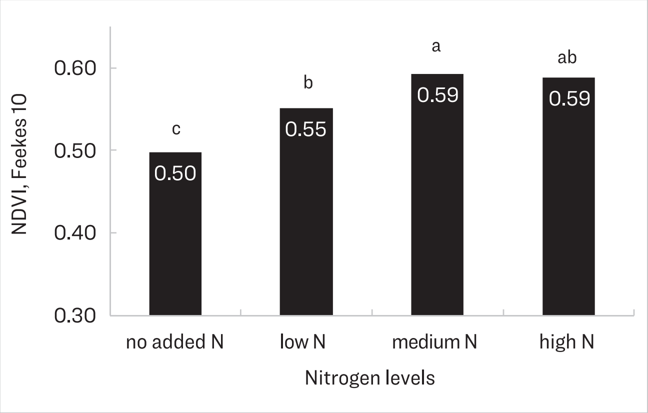

Figure 5. Effects of N rates (no fertilizer applied, low [68 kg N ha^{-1}], medium [224 kg N ha^{-1}], and high [280 kg N ha^{-1}]) on NDVI when averaged over irrigation levels (0% [rainfed or no irrigation], 50% [low irrigation], 75% [medium irrigation], and 100% [high irrigation] crop evapotranspiration [ET$_c$]).

with grain yield but a negative correlation with grain protein (Figures 6 and 7). The SPAD and NDVI values explained approximately 80% and 84% of the variation of wheat yield while they explained only about 37% and 28% of variation in grain protein, respectively.

These findings suggest the suitability of using crop sensors to assess yield response to irrigation and N fertilization. The NDVI has been widely utilized for yield prediction during the growing season. Our results agreed with high coefficients of determination between NDVI and wheat yield (Bronson et al. 2017). Overall, in our study, lower NDVI and SPAD measurements corresponded to higher wheat grain protein values. Although the in-season NDVI and SPAD measurements increased with increasing N and irrigation, they were closely correlated only with wheat yield due to irrigation. This suggests an ability to predict yield at varied irrigation levels using NDVI and SPAD data. Our findings support the results discovered by Freeman et al. (2003), who observed no consistent relationship between NDVI and wheat grain protein content.

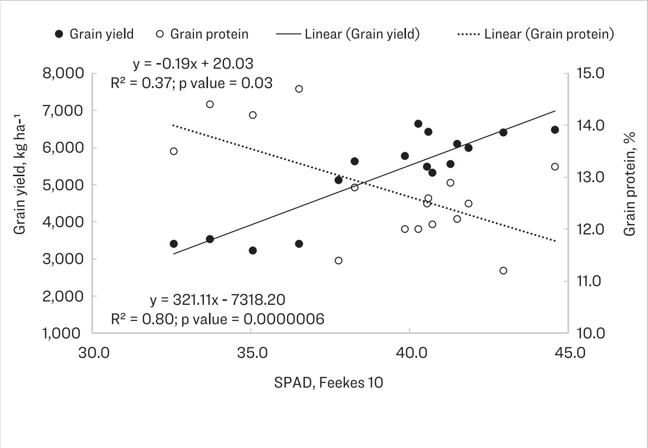

Figure 6. Relationship between grain yield or grain protein content with relative greenness (SPAD) across six site years.

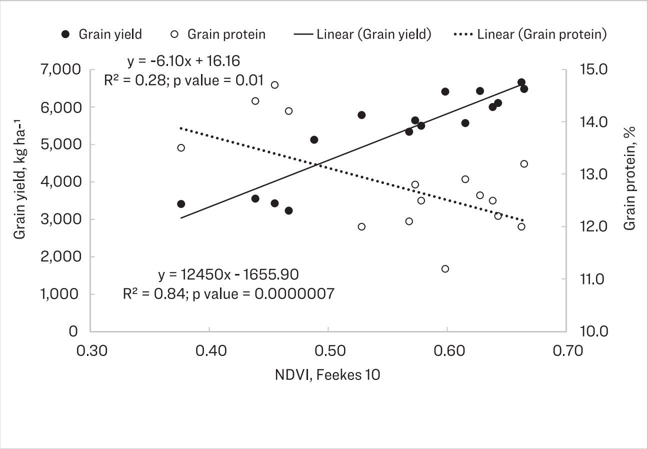

Figure 7. Relationship between grain yield or grain protein content with NDVI across six site years.

Conclusion

- A strong positive correlation was observed between grain yield and irrigation but not with the N rate. The results suggest that irrigation can be reduced by 25% (medium irrigation) while crops maintain optimal grain yield and grain protein content. This recommendation will help to reduce water usage by 25% during wheat production in semiarid cropping systems.
- Application of 150 kg N ha^{-1} (soil residual N plus added fertilizer) is sufficient to optimize the grain yield and protein content of irrigated spring wheat grown in Idaho and Montana. This rate is lower than the currently recommended N rate in each state. Therefore, this recommendation will minimize input costs during wheat production, environmental impacts, and human health concerns.
- Strong positive correlations of SPAD or NDVI with grain yield suggest the feasibility of using these crop sensors for in-season wheat yield assessment, especially in irrigated cropping systems.

Further Reading

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