Late Season Water and Nitrogen Effects on Durum Quality, 1995 (Final)

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Abstract

Durum grain quality is affected by many factors, but water and nitrogen are factors that the grower can control. The purpose of this research was to determine 1) the nitrogen application rate required at pollen shed to maintain adequate grain protein levels if irrigation is excessive or deficient during grain fill and 2) if nitrogen applications during grain fill can elevate grain protein. Field research was conducted at the Maricopa Agricultural Center using the durum varieties Duraking, Minos, and Turbo. The field was treated uniformly until pollen shed when nitrogen was applied at rates of 0, 30, and 60 lbs/acre. During grain fill, the plots were irrigated based on 30, 50, or 70% moisture depletion. In a separate experiment, nitrogen fertilizer was applied at a rate of 30 lbs N/acre at pollen shed only, pollen shed and the first irrigation after pollen shed, and pollen shed and the first and second irrigation after pollen shed. Irrigation had no effect on grain protein level, although increasing nitrogen rates at pollen shed from 0 to 30 and 30 to 60 lbs N/acre increased protein by 1 percentage point. Nitrogen fertilizer application at the first irrigation after pollen shed increased grain protein content from 10.4 to 11.4% and application at the first and second irrigation after pollen shed increased grain protein content further to 11.9% averaged over varieties. Irrigation management during grain fill may not play as large a role in controlling grain protein content as was originally thought except perhaps on heavy soils, and nitrogen fertilizer application during grain fill may not be too late to increase grain protein content.

Introduction

The biggest problem facing the durum industry in Arizona is producing an acceptable quality of grain for pasta-making. Many factors influence durum grain quality such as the cultivar and growing season weather, but only nitrogen and water management can be controlled after planting by the grower. Nitrogen fertilizer management plays a major role in the production of high quality grain. Applications of nitrogen fertilizer during early stages affects yield while applications near pollen shed increase grain protein levels. An application of 30 pounds of nitrogen per acre is recommended near pollen shed to ensure acceptable grain protein levels according to current University of Arizona guidelines. This recommendation assumes that irrigations during the grain fill period will be applied according to crop requirements and that yields will be "normal". Excessive irrigations can reduce nitrogen availability due to leaching and lack of oxygen in the soil, and lead to reduced grain protein concentration. High yields tend to dilute the protein accumulated in the grain and reduce protein concentration.

This research was undertaken to answer the following questions: 1) Will an application of 30 pounds of nitrogen fertilizer per acre at pollen shed ensure acceptable grain quality if irrigations during grain fill are inadequate or excessive? and 2) Can nitrogen fertilizer applications during the grain fill period elevate grain protein concentration in anticipation of high yields?

Procedure

Field studies were conducted at the Maricopa Agricultural Center on Field 105, a Casa Grande Sandy Loam. The previous crop in the field was sudangrass. Preplant fertilizer was applied at the rate of 60 lbs N/acre and 75 lbs P_2O_5/acre as 16-20-0. Duraking, Minos, and WestBred Turbo were planted into dry soil and irrigated up on November 30, 1994. The seed was planted with a grain drill in 12 ft. wide strips. The seeding rate was 120 pounds of seed per acre. The plots were 12 ft. x 50 ft.

Irrigation water and nitrogen fertilizer were applied at similar rates until pollen shed (see Tables 1 and 2). Starting at pollen shed, two experiments were conducted to determine: 1) the influence of irrigation during grain fill on the effectiveness of nitrogen applications at pollen shed and 2) the influence of nitrogen applications during grain fill on grain protein. Experiment 1 was designed as a split-split plot with four replications and irrigation levels during grain fill as main plots, varieties as subplots, and nitrogen rate at pollen shed as sub-subplots. Irrigation levels maintained during grain fill were 30, 50, and 70% soil moisture depletion as determined by neutron probe readings. The amount of water applied for each irrigation level during grain fill was based on the soil moisture depletion and assuming an irrigation efficiency of 0.7. A larger volume of water than necessary to replace depleted moisture was applied to the 30% treatment in order to get water down to the end of the field. Duraking, Minos, and Turbo were the varieties and nitrogen was applied at pollen shed at rates of 0, 30, and 60 lbs N/acre. Experiment 2 was designed as a split plot with varieties as main plots and nitrogen application during grain fill as subplots. Nitrogen was applied at a rate of 30 lbs N/A at pollen shed only, pollen shed plus the first irrigation after pollen shed, and pollen shed plus the first and second irrigation after pollen shed.

The plots were harvested with a small plot combine on May 19, 1995 (Duraking and Minos) and on June 1, 1995 (Turbo). The harvested area was 5 ft. x 45 ft. The grain was weighed, moisture determined, and grain yield was calculated on a 10% moisture basis. Grain protein was estimated by multiplying 5.7 by total grain nitrogen determined by the Kjeldahl method and adjusting to 12% moisture. Hard vitreous amber count and black tip were determined from a 10 g sample and expressed as % by weight. Plant height and lodging were measured before harvest. Pollen shed was defined as the first day of pollen shed and physiological maturity date was defined as the point when the glumes turn color. Whole plant samples were removed from an 8 ft^2 area for the variety Turbo. Harvest index was determined from these samples, and straw, total yields, and nitrogen uptake calculated. Durum quality was analyzed by the California Wheat Commission Lab in Woodland, CA.

