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Irrigation and Nitrogen Fertilization Affect End-Use Quality of Spring Wheat of Three Market Classes

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Contents

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Introduction

WATER AND NITROGEN (N) are two key production inputs for most cropping systems, particularly in semiarid and arid regions of the western United States, where limited water availability (especially freshwater) threatens crop production. Cereal production in those regions becomes increasingly dependent on supplemental irrigation application due to erratic rainfall distribution and the increased frequency of extreme weather events, such as heat and drought stresses. In addition, increasing costs of irrigation, including energy, water, and labor, lower the economic return for cereal crops.

A principal and costly nutrient input is N fertilizer, but its use efficiency is only about 40%–50% in most US agricultural operations. Low N use efficiency (pounds of N applied per bushel of crop produced) results from a loss of applied N to the soil-plant system via various pathways (e.g., gaseous plant emission, denitrification, leaching, surface runoff, and volatilization). Improving N use efficiency in cereal crops is thus a challenging task. It requires an ability to coordinate an accurate estimate of crops' need for N with the development of nutrient management practices that provides the best return from N fertilizer application.

Wheat is an integral crop in Idaho, where it is grown as a main cash crop or as a vital rotational crop with others such as vegetables, potatoes, sugar beet, pulses, and oil seeds. In order to maximize wheat grain yields and enhance grain quality, wheat producers urgently need to develop more efficient water and nutrient management strategies. But it's a complex pursuit. The uptake of water and N for crop growth and production is fundamentally interactive. Soil moisture significantly affects both nutrient release from applied fertilizers and mineralization reactions within the soil ecosystem. Thus, when developing N guidelines for irrigated crops, it is necessary to address the efficiency of water and N applications at the same time.

Water and N management for wheat grain yield improvement have been well documented, whereas there is a lack of evaluations of grain quality in response to these management practices. Many of the parameters that are indicative of wheat grain quality deserve more discussion or attention, starting with the utility of test weight as a measure of grain bulk density and quality. Indeed, a high test weight generally represents good grain quality and a great economic value. Falling number is another one that indicates α-amylase activity and the degree of sprout damage. Generally speaking, a wheat grain sample with a greater falling number (e.g., > 350 sec) denotes lower enzyme activity and better quality. Protein content is probably the single most important grain quality trait, since it directly relates to many important processing properties such as water absorption, gluten strength, texture, and appearance. Higher-protein dough usually absorbs more water and takes longer to mix, qualities usually regarded as undesirable in baking. The solvent retention capacity (SRC) test is a more recently developed method and provides useful information such as gluten strength and starch damage during the milling process. Flour yield represents the portion of the wheat kernel that can be milled into flour and is an important indicator of milling profitability. Lastly, ash content indicates how well flour separates from the bran. Since ash content can affect flour color, a low ash content is often a high priority among millers for white flours.

To date, most recommendations for irrigation and N fertilization are calibrated for optimal grain yield, but few studies have investigated their effects on grain quality. Therefore, the objective of this study is to determine N and water requirements for optimal wheat grain quality.

Field Experiments

Three field experiments were performed in 2016 and 2017 at three locations, including the University of Idaho Aberdeen Research and Extension Center; the University of Idaho Parma Research and Extension Center; and the Montana State University Northwestern Agricultural Research Center at Kalispell. Characterization of the top-foot soil at each location and in each year is listed in Table 1. Experimental locations in 2016 and 2017 at each location were adjacent to each other to minimize soil heterogeneity and carryover effects from different experimental treatments from previous seasons. Experimental plot size was 10 × 20 ft (i.e., 200 ft^2) with 7-in row spacing, and the seeding rate was 1,000,000 seeds/ac at each location. Hard white spring wheat (‘Dayn’), soft white spring wheat (‘Alturas’), and hard red spring wheat (‘Egan’) were planted at Aberdeen, Parma, and Kalispell, respectively (Table 2).

