Production of malting quality two-row barley (Hordeum distichon L., var. Betzes) under irrigation and N fertilization

by David John Vaughan Redgrave

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
Montana State University

Abstract:
Betzes barley, a western two-row variety (Hordeum distichon, L.) was grown under five different irrigation regimes with six N-rates, from 0 to 200 pounds per acre, at two locations in southwestern ,Montana during the 1966 season. Irrigation timing was keyed to four plant growth stages, water being applied or witheld at the tillering, boot, milk and hard dough stages.

The primary purpose of the experiment was to find which irrigation regimes and N-rate combinations would produce high, economical yield levels of malting quality barley. At one location, rain during the season and subirrigation essentially negated the effects of omitting an irrigation. At the second location, the irrigation regime, N-rate and the interaction of the treatments all showed significant effects on the yield and malting quality of the grain. In general, yield and protein increased and plumpness decreased with increasing N-rate, However, the irrigation regime showed a substantial differential modifying effect on these changes.

174

PRODUCTION OF MALTING QUALITY TWO-ROW BARLEY
(Hordeum distichon L., VAR. Betzes)
UNDER IRRIGATION AND N FERTILIZATION

by

DAVID JOHN VAUGHAN REDGRAVE

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Soils

Approved:

E. R. Hehn
Head, Major Department

Charles M. Smith
Chairman, Examining Committee

R. Goering
Dean, Graduate Division

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1968

ACKNOWLEDGEMENTS

The author wishes to express his appreciation of the assistance received from Dr. Charles M. Smith during the entire course of this project. The help received from Dr. Hayden Ferguson in the interpretation of the data and from Dr. Clarence Jenson during the economic analysis was gratefully received. Special appreciation is also due Dr. Ervin Smith and Mr. David Jacobson who gave freely of their time during the development of the statistical procedures and to Dr. Alvin Southard for his assistance in the description of the soils. Mr. Gerald Ellis and Mr. Stanley Howard provided able, and at times voluminous, assistance with the field work. To Dr. Paul Brown and Mr. Glennis Boatwright, special thanks is extended for the use of their neutron equipment.

This project was partially supported by funds from the Bureau of Reclamation.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF TABLES

Context Tables

Context Tables
(continued)

Appendix Tables

ABSTRACT

Betzes barley, a western two-row variety (Hordeum distichon, L.) was grown under five different irrigation regimes with six N-rates, from 0 to 200 pounds per acre, at two locations in southwestern Montana during the 1966 season. Irrigation timing was keyed to four plant growth stages, water being applied or witheld at the tillering, boot, milk and hard dough stages.

The primary purpose of the experiment was to find which irrigation regimes and N-rate combinations would produce high, economical yield levels of malting quality barley. At one location, rain during the season and subirrigation essentially negated the effects of omitting an irrigation. At the second location, the irrigation regime, N-rate and the interaction of the treatments all showed significant effects on the yield and malting quality of the grain. In general, yield and protein increased and plumpness decreased with increasing N-rate. However, the irrigation regime showed a substantial differential modifying effect on these changes.

INTRODUCTION

The timing of water applications is a major problem in irrigation agriculture. Should this timing be dictated by soil moisture levels, evapotranspiration rates or consumptive use? Many irrigation studies have been concerned with these criteria.

The growth stage of the plant must also be considered as a plant's water requirement is not solely a function of its environment (15). The presence of an adequate supply of water may be more critical at some times than at others. For wheat, barley and corn, the flowering period seems to be one of these "critical stages". Another is the period during which the crop is ripening.

The purpose of this study was threefold: (1) to investigate the affects of various irrigation regimes when water application is keyed to the growth stage of the plant, (2) to see how these affects are modified by various soil fertility levels and (3) to delineate the irrigation regime and N-rate combinations which would produce maximum economical yields of barley acceptable for malting uses.

Betzes is a two-row barley used for malting or feed. It has been approved as a malting barley variety by the Malting Barley Improvement Association (27). To be acceptable for malting uses, two-row barley must meet certain quality requirements. At least 80 percent must remain above a 6/64 sieve (22,43) (this is considered percentage plump kernels) and have a protein content of less than 12.5 percent fo quality for a price premium based on low protein (10).