Discussion

Nitrogen rate at pollen shed and variety influenced grain protein and other measured variables, but irrigation during grain fill had no effect (Table 3). Duraking yielded the highest, but Minos had the highest grain protein, hard vitreous amber count, and amount of black point (a fungal disease on the grain that decreases grain quality). Nitrogen rates of 30 and 60 pounds nitrogen per acre at pollen shed increased grain yield of Duraking and Turbo, but not of Minos. Increasing nitrogen rates from 0 to 30 and 30 to 60 lbs N/acre increased grain protein by about 1 percentage point. Hard vitreous amber counts and black point was also increased by an increase in nitrogen rate at pollen shed. Currently, 30 lbs N/acre is recommended at pollen shed to ensure adequate protein content in durum. Higher rates may be needed for certain varieties or if the nitrogen status of the plant is low at pollen shed. The fact that irrigation during grain fill had no main or interactive effect on grain protein is surprising. The irrigation interval of the wettest treatment averaged every 7 days during grain fill, and protein levels in this treatment were similar to the driest treatment, which received water every 14 days on average during grain fill. Presumably, protein levels would decrease with excessive irrigation and a higher rate of nitrogen at pollen shed would be required to maintain adequate protein. This was not the case in our experiment on a sandy loam soil, but excessive irrigation during grain fill may decrease grain protein content on heavier soil types.

Nitrogen application during grain fill increased grain protein content and hard vitreous amber count, but did not affect grain yield or occurrence of black point. The highest yielding variety was Duraking in this experiment, and varietal differences in plant height and maturity were noted. Nitrogen applications during grain fill were too late to affect yield as anticipated, but increases in grain protein content from these applications were also not expected. Nitrogen applications during grain fill have not been recommended in the past, but our research suggests that this practice may be effective in increasing grain protein levels.

Acknowledgments

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Table 1. Schedule of nitrogen fertilizer application.

			Irrigation x Nitrogen Experiment lbs N/acre at pollen shed			Late Season Nitrogen Experiment 30 lbs N/acre at		
Date	Stage	Form of nitrogen	0	30	60	Pollen shed only	Pollen shed and 1st irrigation after pollen shed	Pollen shed and 1st and 2nd irrigation after pollen shed
			------------------- lbs N/acre -------------------					
Nov 29	Preplant	16-20-0	60	60	60	60	60	60
Feb 09	6 leaf	UN32	50	50	50	50	50	50
Mar 06	Late boot	UN32	75	75	75	75	75	75
Mar 23	Pollen shed	Urea	0	30	60	30	30	30
Apr 04	+ 12 d	Urea	0	0	0	0	30	30
Apr 17	+ 25 d	Urea	0	0	0	0	0	30
SUM	Season		185	215	245	215	245	275

Table 2. Irrigation schedule.

Irrigation x Nitrogen Experiment									Late Season Nitrogen Experiment		
Post pollen shed soil moisture depletion											
30%			50%			70%			50%		
Date	Stage	Inches	Date	Stage	Inches	Date	Stage	Inches	Date	Stage	Inches
30Nov	Planting	4	30Nov	Planting	4	30Nov	Planting	4	30Nov	Planting	4
09Feb	6 leaf	3	09Feb	6 leaf	3	09Feb	6 leaf	3	09Feb	6 leaf	3
06Mar	Late boot	3	06Mar	Late boot	3	06Mar	Late boot	3	06Mar	Late boot	3
23Mar	Pollen shed	3	23Mar	Pollen shed	3	23Mar	Pollen shed	3	23Mar	Pollen shed	3
31Mar	+ 8 d	2.1	04Apr	+ 12 d	2.8	06Apr	+ 14 d	3.9	04Apr	+ 12 d	2.8
06Apr	+ 14 d	2.1	15Apr	+ 23 d	2.8	21Apr	+ 29 d	3.9	17Apr	+ 25 d	2.8
14Apr	+ 22 d	2.1	28Apr	+ 36 d	2.8				28Apr	+ 36 d	2.8
21Apr	+ 29 d	2.1									
27Apr	+ 35 d	2.1									

Table 3. Irrigation, variety, and nitrogen application at pollen shed effects on grain yield and various grain and plant characteristics.