At each location, the experiment was established with two factors and four replications for each year. The first factor was irrigation treatment, including 0% (dryland control), 50%, 75%, and 100% crop

Table 1. Characterization of the top-foot soil at the Aberdeen Research and Extension Center (AREC) and Parma Research and Extension Center (PREC) in Idaho and the Northwestern Agricultural Research Center (NWARC) in Montana in 2016 and 2017.

Location	Year	pH	Organic matter (%)	N (lb/ac)	P (ppm)	K (ppm)	Sulfate-S (ppm)
AREC, ID	2016	8.3	1.1	106	21	175	20
	2017	8.3	1.3	139	15	175	16
PREC, ID	2016	8.0	1.9	173	98	319	30
	2017	8.1	2.1	180	59	283	33
NWARC, MT	2016	7.6	2.7	97	10	95	6
	2017	7.8	2.5	33	10	112	9

Table 2. Rainfall during the growing seasons and irrigation quantities of the 100% ET_c treatment at the Aberdeen Research and Extension Center (AREC) and the Parma Research and Extension Center (PREC) in Idaho and the Northwestern Agricultural Research Center (NWARC) in Montana in 2016 and 2017.

Location	Cultivar	Market class	Rainfall during the growing seasons		Irrigation for the 100% Et_c treatment	
			2016 (in)	2017 (in)	2016 (in)	2017 (in)
AREC, ID	'Dayn'	Hard white spring wheat	2.7	2.2	12.0	15.0
PREC, ID	'Alturas'	Soft white spring wheat	3.5	2.3	7.4	8.5
NWARC, MT	'EGAN'	Hard red spring wheat	11.0	5.6	5.0	6.0

Table 3. Evaluated flour end-use quality attributes and their implications.

End-use quality attribute	Description
Test weight	Represents grain bulk density. Higher values are preferred.
Falling number	Represents the degree of sprout damage. Higher values are preferred.
Flour yield	The percentage of flour obtained from grain. Higher is better.
Flour ash	The percentage of mineral materials in flour (e.g., bran and germ). Lower is better.
Flour protein	Lower is better for soft wheat; higher is preferred for hard wheat.
Mixograph peak time	Represents time to optimal dough mixing.
Mixograph height	Represents dough strength.
Water-retention capacity	Represents flour water absorption.
Lactic acid-retention capacity	Represents gluten strength.
Baking volume	Baking bread volume for hard wheat.
Cookie diameter	Baking cookie diameter for soft wheat.

evapotranspiration (ET_c) replenishment. Daily ET_c was calculated by daily atmospheric grass-referenced evapotranspiration (ET_o) multiplied by crop coefficient (K_c). Daily ET_o was retrieved from AgriMet Cooperative Agricultural Weather Network weather stations located within 1 mile of each experimental location. The K_c for key growth stages of wheat was obtained from Allen et al. (1998). Irrigation was applied via dripping systems and was triggered when 35% of the plant-available water in the soil was depleted and terminated at stages between late milking and early soft dough. Rainfall and irrigation for the 100% ET_c treatment during each growing season are listed in Table 2.

The second factor was N fertilization. Target soil N levels included 150-, 200-, and 250-lb N ac-1, which were denoted by low, medium, and high N rates, respectively. Actual N application rate was calculated by subtracting soil residual N (Table 1) from the target N level. N as urea (46–0–0) was incorporated prior to planting. A control treatment with no N addition (i.e., zero N rate) was also included. Phosphorus (P) and potassium (K) were supplied as monoammonium phosphate (11–52–0) and potassium chloride (0–0–60), according to soil test results for each location and year, following the guidelines of the University of Idaho and Montana State University for crop fertilization under irrigated conditions. Herbicides, fungicides, and insecticides were applied as needed at each location.

Plots were harvested at maturity using a small-plot combine. The University of Idaho's Wheat Quality Laboratory at Aberdeen analyzed all end-use quality attributes. Evaluated end-use quality traits and their implications are listed in Table 3.