Other grain quality factors are a low amount of cracked or skinned kernels and no weather damage. Germination should be vigorous and uniform (22).

This thesis will present the effects of irrigation timing and N application rate on the yield, protein percentage and percentage plump kernels of Betzes barley and an economic analysis of the data. The field work was done at two locations in southwestern Montana, Dillon and Manhattan, during the 1966 season.

REVIEW OF LITERATURE

Crop production under irrigation allows the producer to exercise some degree of control over the soil moisture supply to the plant. This removes one of the uncertainties of production that is present in humid regions where, without supplemental irrigation, moisture supply is dependent upon the amount and frequency of precipitation.

Having control of the moisture supply poses certain problems. How much water should be applied and how should it be distributed throughout the growing season?

Consumptive Use Criterion

One approach to this problem is to consider the soil to be a "water bank" and replace the water when the supply has decreased to a certain level. This approach has been extensively investigated. Blaney and Criddle (5) have developed formulas that relate irrigation frequency and recharge amounts to climatic conditions.

Grain Yield

Irrigation experiments have been conducted to determine how N application rate and various soil moisture recharge regimes affect the yield, protein percentage and kernel size of barley.

Stanberry (37) found that the affect of applied N-rate on barley yield was greater than the affects of irrigation frequency. This differential effect was most pronounced at N-rates above 120 pounds per acre. Similar effects have been noted by Tempest and Snelson (41).

Other experiments, Stanberry and Lowrey (38) and Hanks and Tanner (12), have shown that the moisture use per unit of yield was decreased as N-rate was increased.

Grain Protein Percentage

The grain protein percentage has been shown to be inversely related to the malting quality of barley (Den Hartog and Lambert (7) and Reinsenauer and Dickson (29)). To be acceptable for malting uses, two-row barley should have a protein content below 13 percent (10,25). A high protein content produces a malt of low extract and causes erractic germination increasing the time required for malting (25).

An increase in the amount of applied N caused an increase in protein percentage according to Dubetz and Wells (8). This affect can occur at N-rates as low as 20 pounds per acre according to Lejeune and Parker (23) and increases in magnitude within a given N-rate when irrigation frequency is decreased (Solsulski and Bendelow (36)) or soil moisture supply is limited (Richards and Wadleigh(30)).

Kernel Size

Large kernel size is a requirement that barley must meet to be classified as malting barley under the official grain standards (43). Kernels of high starch content produce high yields of alpha and beta amylase enzymes when malted (25). Kernel plumpness can be judged by test weight; but to avoid having skinned and broken kernels, the barley should be threshed carefully leaving a small portion of the awn on the kernel. When this is done, the test weight will decrease so kernel size is judged by sieving the grain. The Malting Barley Improvement Association defined plump as those kernels remaining on a 6/64 sieve (22). 1/ Dubetz and Wells (8) found that kernel size was not affected by soil moisture supply but did decrease as the amount of applied N was increased. Similar changes have been noted by Reisnauer and Dickson (29).

In all of the foregoing experiments, soil moisture supply was modified by a change in the frequency of irrigation or by allowing the moisture in the soil to decrease to predetermined levels before it was restored to field capacity.

Plant Growth Stage Criterion

A second approach to irrigation timing is to consider the growth stage of the plant. Harlan and Anthony (13) stated, "Knowledge of the period during which the application of water affects the growth or maturation of the plant affords a basis for the better understanding of irrigation".

Summarizing the results of some irrigation experiments, Thorne and Peterson (42) state "...it is important to know something of the total amount of water needed, the stage of plant growth at which adverse moisture conditions are most critical and the ability of crops to adjust to adverse conditions associated with high moisture stress."

1/ A sieve with openings 6/64" X 3/4".

The critical period for corn, in relation to yield, seems to be during the silking stage according to Jenne et al. (19) and Robins and Domingo (31). This period was found to extend from seven days before to ten days after the silking stage, Swanson and Tyner (40). With wheat, Hutcheon and Paul (18) found that a moisture stress during the soft dough stage had the greatest depressional affect on yield. According to the results of Harris (14), the most critical period for wheat was the early booting stage. When supplemental water was applied to barley, Luebs and Laag (24) found that application at the heading stage gave the best yield response.