Irrigation during grain fill	Variety	Nitrogen at Pollen shed	Grain Yield[1]	Grain Protein[2]	Hard Vitreous Amber	Black Point[3]	Plant Height	Lodging	Pollen shed	Physio-logical Maturity
% depletion		lbs/acre	lbs/acre	%	%	%	inches	%		
30	Duraking	0	8000	9.8	43	0.6	37	0	3/18	4/28
30	Duraking	30	8006	10.3	65	0.4	37	13	–	4/29
30	Duraking	60	8623	12.6	91	2.0	37	13	–	4/29
30	Minos	0	6632	11.7	68	0.9	41	8	3/17	4/29
30	Minos	30	6816	13.4	93	1.8	39	28	–	4/28
30	Minos	60	6877	13.8	94	1.4	39	0	–	4/29
30	Turbo	0	6260	10.0	62	0.2	44	0	3/24	5/02
30	Turbo	30	7139	10.9	77	0.2	44	0	–	5/02
30	Turbo	60	6686	11.2	88	0.8	43	0	–	5/02
50	Duraking	0	8414	10.2	67	1.1	37	0	3/19	4/30
50	Duraking	30	8227	11.3	79	0.8	36	0	–	4/29
50	Duraking	60	8457	12.0	93	0.8	36	10	–	4/29
50	Minos	0	6631	10.9	67	1.1	40	8	3/18	4/29
50	Minos	30	6619	12.1	84	1.6	39	5	–	4/28
50	Minos	60	6943	14.1	98	1.8	40	5	–	4/29
50	Turbo	0	6929	9.5	57	0.0	44	0	3/24	5/03
50	Turbo	30	7372	10.7	81	0.6	42	0	–	5/03
50	Turbo	60	7473	11.3	85	1.0	43	0	–	5/03
70	Duraking	0	6938	9.2	36	0.3	36	0	3/18	4/28
70	Duraking	30	7232	10.2	66	1.9	38	0	–	4/28
70	Duraking	60	7838	11.2	89	0.3	35	0	–	4/28
70	Minos	0	6765	9.8	53	0.7	40	0	3/17	4/28
70	Minos	30	6902	11.5	87	2.2	41	15	–	4/28
70	Minos	60	6531	13.3	97	2.1	40	5	–	4/28
70	Turbo	0	6073	9.6	63	0.2	43	0	3/24	5/02
70	Turbo	30	6956	10.5	87	0.4	43	0	–	5/02
70	Turbo	60	6479	11.5	92	0.4	42	0	–	5/03
LSD (5%)[4]			620	1.65	24.4	1.27	2.3	16.5	1.9	1.1
30	All	All	7204	11.5	76	0.9	40	7	3/20	4/30
50	All	All	7451	11.3	79	1.0	40	3	3/20	5/01
70	All	All	6857	10.8	74	0.9	40	2	3/20	4/30
LSD (5%)			NS	NS	NS	NS	NS	NS	NS	NS
All	Duraking	All	7969	10.8	70	0.9	36	4	3/18	4/28
All	Minos	All	6746	12.3	82	1.5	40	8	3/17	4/28
All	Turbo	All	6819	10.6	77	0.4	43	0	3/24	5/03
LSD (5%)			422	0.64	8.1	0.42	0.9	5.2	1.0	1.5
All	All	0	6930	10.1	57	0.6	40	2	–	4/30
All	All	30	7252	11.2	80	1.1	40	7	–	4/30
All	All	60	7323	12.3	92	1.1	39	4	–	4/30
LSD (5%)			207	0.55	7.9	0.39	NS	NS	–	NS

Table 3. (con'd) Irrigation, variety, and nitrogen application at pollen shed effects on grain yield and various grain and plant characteristics.

	Grain Yield	Grain Protein	Hard Vitreous Amber	Black Point	Plant Height	Lodging	Pollen shed	Physio-logical Maturity
Effect				Significance of Effects[5]				
Irrigation	NS	NS	NS	NS	NS	NS	NS	NS
Variety	**	**	*	**	**	*	**	**
Variety x Irrigation	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen	**	**	**	**	NS	NS	–	NS
Nitrogen x Irrigation	NS	NS	NS	NS	NS	NS	–	NS
Nitrogen x Variety	**	NS	NS	NS	NS	NS	–	NS
Nitrogen x Irrigation x Variety	NS	NS	NS	NS	NS	NS	–	NS

1 Grain yield calculated on a 10% moisture basis.

2 Grain protein calculated on a 12% moisture basis.

3 Black point is a fungal disease of the grain that appears as specks in the pasta.

4 LSD (5%) = least significant difference at the 5% probability level.

5 NS, *, and ** = not significant at the 5% probability level, and significant at the 5% and 1% probability level, respectively.

Table 4. Irrigation, variety, and nitrogen application at pollen shed effects on total yield and nitrogen uptake for the variety Turbo.