Hard White Spring Wheat at the Aberdeen Research and Extension Center

'Dayn' is a hard white spring wheat cultivar that the Washington State University Agricultural Research Center and the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) released in 2012. It produced the highest grain yield in variety trials conducted in 2016 and 2017 in southern Idaho. In the Aberdeen experiment, irrigation significantly improved test weight and flour yield; however, flour ash content, flour protein content, dough optimal mixing time (mixograph peak time), dough/gluten strength (mixograph height and lactic acid-retention capacity), and baking loaf volume decreased following irrigation (Table 4). There was no significant difference in any evaluated grain quality traits between the 75% and 100% ET_c irrigation treatments. Falling number was not affected by irrigation treatment nor N rate.

N fertilization slightly decreased test weight, but increased flour ash content, flour protein content, mixograph height, and baking loaf volume. No significant difference was observed in any evaluated end-use quality attribute among the low, medium, and high N rates.

Hard Red Spring Wheat at the Northwestern Agricultural Research Center

'Egan' is a recently released hard red spring wheat cultivar by Montana State University and is known for its high yield potential, high protein content, and resistance to orange wheat blossom midge. In the experiment conducted at Kalispell, the 75% and 100% ETc irrigation treatments produced similar grain quality (Table 5). 'Egan' was able to maintain high and consistent flour protein content (>15%) under different irrigation treatments, which surpasses the premium market quality of grain protein content for hard red spring wheat (14%). This cultivar also showed improved dough/gluten strength (mixograph height and lactic acid-retention capacity) and baking loaf volume with irrigation.

Although N application decreased the falling number, it is not a primary concern since the falling numbers were all above 350 sec (Table 5). Minimal differences were observed between the medium and high N rates in most evaluated end-use quality attributes.

Table 4. End-use quality as affected by irrigation treatment and N rate in hard white spring wheat 'Dayn' at the Aberdeen Research and Extension Center (AREC) in Idaho.

Treatment		Test weight (lb/bu)	Falling number (s)	Flour yield (%)	Flour ash content (%)	Flour protein content (%)	Mixograph peak time (min)	Mixograph height (cm)	Water-retention capacity (%)	Lactic acid-retention capacity (%)	Loaf volume (cm³)
Irrigation	0% ET_c	56.4 b	333 a	58.7 b	0.38 a	16.4 a	4.5 a	7.8 a	59.4 a	140.0 a	1362.5 a
	50% ET_c	62.6 a	331 a	60.8 a	0.34 b	12.9 b	3.7 b	7.1 b	56.7 a	126.7 ab	1173.4 b
	75% ET_c	63.0 a	329 a	60.2 a	0.34b	11.5 c	3.2 bc	6.8 b	55.7 a	114.9 b	1053.9 c
	100% ET_c	62.6 a	319 a	59.8 ab	0.34 b	11.3 c	2.9 c	6.8 b	56.1 a	103.3 b	1039.8 c
N rate	Zero	62.6 a	329 a	59.5 a	0.34 b	12.0 b	3.5 a	6.8 b	55.3 a	115.7 a	1104.7 b
	Low	61.4 ab	332 a	60.0 a	0.35 ab	13.1 ab	3.6 a	7.1 ab	56.4 a	123.4 a	1160.2 ab
	Med	60.6 ab	325 a	60.0 a	0.36 a	13.3 a	3.5 a	7.1 ab	57.1 a	118.8 a	1168.0 ab
	High	60.3 b	326 a	60.0 a	0.36 a	13.6 a	3.6 a	7.3 a	58.3 a	123.3 a	1185.8 a

The values of each parameter are the average of 2016 and 2017. Different letters within each column (a, b, ab, bc, c) indicate significant differences among irrigation treatments or N rates at a 0.05 significance level.

Table 5. End-use quality as affected by irrigation treatment and N rate in hard red spring wheat 'Egan' at the Northwestern Agricultural Research Center (NWARC) in Montana.