Previous field experiments in Montana conducted by Smith et al. (32, 33,34) showed that there were at least three stages in the growth of Betzes barley when a moisture stress resulted in deletereous affects on grain yield, protein percentage and percentage plump kernels. These stages were tillering, heading (boot stage) and during the time that the kernels were filling. The magnitude of the effects of a moisture stress at these periods was influenced by the applied N-rate.

Part of the data from experiments which were initiated to determine the effects on Betzes barley of a moisture stress imposed at various growth stages of the plant will be presented in this thesis. Of primary interest were the effects of this stress as reflected by the changes in the grain yield, protein percentage and percentage plump kernels; and how these affects would be modified by the rate of applied N.

This information would be useful in developing the irrigation timing and fertility levels required to produce high yields of malting quality barley.

MATERIALS AND METHODS

Western two-row malting barley (Hordeum distichon, L., VAR., Betzes, (3)) was grown under five irrigation regime and nitrogen application rates ranging from 0 to 200 pounds per acre during the 1966 season.

Field plots were located on the East Bench Project of the Bureau of Reclamation near Dillon, Montana, on the farm of Pete Rebish and Joe Helle and on the Feedes' Brothers farm near Manhattan, Montana.

Experimental Design

The field design was a split plot (6) with subunits in strips. Four replications were used. The irrigation treatments strips were across an entire replication and the fertilizer treatment strips were along an entire replication at right angles to the irrigation treatment strip. Each treatment strip was randomized separately for each replication.

This type of design gives the maximum information about the interaction effects (Cochran and Cox (6) and Steele and Torre (39)).

Seeding

The area was seeded with certified Betzes barley at a rate of 95 to 100 pounds per acre using a seven-row press wheel drill with 3 inch shovel openers. The rows were twelve inches apart. Seeding was done along the fertilizer treatment strips across all irrigation treatments. At Dillon, the first seeding had not produced a uniform stand after a light irrigation had been applied to germinate the seed. A second light irrigation was applied, then the area was cultivated prior to reseeding. The second seeding was spaced to coincide with the location of the fertilizer applied during the first seeding.

Fertilizer Treatments

Fertilizer was band-applied during seeding one to one and one-half inches below and to the side of the seed. Each fertilizer strip was seven rows wide. N application rate varied from 0 to 200 pounds per acre in 40 pound increments. Both P and K were applied at the rate of 40 pounds per acre to all N-rate plots. Other treatments were concerned with the response to P and K. Only the N-rate effects will be presented in this thesis. Details of the fertilizer treatments are given in table I.

Irrigation Treatments

After the area was seeded and fertilized, lateral ditches were dug above and below each irrigation treatment. These ditches ran across all four replications approximately on the contour. Deviations from contour were made so that an irrigation treatment strip would not be too narrow. Two ditches were dug at the sides of the experimental area, parallel to the fertilizer strips, connecting all the laterals.

Timing of Irrigation

Irrigation timing was keyed to the growth stage of the plant, table II. Four stages were used: (1) tillering, (2) boot, (3) milk and (4) hard dough. These are defined by Feekes (11) as stages 3, 10.0-10.1, 10.5.2-10.5.4 and 11.2-11.3, respectively. Illustrations of these stages are given by Large (20). A treatment was irrigated when the 80 pound per acre N-rate treatment in an irrigation strip was at the correct growth stage. The difference in growth stages among fertilizer plots increased as the season progressed until the 0 and 200 pound per acre N-rates were a week

Table I. Fertilizer and irrigation treatments, Dillon and Manhattan locations.

Fertilizer Rates lb/A a/ N	P	K	Irrigation Treatments b/
0	40	40	A B C D
40	40	40	- B C D
80	40	40	A - C D
120	40	40	A B - D
160	40	40	A B C -
200	40	40	

a/ Fertilizer sources

N - Ammonium Nitrate (33.5-0-0)

P - Monocalcium Phosphate (0-45-0)

K - Potassium Chloride (0-0-60)

Irrigation stages

A - Tillering	Feekes 3.0
B - Boot	Feekes 10.0-10.1
C - Milk - Soft dough	Feekes 10.5.2-10.5.4
D - Hard dough	Feekes 11.2-11.3

b/ - indicates omission of this irrigation stage.