Irrigation during grain fill	Nitrogen at Pollen shed	Total Yield[1]	Grain Yield	Straw Yield	Harvest Index	Straw Nitrogen	Total N Uptake	Grain N Uptake	Straw N Uptake	Nitrogen Harvest Index
% deplet.	lbs/acre	lbs/acre	lbs/acre	lbs/acre	%	%	lbs/acre	lbs/acre	lbs/acre	%
30	0	16720	6260	10460	37.4	0.50	163	113	50	69.0
30	30	17814	7139	10675	40.0	0.30	171	140	31	82.1
30	60	16319	6686	9632	40.9	0.35	167	135	32	80.5
50	0	17936	6929	11006	38.7	0.35	157	119	37	76.2
50	30	18799	7372	11427	39.3	0.37	184	142	41	78.4
50	60	18442	7473	10969	40.5	0.37	191	151	39	79.6
70	0	15803	6073	9730	38.3	0.35	140	106	34	76.5
70	30	18082	6956	11125	38.5	0.36	171	132	39	77.8
70	60	16836	6479	10356	38.7	0.36	172	135	37	79.1
LSD (5%)[2]		1482	669	989	2.1	0.09	27	24	11	5.6
30	All	16951	6695	10256	39.5	0.38	167	129	38	77.2
50	All	18392	7258	11134	39.5	0.36	177	138	39	78.1
70	All	16907	6503	10404	38.5	0.36	161	124	37	77.8
LSD (5%)		NS[3]	NS	NS	NS	NS	NS	NS	NS	NS
All	0	16820	6421	10399	38.1	0.40	153	113	40	73.9
All	30	18231	7156	11076	39.3	0.34	175	138	37	79.4
All	60	17199	6879	10319	40.0	0.36	176	140	36	79.7
LSD (5%)		856	386	568	1.2	NS	15	14	NS	3.2
Effect					Significance of Effect[4]					
Nitrogen x Irrigation		NS	NS	NS	NS	*	NS	NS	*	*

[1] Total, grain, and straw yields calculated on a 10% moisture basis.

[2] LSD (5%) = least significant difference at the 5% probability level.

[3] NS = not significant at the 5% probability level.

[4] NS and * = not significant at the 5% probability level, and significant at the 5% probability level, respectively.

Table 5a. Durum kernel characteristics as affected by irrigation, variety, and nitrogen application at pollen shed.

Irrigation during grain fill	Variety	Nitrogen at Pollen Shed	Ash	NIR Kernel Hardness	Test Weight	1000 Kernel Weight	Kernel Size Distribution (200 g) 7W (2.8 mm)	10W (2.0 mm)	12W (1.7 mm)	Pan (<1.7mm)
% depletion		lbs/acre	%		lbs/bu	g	g	g	g	g
30	Duraking	0	1.50	90	64.6	51.3	184.0	14.4	1.3	0.3
30	Duraking	30	1.56	97	65.4	53.4	185.9	12.8	1.0	0.3
30	Duraking	60	1.56	105	65.6	54.6	189.0	10.0	0.8	0.2
30	Minos	0	1.65	89	65.6	49.2	191.2	7.9	0.7	0.2
30	Minos	30	1.49	107	65.5	50.0	190.4	8.6	0.9	0.1
30	Minos	60	1.50	108	65.7	51.3	193.1	6.2	0.5	0.3
30	Turbo	0	1.44	96	64.6	54.7	185.3	13.5	1.0	0.2
30	Turbo	30	1.46	98	64.8	52.4	188.3	10.6	0.9	0.2
30	Turbo	60	1.64	108	65.1	52.4	187.9	11.3	0.7	0.1
50	Duraking	0	1.42	101	65.8	51.2	185.6	13.0	1.1	0.3
50	Duraking	30	1.51	102	65.8	56.4	185.7	12.9	1.1	0.3
50	Duraking	60	1.41	112	65.9	55.2	189.3	9.5	0.9	0.3
50	Minos	0	1.63	109	66.0	49.9	189.0	10.0	0.8	0.2
50	Minos	30	1.63	107	66.0	50.7	189.9	9.0	0.8	0.1
50	Minos	60	1.54	117	65.9	57.6	193.6	5.7	0.3	0.1
50	Turbo	0	1.45	90	64.6	56.8	186.1	12.6	1.2	0.2
50	Turbo	30	1.46	108	65.0	57.8	188.5	10.2	1.0	0.3
50	Turbo	60	1.54	110	64.7	60.2	188.9	9.8	0.9	0.4
70	Duraking	0	1.59	77	64.3	53.6	184.3	13.9	1.4	0.4
70	Duraking	30	1.65	92	65.5	51.5	185.1	13.5	1.2	0.2
70	Duraking	60	1.57	105	65.8	52.9	182.0	15.6	2.0	0.4
70	Minos	0	1.57	95	65.8	53.9	191.3	7.9	0.7	0.1
70	Minos	30	1.66	99	66.2	52.3	193.2	6.4	0.4	0.0
70	Minos	60	1.61	111	65.9	51.6	191.7	7.6	0.7	0.1
70	Turbo	0	1.58	97	64.3	54.9	185.4	13.0	1.4	0.2
70	Turbo	30	1.61	102	65.0	57.7	185.9	12.8	1.1	0.2
70	Turbo	60	1.55	107	65.0	58.8	186.0	12.9	1.1	0.0
30	All	All	1.53	100	65.2	52.1	188.3	10.6	0.9	0.2
50	All	All	1.51	106	65.5	55.1	188.5	10.3	0.9	0.2
70	All	All	1.60	98	65.3	54.1	187.2	11.5	1.1	0.2
All	Duraking	All	1.53	98	65.4	53.3	185.7	12.8	1.2	0.3
All	Minos	All	1.59	105	65.8	51.8	191.5	7.7	0.6	0.1
All	Turbo	All	1.53	102	64.8	56.2	186.9	11.9	1.0	0.2
All	All	0	1.54	94	65.1	52.8	186.9	11.8	1.1	0.2
All	All	30	1.56	101	65.5	53.6	188.1	10.8	0.9	0.2
All	All	60	1.55	109	65.5	55.0	189.1	9.8	0.9	0.2

Table 5b. Durum milling and semolina characteristics as affected by irrigation, variety, and nitrogen application at pollen shed.