Treatment		Test weight (lb/bu)	Falling number (s)	Flour yield (%)	Flour ash content (%)	Flour protein content (%)	Mixograph peak time (min)	Mixograph height (cm)	Water-retention capacity (%)	Lactic acid-retention capacity (%)	Loaf volume (cm³)
Irrigation	0% ET_c	59.8 c	510 a	53.3 b	0.65 a	15.5 a	5.4 a	6.9 b	70.1 a	118.1 b	1068.8 c
	50% ET_c	60.8 b	487 ab	54.7 ab	0.64 a	15.7 a	4.5 b	7.4 a	69.6 ab	124.3 ab	1129.5 b
	75% ET_c	61.0 ab	488 b	54.4 a	0.64 a	15.6 a	4.3 b	7.7 a	69.2 ab	129.1 a	1182.1 a
	100% ET_c	61.1 a	482 b	55.3 a	0.64 a	15.5 a	3.9 b	7.6 a	68.8 b	131.3 a	1161.6 ab
N rate	Zero	61.0 a	509 a	57.1 a	0.62 c	14.2 b	4.7 a	7.3 b	68.6 b	135.6 a	1112.5 b
	Low	60.7 b	493 b	53.7 b	0.64 b	15.7 a	4.6 a	7.6 a	69.0 b	124.0 b	1123.2 b
	Med	60.6 bc	485 b	53.6 b	0.66 a	16.2 a	4.5 a	7.4 ab	70.1 a	120.5 b	1128.6 b
	High	60.4 c	490 b	53.4 b	0.65 a	16.2 a	4.4 a	7.4 ab	69.9 a	122.8 b	1177.7 a

The values of each parameter are the average of 2016 and 2017. Different letters within each column (a, b, ab, bc, c) indicate significant differences among irrigation treatments or N rates at a 0.05 significance level.

Table 6. End-use quality as affected by irrigation treatment and N rate in soft white spring wheat 'Alturas' at the Parma Research and Extension Center (PREC) in Idaho.

Treatment		Flour yield (%)	Flour protein content (%)	Flour ash content (%)	Cookie diameter (cm)
Irrigation	0% ET_c	66.6 a	7.8 a	0.353 a	8.8 a
	50% ET_c	65.9 a	7.8 a	0.353 a	8.9 a
	75% ET_c	66.8 a	8.0 a	0.352 a	8.9 a
	100% ET_c	66.2 a	7.9 a	0.354 a	8.9 a
N rate	Zero	65.9 a	7.2 c	0.352 a	8.9 a
	Low	66.5 a	7.6 b	0.351 a	8.8 a
	Med	66.0 a	8.3 a	0.354 a	8.9 a
	High	67.0 a	8.3 a	0.356 a	8.9 a

The values of each parameter were obtained from an experiment conducted in 2017. Different letters within each column (a, b, c) indicate significant differences among irrigation treatments or N rates at a 0.05 significance level.

Soft White Spring Wheat at the Parma Research and Extension Center

'Alturas' is a soft white spring wheat cultivar released by the Idaho Agricultural Experiment Station and USDA-ARS in 2002 that has been planted throughout southern Idaho. In the experiment conducted in Parma, flour protein content of 'Alturas' increased with N rate, but flour yield, flour ash content, and cookie diameter were not affected by N fertilization (Table 6). Flour yield, flour protein content, flour ash content, and cookie diameter responded minimally to irrigation treatments.

Conclusion and Recommendations

The results from experiments conducted at multiple locations in multiple years provide helpful data on water and N management to achieve optimal grain quality in spring wheat of different market classes.

No difference was observed in any end-use quality attributes under a 25% reduction in irrigation (i.e., 75% ET_c) compared to the full irrigation treatment (i.e., 100% ET_c) in spring wheat of any class, suggesting minimal effects on end-use quality from the irrigation reduction.

End-use quality attributes did not differ between the high (250 lb/ac) and medium N rate (200 lb/ac equals soil residue N plus applied N fertilizer) in any tested spring wheat cultivar, suggesting that 200 lb/ac might be adequate to achieve optimal end-use quality.

Further Reading

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