Table II. Plant stages used to time application of irrigation at Dillon and Manhattan.

Irrigation	Plant Growth Stage	Feekes Scale a/
A	Tillering	3.0
B	Boot, awns just protruding	10.0-10.1
C	Milk - Soft dough	10.5.2-10.5.4
D	Hard dough b/	11.2-11.3

a/ As illustrated by Large (21).

b/ 11.3 kernel is hard and difficult to divide by thumbnail.

to ten days apart at harvest. Each irrigation treatment strip, all fertilizer treatments in the strip, was irrigated as a unit. Table III gives the dates of application of each irrigation for both locations.

Water Application

Water was applied to the seeding furrows by notching the bank of the lateral ditch above the irrigation strip or by using one-half to three-quarter inch diameter siphon tubes. The lower lateral ditch was used to remove excess water. The water was applied rapidly at first until the entire row was covered. Application rate was then adjusted to provide a continuous flow along the furrow with a slight amount of runoff. Application was stopped when a one-fourth inch diameter probe easily penetrated the soil to a depth of two feet. Moisture determinations with a neutron probe two to three days after an irrigation showed that the profile had received water down to a 3 to 4 foot depth. Little water use was expected to occur from depths greater than this (4).

Harvesting

Each fertilizer-irrigation plot was harvested when the grain could no longer be dented by the fingernail. At Manhattan, the inner three rows were cut leaving the outer two as borders. At Dillon, the inner five rows were cut where possible in an attempt to overcome the affects of a variable stand. The length of the harvested area of each plot was limited to that part which was free of any visible effects of the irrigation ditches. This gave an area of 51 and 75 square feet at the Manhattan and Dillon locations, respectively. On a few plots, the area was less to eliminate some rows in

Table III. Dates of irrigations and of soil moisture determinations using a Nuclear-Chicago neutron meter.

Location	Irrigation	Dates (1966)
Manhattan	A (Tillering)	6 - 21,22 and 23
	B (Boot)	7 - 11,12
	C (Milk - Soft dough)	7 - 20,21
	D (Hard dough)	8 - 9,10
Dillon a/	A (Tillering)	7 - 8, 9 and 10
	B (Boot)	7 - 26,27
	C (Milk - Soft dough)	8 - 10,11
	D (Hard dough)	9 - 1, 2

Location	Moisture Determinations	Dates (1966)
Manhattan	Pre-A	b/
	Post-A	6 - 28,29
	Pre-B	7 - 9,12
	Post-B	7 - 15,16
	Pre-C	7 - 19,20
	Post-C	7 - 22,23
	Pre-D	8 - 9,10
	Post-D	8 - 11,12
	Ripening	8 - 18
	Post Harvest - Calibration	9 - 8
Dillon	Pre-A	7 - 7, 8
	Post-A	7 - 13
	Pre-B	7 - 25
	Post-B	7 - 29
	Pre-C	8 - 8
	Post-C	8 - 13
	Pre-D	9 - 1
	Post-D	9 - 5
	Post Harvest - Calibration	10 - 25

a/ Germination irrigations applied 5 - 18 and 6 - 1.

b/ Access tube installation not completed in time to take readings prior to irrigation A.

the plot that had poor stands. Some parts of the Manhattan location, which showed effects of old field ditches, were also omitted. The plants were cut about one inch above ground level, bundled in large paper bags and air-dried prior to threshing.

Turgor Samples

Ten flag leaves were taken at random from the 0, 80, 160 and 200 pounds per acre N treatments within the complete (ABCD) and minus A, B, C or D irrigation treatments. Dates of sampling at Manhattan were June 10 and July 18 and 20, 1966. At Dillon, samples were collected on July 25 and August 1, 15, 16 and 30, 1966. The samples were cut laterally into one-inch strips, placed in 20 cc glass bottles with snap tops and cooled in an ice bath. The samples were transported to the laboratory in the ice bath, and relative turgidity was determined by measuring the weight increase of the samples when placed in water. These data will not be presented in this thesis.