Irrigation during grain fill	Variety	Nitrogen at Pollen Shed	Total Extrac-tion	Semo-lina Extrac-tion	Semo-lina Pro-tein	Semo-lina Moist-ure	Semo-lina Ash	Speck	Alveo-graph W	Alveo-graph P/L	Wet Gluten	Dry Gluten	Fall No.	Color "b" Value
% depletion		lbs/acre	%	%	%	%	%	$10in^{-2}$			%	%		
30	Duraking	0	77.2	62.3	8.5	13.9	0.72	24	88	2.38	23.1	8.8	686	21.2
30	Duraking	30	78.6	65.6	8.9	13.8	0.83	22	102	3.13	22.6	8.4	558	20.7
30	Duraking	60	77.4	67.7	10.6	14.0	0.80	42	134	2.65	30.0	10.6	489	22.8
30	Minos	0	77.8	65.1	9.9	14.0	0.75	27	143	1.94	27.3	10.7	526	25.0
30	Minos	30	76.9	66.8	11.3	14.0	0.72	28	167	1.95	31.5	11.6	543	25.3
30	Minos	60	78.8	68.3	11.5	13.7	0.82	24	144	2.13	34.1	12.4	539	25.4
30	Turbo	0	79.3	66.0	9.4	14.0	0.95	22	56	1.86	23.1	8.2	457	22.7
30	Turbo	30	77.7	65.4	9.3	13.7	0.76	35	75	1.70	28.1	10.1	439	22.8
30	Turbo	60	79.2	68.3	9.6	13.7	0.76	21	70	1.84	29.2	10.2	490	22.5
50	Duraking	0	78.3	67.0	8.9	13.7	0.73	26	119	2.93	27.7	9.5	425	23.6
50	Duraking	30	78.1	66.8	9.6	13.7	0.75	34	115	2.65	26.3	10.0	472	22.7
50	Duraking	60	78.7	67.9	10.5	13.9	0.75	22	123	2.40	31.0	11.0	430	23.0
50	Minos	0	77.0	64.7	9.1	13.6	0.79	33	144	2.27	26.9	10.2	529	24.7
50	Minos	30	76.1	65.1	13.8	13.8	0.80	30	157	2.00	30.6	11.6	504	24.5
50	Minos	60	78.8	68.0	11.8	13.2	0.80	41	145	1.64	33.4	12.1	524	24.2
50	Turbo	0	77.9	65.2	8.2	13.8	0.79	24	72	1.73	22.3	8.5	481	21.8
50	Turbo	30	77.5	66.7	9.7	13.8	0.78	17	74	1.43	27.9	10.0	496	23.1
50	Turbo	60	77.6	67.0	10.3	13.9	0.72	18	73	1.57	31.5	11.5	499	21.9
70	Duraking	0	78.5	62.2	8.2	13.4	0.53	28	69	1.88	20.6	7.3	422	21.6
70	Duraking	30	77.1	65.0	9.0	13.5	0.65	26	101	2.27	24.5	9.2	456	20.9
70	Duraking	60	77.1	66.7	9.9	13.4	0.68	40	127	2.26	27.1	10.4	448	23.7
70	Minos	0	76.4	63.7	8.5	13.5	0.66	33	108	1.85	21.7	7.8	496	24.2
70	Minos	30	77.4	67.0	9.6	13.6	0.80	29	127	1.75	27.7	10.3	540	27.4
70	Minos	60	77.8	67.7	11.1	13.6	0.75	26	150	1.61	33.2	13.4	552	24.3
70	Turbo	0	77.1	64.8	9.2	13.7	0.75	28	52	1.58	26.5	10.1	424	22.8
70	Turbo	30	77.1	65.1	9.3	13.5	0.69	20	75	1.39	28.5	10.8	483	22.9
70	Turbo	60	76.0	65.1	9.7	13.4	0.67	23	66	1.25	31.3	11.4	495	22.8
30	All	All	78.1	66.2	9.9	13.9	0.79	27	109	2.18	27.7	10.1	525	23.2
50	All	All	77.8	66.5	10.2	13.7	0.77	27	114	2.07	28.6	10.5	484	23.3
70	All	All	77.2	65.3	9.4	13.5	0.69	28	97	1.76	26.8	10.1	480	23.4
All	Duraking	All	77.9	65.7	9.3	13.7	0.72	29	109	2.51	25.9	9.5	487	22.2
All	Minos	All	77.4	66.3	10.7	13.7	0.77	30	143	1.90	29.6	11.1	528	25.0
All	Turbo	All	77.7	66.0	9.4	13.7	0.76	23	68	1.59	27.6	10.1	474	22.6
All	All	0	77.7	64.6	8.9	13.7	0.74	27	95	2.05	24.4	9.0	494	23.1
All	All	30	77.4	65.9	10.1	13.7	0.75	27	110	2.03	27.5	10.2	499	23.4
All	All	60	77.9	67.4	10.6	13.7	0.75	29	115	1.93	31.2	11.4	496	23.4