Frozen Plant Samples

Once before and twice after the D stage irrigation (August 8, 11 and 17), whole plant samples were taken from the 0, 80, 120 and 200 pounds per acre N treatment plots within the complete (ABCD) and minus D (dough) stage irrigation strips at the Manhattan location. A four-foot section of row was cut one inch above ground level. From this sample, ten immature and ten mature plants were taken. These subsamples were divided into head and stem samples and frozen in the field using dry ice (CO_2) to stop metabolism as quickly as possible. The samples were transported frozen and stored in a deepfreeze until removed for analysis. The remainder of the four-foot sample was bagged and later dried in a forced-air oven at 110° centigrade. A preliminary report, based on the analysis of these samples, has been presented by Redgrave et al. (28).

Grain Analysis

1. Yield. The grain from each plot was measured in grams and converted to pounds per acre using the harvested area of that plot.
2. Kernel weight. The number of seeds in a 100 gram sample was determined with an electronic counter. This sample was then used for kernel size distribution.
3. Kernel size distribution. A 100 gram sample was placed on a nest of 7/64, 6/64, 5½/64, and 5/64 sieves. This was mechanically shaken for one minute; then the amount remaining on each sieve was weighed. Percent plump is the total amount remaining on and above the 6/64 sieve. Percent thin is the amount going through the 5½/64 sieve (1,25).
4. Protein. Approximately 20 grams of grain was ground and N was determined by a standard Kjeldahl procedure using a 1 gram sample (1). Percent protein was calculated by multiplying percent N by 6.25 (1,2).

Soil Moisture Determination

Neutron probe access tubes were placed in selected plots at both locations as shown in table IV. Aluminum tubes were used at Dillon and steel tubes at Manhattan.

Soil samples were taken with a king tube approximately one and one-half feet from the access tube. After harvest, additional samples were taken six inches from the access tube. At this time, three sets of samples were taken per tube. These soil samples were dried in a forced draft oven at 65° centigrade for 48 hours to determine moisture gravimetrically. These data, with the neutron readings taken concurrently, were used to calibrate the neutron meter. Desorption curves were developed using these samples and a ceramic plate pressure apparatus.

A Nuclear-Chicago model 2800 neutron meter was used to determine soil moisture changes in the field throughout the season. A counting time of two minutes was used with six to eight background counts of the same duration. Neutron readings were taken before and two to three days after each irrigation. At Manhattan, additional readings were taken up through harvesting.

At Dillon, readings were taken at 6 inches and 1, 2, 3 and 4 feet below the surface. At Manhattan, readings were taken at the 6 inch and 1, 2, 3, 4, 5 and 6 foot depths. The bulk density at each depth was determined using ped samples and the parafin wax method.

Precipitation

Table V gives the rainfall distribution during the season at the

Table IV. Irrigation-fertilizer treatment plots which had neutron access tubes.

Location	Irrigation Treatments				Fertilizer Treatments a/ N Rate lb/A			
Manhattan b/	A	B	C	D	0	80	160	
c/	-	B	C	D	0	80	160	
	A	-	C	D	0	80	160	
	A	B	-	D	0	80	160	
	A	B	C	-	0	80	160	
Dillon	A	B	C	D	0	80	160	200
	-	B	C	D	0	80	160	
	A	-	C	D	0	80	160	
	A	B	-	D	0	80	160	
	A	B	C	-	0	80	160	200

a/ These fertilizer treatments also had 40 pounds of P and K per acre.

b/ Replications I, II and III at Manhattan. Replications I and II at Dillon.

c/ - indicates omitted irrigation.

Table V. Rainfall at the Manhattan location during the 1966 season.

Date		Inches Precipitation
June	19	.02
	20	.08
	21	.41
	23	.18
	24	.19
	29	.11
	30	.01
July	7 and 8	.50
	17	.22
August	4	.18
	20	.30
TOTAL		2.20

Manhattan location. The total rainfall at Dillon during the season was less than one-half inch and was so scattered that it was ineffective.

Weed Control

The plots at Manhattan were sprayed once with 2,4-D at one-fourth pound per acre to control sweet clover and thistle.

Statistical Analysis

Curvilinear regression analysis has been used to develop equations relating the measurements of yield in pounds per acre, percentage protein and percentage plump kernels as a function of applied N-rate. The irrigation treatments were concerned with the timing and omission of an irrigation stage. They were not additive in magnitude and a response surface could not be calculated. Instead, each irrigation treatment has been analyzed separately. All computations were performed on an IBM 1620 Model II computer, using programs written by the author. An analysis of variance of yield, protein and plumpness was made for each irrigation treatment for all N-rates. This analysis was done separately for each location. The results are given in the Appendix, tables XXV and XXVI.

Example of Curve Fitting

If the response to N was not significant over the range of rates studied, then the treatment mean, a horizontal line, was used to describe the data.

This equation is of the form:

$$Y = a$$

where Y = the value of the measured dependent variable

and a = mean of the values of the dependent variable for that irrigation treatment.

When the N treatment was significant, a regression equation was fitted to the data using the treatment means.

The calculation procedure used was developed by Fisher and presented by Snedecore (35). This method fits successive factors of a polynomial equation to the data points.

In the calculation of a regression equation, a basic assumption is that the independent variable (X) is measured without error (Steele and Torre (39) p. 165). This requires that the N application rate be accurate. No measure of this accuracy is available so it was assumed that this condition had been met.

The equation that best describes the data is a polynomial of X (N-rate), up to and including, X to the n-1 power where n is equal to the number of data points. Six N treatment mean values were used. The equation which best fits (sum square deviation from regression at a minimum) the data is:

$$Y = a(X)^0 + b(X)^1 + c(X)^2 + d(X)^3 + e(X)^4 + f(X)^5$$

Where Y = dependent variable,

X = nitrogen rate,

and a to f = slopes of the various exponential effects of the N-rate.

In curvilinear regression, after each slope is fitted a residual sum of squares exists. This is the sum square deviation from the regression equation thus far calculated.

To calculate r, the correlation coefficient,

$$r = \sqrt{1 - (\text{Residual sum squares}/\text{sum square total})}$$

The successive factors of the equation were fitted until r was at least .90 for grain yield and protein percentage. A linear regression was used to describe the percentage plump values.

Soils

The soil at the Manhattan location is a member of the Manhattan series. This group of soils has been classified as Calcisols of the Chestnut soils zone which have developed in sandy alluvial deposits at elevations of 3,000 to 5,000 feet under a cool semiarid climate.

At the Dillon location, the soil is a member of the Avalanche series. This group of soils has been classified as Calcisols of the Brown soils zone, developed in strongly calcareous alluvium under a cool semiarid climate.

The distinctive characteristics and profile descriptions of these soils are given in Appendix tables XXVII and XXVIII.

RESULTS AND DISCUSSION

An analysis of variance was calculated for grain yield, in pounds per acre, percentage grain protein and percentage plump kernels. The two locations, Manhattan and Dillon, were analyzed separately. The significance, at the .10 level of probability for N-rate, irrigation regime, and N-rate X irrigation regime was determined by F test. The results of this test are given in table VI. At the Manhattan location, the affect of N-rate on yield, protein and plumpness was significant; but irrigation regime and the interaction affects were not significant. Yield, protein and plumpness at the Dillon location were all significantly affected by N-rate, irrigation regime and N rate X irrigation regime, table VI.

Grain Yield

Separate analyses of variance were performed for each N-rate and the significance of the irrigation treatment affects on grain yield was determined. Then irrigation treatment was held constant and the significance of the N-rates determined. The significance was calculated using an F test. The results for both locations are given in table VII.

Manhattan

Only the N-rate showed significant affects on grain yield. The lack of a yield response differential between irrigation treatments was probably due to two factors. The rainfall at this location came during the boot stage, table III and V. This stage has been shown to be a critical one as regards the effects of a soil moisture deficit on yield, Luebs and Laag (24) and Smith et al. (33).

Table VI. Significant effects of irrigation and N rate treatments.

		Irrigation Treatment	N Rate	Interaction
Manhattan	Yield	NS a/	**	NS
	Protein Percentage	NS	**	NS
	Percentage Plump	NS	**	NS
Dillon	Yield	**	**	**
	Protein Percentage	**	**	**
	Percentage Plump	**	**	**

a/ NS Not significant.

* Significant at .10.

** Significant at .01.

Table VII. Grain yield values, pounds per acre, used in the calculation of the curvilinear regression equations. Each value is the mean of four replications.