Table 5c. Durum pasta analysis as affected by irrigation, variety, and nitrogen application at pollen shed.

Irrigation during grain fill	Variety	Nitrogen at Pollen Shed	Color "L" Value	Color "b" Value	Color Score	Cooked Weight	Cooking Loss	Firmness
% depletion		lbs/acre				g	g	g/cm^2
30	Duraking	0	58.9	35.8	7.0	32.1	7.9	3.8
30	Duraking	30	64.9	36.4	7.5	32.3	8.8	4.0
30	Duraking	60	56.1	34.2	7.0	31.5	7.8	4.6
30	Minos	0	64.4	42.6	10.0	34.2	8.7	4.2
30	Minos	30	53.7	40.5	8.5	31.0	8.3	5.2
30	Minos	60	58.2	42.0	6.0	31.7	7.7	5.2
30	Turbo	0	54.4	41.7	9.0	33.6	8.6	3.8
30	Turbo	30	57.9	37.9	8.0	33.7	8.5	3.7
30	Turbo	60	56.3	36.8	7.5	32.8	8.3	3.8
50	Duraking	0	59.5	37.6	8.0	32.9	7.4	3.6
50	Duraking	30	59.7	36.9	8.0	33.0	8.1	3.9
50	Duraking	60	57.2	35.9	7.0	32.8	8.7	4.1
50	Minos	0	55.3	42.1	9.5	31.8	8.1	4.6
50	Minos	30	57.9	42.6	9.5	30.9	7.5	5.2
50	Minos	60	55.4	41.2	9.0	31.7	7.9	5.0
50	Turbo	0	56.8	38.6	8.5	33.0	7.5	3.8
50	Turbo	30	58.1	37.9	8.0	33.0	7.5	3.8
50	Turbo	60	57.7	38.1	8.5	30.0	6.9	4.1
70	Duraking	0	58.0	36.9	8.0	31.9	7.5	3.9
70	Duraking	30	58.4	37.6	8.0	32.5	7.7	4.0
70	Duraking	60	58.3	36.8	8.0	32.0	7.3	4.5
70	Minos	0	57.3	44.8	10.0	32.3	9.3	4.2
70	Minos	30	57.9	44.2	10.0	32.5	8.5	4.5
70	Minos	60	56.7	42.5	9.5	30.9	6.6	5.1
70	Turbo	0	57.7	40.9	9.0	32.7	8.3	4.1
70	Turbo	30	56.4	37.0	8.0	31.5	8.3	4.6
70	Turbo	60	59.0	38.8	8.5	31.5	7.7	4.8
30	All	All	58.3	38.7	7.8	32.5	8.3	4.3
50	All	All	57.5	39.0	8.4	32.1	7.7	4.2
70	All	All	57.7	39.9	8.8	32.0	7.9	4.4
All	Duraking	All	59.0	36.4	7.6	32.3	7.9	4.0
All	Minos	All	57.4	42.5	9.1	31.9	8.1	4.8
All	Turbo	All	57.1	38.6	8.3	32.4	8.0	4.1
All	All	0	58.0	40.1	8.8	32.7	8.1	4.0
All	All	30	58.3	39.0	8.4	32.3	8.1	4.3
All	All	60	57.2	38.5	7.9	31.7	7.7	4.6

Table 6. Variety and late season nitrogen application effects on grain yield and various grain and plant characteristics.