Location	Irrigation Treatment	N Rate lb/A 0	40	80	120	160	200	F a/	LSD .10
Manhattan	A B C D	2131	2651	3212	3950	4130	4515	**	595
	- B C D b/	2114	2839	3560	3824	4102	4132	**	309
	A - C D	2044	3229	3590	4217	4157	5185	**	737
	A B - D	1914	2946	3780	3970	3961	3969	**	498
	A B C -	2138	2854	3611	3737	3911	3786	**	453
	F	NS	NS	NS	NS	NS	NS		
	MEAN	2222	2904	3551	3939	4052	4164		
Dillon	A B C D	2199	1787	2554	2851	2873	2929	*	599
	- B C D	1781	2158	2742	3341	3905	4203	**	355
	A - C D	1810	1897	1975	2164	1973	2177	NS	435
	A B - D	1971	2239	2412	2862	2595	2556	*	383
	A B C -	2591	2390	3067	3106	3279	3053	**	306
	F	*	*	*	NS	**	**		
	LSD .10	528	450	500	---	670	708		

a/ * Significant at .10.
** Significant at .01.
NS Not significant.

b/ - indicates omitted irrigation.

In addition to the rainfall, the moisture determinations throughout the season, measured with a neutron probe, indicate that subirrigation probably occurred. Evidently, the combination of these factors provided sufficient water to essentially negate the effects of omitting irrigations.

The grain yield values of these treatments were considered as additional replications for the N-rates (6,39). The mean values for yield at each N-rate were used to calculate a regression equation. The equation, the first and second derivative, and the slope at selected N-rates are given in tables VIII and IX.

Dillon

At this location, N-rate, irrigation regime and the interaction of N-rate-irrigation regime, each had a significant affect on grain yield. As previously mentioned in the statistical analysis section, irrigation regimes were discrete treatments so a response surface could not be calculated. The regression of yield on N-rate has been calculated for each irrigation treatment. The significance of the N-rate X irrigation regime interaction indicates that these regressions are different. The regression equations and the first and second derivatives are given in table VIII.

A moisture deficit at and after the hard dough stage, the minus D treatment, did not significantly change the maximum yield obtained when compared with the complete (ABCD) irrigation treatment; but the N-rate at which this maximum point was reached was slightly different. With

Table VIII. Equations for the regression of grain yield, in pounds per acre, on N application for each irrigation treatment. X = N-rate ÷ 40.

Location	Irrigation Treatment	Regression Equation	r
Manhattan	a/	$Y = 2207.8 + 832.37(X) - 89.09(X^2)$	.998
		$\frac{dy}{dx} = 832.37 - 178.18(X)$	
		$\frac{d^2y}{dx^2} = -178.18$	
Dillon	A B C D	$Y = 2121.98 - 389.00(X) + 345.68(X^2) - 47.63(X^3)$	.926
	- B C D b/	$Y = 1739.60 + 512.84(X)$	.996
	A - C D	Y = 1999. No significant change c/	
	A B - D	$Y = 1925.86 + 420.83(X) - 58.77(X^2)$	.929
	A B C -	$Y = 2541.26 - 180.98(X) + 243.98(X^2) - 37.63(X^3)$	.925

Irrigation Treatment	dy/dx	d^2y/dx^2
A B C D	$-389.00 + 691.36(X) - 142.89(X^2)$	$691.36 - 285.78(X)$
- B C D	512.84	
A - C D	No significant change.	
A B - D	$420.83 - 117.46(X)$	-117.46
A B C -	$-180.98 + 487.96(X) - 112.89(X^2)$	$+487.96 - 225.78(X)$

a/ No significant difference between irrigation treatments.

b/ - indicates omitted irrigation.

c/ Determined by F .10.

Table IX. Slopes of grain yield regression equations at selected N-rates and N-rate giving maximum yield.