Variety	Late season nitrogen[1]	Grain Yield[2]	Grain Protein[3]	Hard Vitreous Amber Count	Black Point[4]	Plant Height	Lodging	Pollen shed	Physio-logical Maturity
	lbs/acre	lbs/acre	%	%	%	inches	%		
Duraking	30	8018	12.0	92	1.8	35	0	3/20	4/29
Duraking	30+30	8551	12.2	95	3.1	35	0	–	4/30
Duraking	30+30+30	8687	13.1	98	2.8	36	0	–	4/30
Minos	30	7166	11.8	89	1.8	39	0	3/16	4/30
Minos	30+30	6750	13.5	96	3.1	39	28	–	4/30
Minos	30+30+30	6611	13.8	99	3.0	41	23	–	4/30
Turbo	30	7296	11.0	83	1.1	43	0	3/24	5/03
Turbo	30+30	7644	12.4	90	2.5	43	0	–	5/04
Turbo	30+30+30	7843	12.9	96	1.5	44	0	–	5/03
LSD (5%)[5]		NS	0.86	4.4	NS	1.6	NS	1.7	0.9
Duraking	All	8419	11.2	95	2.6	35	0	3/20	4/30
Minos	All	6863	11.7	95	2.6	39	18	3/16	4/30
Turbo	All	7611	10.9	90	1.6	43	0	3/24	5/03
LSD (5%)		751	NS	NS	NS	1.6	NS	1.7	1.9
All	30	7493	10.4	88	1.6	39	0	–	5/01
All	30+30	7648	11.4	94	2.9	38	12	–	5/01
All	30+30+30	7817	11.9	97	2.3	40	6	–	5/02
LSD (5%)		NS	0.49	2.6	NS	NS	NS	–	NS
Effects					Significance[6]				
Variety		**	NS	NS	NS	**	NS	**	**
Nitrogen		NS	**	**	NS	NS	NS	–	NS
Nitrogen x Variety		NS	NS	NS	NS	NS	NS	–	NS

[1] Late season nitrogen: 30 = 30 lbs N/acre at pollen shed, 30+30 = 30 lbs N/acre at pollen shed and 30 lbs N/acre at the first irrigation after pollen shed, and 30+30+30 = 30 lbs N/acre at pollen shed, 30 lbs N/acre at the first irrigation after pollen shed, and 30 lbs N/acre at the 2nd irrigation after pollen shed.

[2] Grain yield calculated on a 10% moisture basis.

[3] Grain protein calculated on a 12% moisture basis.

[4] Black point is a fungal disease of the grain that appears as specks in the pasta.

[5] LSD (5%) = least significant difference at the 5% probability level.

[6] NS and ** = not significant at the 5% probability level, and significant at the 1% probability level.

Table 7. Yield and nitrogen uptake as affected by late season nitrogen application for the variety Turbo.

Late season nitrogen[1]	Total Yield[2]	Grain Yield	Straw Yield	Harvest Index	Straw Nitrogen	Total N Uptake	Grain N Uptake	Straw N Uptake	Nitrogen Harvest Index
lbs/acre	lbs/acre	lbs/acre	lbs/acre	%	%	lbs/acre	lbs/acre	lbs/acre	%
30	18423	7296	11128	39.5	0.35	183	145	38	79.8
30+30	19225	7644	11581	39.8	0.42	215	168	47	78.2
30+30+30	18423	7843	10579	42.7	0.40	222	182	41	81.8
LSD (5%)[3]	NS[4]	NS	NS	NS	NS	28	23	NS	NS

[1] Late season nitrogen: 30 = 30 lbs N/acre at pollen shed, 30+30 = 30 lbs N/acre at pollen shed and 30 lbs N/acre at the first irrigation after pollen shed, and 30+30+30 = 30 lbs N/acre at pollen shed, 30 lbs N/acre at the first irrigation after pollen shed, and 30 lbs N/acre at the 2nd irrigation after pollen shed.

[2] Total, grain, and straw yields calculated on a 10% moisture basis.

[3] LSD (5%) = least significant difference at the 5% probability level.

[4] NS = not significant at the 5% probability level.

Table 8a. Durum kernel characteristics as affected by variety and late season nitrogen application.

Variety	Late season nitrogen[1]	Ash	NIR Kernel Hardness	Test Weight	1000 Kernel Weight	Kernel Size Distribution (200 g) 7W (2.8 mm)	10W (2.0 mm)	12W (1.7 mm)	Pan (<1.7mm)
	lbs/acre	%		lbs/bu	g	g	g	g	g
Duraking	30	1.51	117	65.8	53.1	186.4	12.7	0.7	0.1
Duraking	30+30	1.61	114	65.8	54.7	184.0	14.8	0.9	0.3
Duraking	30+30+30	1.59	115	65.8	54.2	186.7	12.1	1.0	0.2
Minos	30	1.67	102	66.5	50.7	192.5	6.8	0.6	0.1
Minos	30+30	1.62	111	65.7	50.9	193.9	5.6	0.3	0.2
Minos	30+30+30	1.55	123	65.6	51.3	191.7	7.6	0.6	0.1
Turbo	30	1.57	108	65.0	59.6	186.7	11.9	1.1	0.3
Turbo	30+30	1.51	108	64.9	60.5	185.1	13.5	1.3	0.1
Turbo	30+30+30	1.96	116	65.2	61.1	186.0	12.7	1.1	0.2
Duraking	All	1.57	115	65.8	54.0	185.7	13.2	0.9	0.2
Minos	All	1.61	112	65.9	51.0	192.7	6.7	0.5	0.1
Turbo	All	1.68	110	65.0	60.4	185.9	12.7	1.2	0.2
All	30	1.58	109	65.8	54.5	188.5	10.5	0.8	0.2
All	30+30	1.58	111	65.5	55.4	187.7	11.3	0.8	0.2
All	30+30+30	1.70	118	65.5	55.5	188.1	10.8	0.9	0.2

[1] Late season nitrogen: 30 = 30 lbs N/acre at pollen shed, 30+30 = 30 lbs N/acre at pollen shed and 30 lbs N/acre at the first irrigation after pollen shed, and 30+30+30 = 30 lbs N/acre at pollen shed, 30 lbs N/acre at the first irrigation after pollen shed, and 30 lbs N/acre at the 2nd irrigation after pollen shed.

Table 8b. Durum milling and semolina characteristics as affected by variety and late season nitrogen application.

Variety	Late season nitrogen[1]	Total Extraction	Semolina Extraction	Semolina Protein	Semolina Moisture	Semolina Ash	Speck	Alveograph W	Alveograph P/L	Wet Gluten	Dry Gluten	Fall No.	Color "b" Value
	lbs/acre	%	%	%	%	%	$10in^{-2}$			%	%		
Duraking	30	76.2	67.0	10.2	13.5	0.55	30	117	2.85	27.4	10.5	436	21.7
Duraking	30+30	76.4	67.3	10.8	13.5	0.61	36	127	2.71	30.7	11.2	472	23.5
Duraking	30+30+30	77.9	67.7	11.3	13.4	0.68	23	97	1.85	32.2	12.3	443	21.5
Minos	30	77.4	67.8	10.2	13.9	0.78	17	169	1.92	31.1	10.5	514	23.7
Minos	30+30	77.4	67.6	11.2	13.4	0.76	43	192	1.68	34.2	12.5	510	25.9
Minos	30+30+30	76.8	66.4	12.6	13.7	0.68	28	183	1.58	36.9	13.6	550	24.1
Turbo	30	75.8	65.5	9.2	13.8	0.70	19	82	2.04	28.7	10.7	453	22.9
Turbo	30+30	75.6	64.9	10.5	13.8	0.54	24	86	1.70	31.6	11.4	505	22.0
Turbo	30+30+30	75.0	64.2	10.9	13.7	0.70	16	89	1.50	32.9	12.3	553	22.6
Duraking	All	76.8	67.3	10.8	13.5	0.61	30	114	2.47	30.1	11.3	450	22.2
Minos	All	77.2	67.3	11.4	13.7	0.74	29	181	1.73	34.1	12.2	525	24.6
Turbo	All	75.5	64.9	10.2	13.8	0.65	20	86	1.75	31.1	11.5	504	22.5
All	30	76.5	66.8	9.9	13.7	0.68	22	123	2.27	29.1	10.6	468	22.8
All	30+30	76.5	66.6	10.8	13.6	0.64	34	135	2.03	32.2	11.7	496	23.8
All	30+30+30	76.6	66.1	11.6	13.6	0.69	22	123	1.64	34.0	12.7	515	22.7

[1] Late season nitrogen: 30 = 30 lbs N/acre at pollen shed, 30+30 = 30 lbs N/acre at pollen shed and 30 lbs N/acre at the first irrigation after pollen shed, and 30+30+30 = 30 lbs N/acre at pollen shed, 30 lbs N/acre at the first irrigation after pollen shed, and 30 lbs N/acre at the 2nd irrigation after pollen shed.

Table 8c. Durum pasta analysis as affected by variety and late season nitrogen application.

Variety	Late season nitrogen[1]	Color "L" Value	Color "b" Value	Color Score	Cooked Weight	Cooking Loss	Firmness
	lbs/acre				g	g	g/cm^2
Duraking	30	57.0	33.2	6.0	31.4	7.0	4.8
Duraking	30+30	58.0	36.1	7.0	30.3	6.6	5.1
Duraking	30+30+30	56.9	33.7	6.0	30.8	7.3	5.1
Minos	30	58.3	42.3	9.5	31.4	8.5	5.2
Minos	30+30	58.1	41.8	9.5	31.2	7.0	5.9
Minos	30+30+30	57.0	40.9	9.0	31.0	6.1	6.3
Turbo	30	58.2	37.8	8.0	31.6	7.7	4.3
Turbo	30+30	57.7	37.3	8.0	32.2	6.7	4.9
Turbo	30+30+30	57.6	36.5	8.0	31.1	6.8	4.9
Duraking	All	57.3	34.3	6.3	30.8	7.0	5.0
Minos	All	57.8	41.7	9.3	31.2	7.2	5.8
Turbo	All	57.8	37.2	8.0	31.6	7.1	4.7
All	30	57.8	37.7	7.8	31.4	7.7	4.8
All	30+30	57.9	38.4	8.2	31.2	6.8	5.3
All	30+30+30	57.1	37.0	7.7	30.9	6.7	5.4

[1] Late season nitrogen: 30 = 30 lbs N/acre at pollen shed, 30+30 = 30 lbs N/acre at pollen shed and 30 lbs N/acre at the first irrigation after pollen shed, and 30+30+30 = 30 lbs N/acre at pollen shed, 30 lbs N/acre at the first irrigation after pollen shed, and 30 lbs N/acre at the 2nd irrigation after pollen shed.