Irrigation Treatment	Regression Slopes N Rate lb/A					
	0	40	80	120	160	200
Manhattan a/	832.4	654.1	476.0	297.8	119.7	- 58.5
Dillon						
A B C D	-389.0	159.5	422.2	399.1	90.2	-504.4
- B C D b/	512.8	512.8	512.8	512.8	512.8	512.8
A - C D	----- c/	-----	-----	-----	-----	-----
A B - D	420.8	303.4	185.9	68.5	- 49.0	-166.5
A B C -	-181.0	194.1	343.4	266.9	- 35.4	-563.4

Irrigation Treatment	Maximum Yield	N Rate	N Rate showing maximum increase
Manhattan	4152	186	0
Dillon			
A B C D	3058	168	96
- B C D	4304	200	constant
A - C D	1999	0	-- c/
A B - D	2679	140	0
A B C -	3314	156	88

a/ No significant difference between irrigation treatments at .10.

b/ - indicates omitted irrigation.

c/ No yield response at .10 with this irrigation treatment.

the complete irrigation set maximum yield was 3100 pounds per acre at 168 pounds of N. Omitting the D irrigation resulted in a yield maximum of 3300 pounds per acre at 156 pounds of N. A soil moisture deficit prior to this period (minus C or milk stage irrigation) reduced the maximum yield to 2700 pounds per acre at 140 pounds of N. The slopes for this treatment, table IX, show that as N-rate was increased about 80 pounds per acre, the yield response droped rapidly in comparison with the complete irrigation treatment. Similar results with Thatcher wheat were reported by Hutcheon and Paul (18). They found that the critical moisture stress period, as regards grain yield, was the soft dough stage.

When the boot stage (minus B treatment) irrigation was omitted, there was no yield response to applied N. Luebs and Laag (24) found that an application of water at the heading stage gave maximum effects (positive) on yield response of barley. Smith et al. (33) also showed that omitting the boot stage irrigation resulted in the lowest rate of yield response to applied N. This growth stage has also been shown to be a critical period, as regards moisture stress affects on yield, in both corn (19,31, 40) and wheat (14).

The high yield response to applied N when the tillering stage (minus A treatment) irrigation was omitted is not fully understood. Presumably, tiller production would be inhibited by a soil moisture deficit during this period. Since the amount of tillering is an important component of yield (37,38) a depressional effect on yield, when compared to treatments receiving this irrigation, should have occurred if there was a soil water deficiency during this period (Smith et al. (33)).

The yield response to applied N with this irrigation regime may be related to the soil temperature being higher on those plots that did not receive this irrigation. The cold irrigation water would have decreased the soil temperature which could have remained lower on the wetter plots due to the high specific heat of water and a cooling effect by evaporation from the soil surface.

Another possible explanation is concerned with the relative amount of movement, with the irrigation water, of the applied N. After seeding, all plots received a light irrigation to initiate germination. The stand was so variable that a second irrigation was applied to complete germination; then the area was disked and reseeded. The A irrigation was applied when this second stand was at the tillering stage. The minus A treatment had received only two light irrigations up to this point while all other irrigation treatments had received three applications of water, the two germination irrigations and the A stage irrigation, after the N had been applied during the first seeding. Thus, the applied N may have been moved the least on those plots not receiving the A irrigation. This could have provided these plants with a higher amount of N in the root zone at this stage. Luebs and Laag (24) reported that a rain of .31 inches moved applied N into the root zone of barley and increased N uptake of the plants growing under a dry regime. This uptake may have been caused just by the addition of water which allowed an increase in growth rate. However, the uptake rate of N, by grain sorghum, has been shown to be almost independent of soil moisture content until the wilting point is approached (Eck and Fanning (9)).

Whatever the actual reason(s) for the yield response to applied N, shown by the minus A treatment, it is probably not a typical response pattern to this type of irrigation regime.

Grain Protein Percentage

A quality requirement for western two-row malting barley is a protein content of 13.0 percent or less (25). A premium has sometimes been offered for low protein two-row barley. The premium increases as protein percentage declines from 12.5 percent (10). This aspect will be discussed later in the economic analysis section. Den Hartog and Lambert (7) found a negative correlation between grain protein content and the amount of extract (alpha and betz amylase enzymes) produced when the barley was malted. Germination is not uniform when protein content is high and the time required for malting is increased (25). High protein in the grain produces a product with a high protein content which is undesirable (25). These affects of protein are the basis for the requirement that two-row barley, to be used for malting, have a low protein percentage (25).

Manhattan

Protein percentage of the grain, at harvest, was not significantly affected by irrigation treatment as shown in tables VI and X. The omission of the D irrigation (dough stage) did produce an increase in the grain protein content in relation to the complete (ABCD) irrigation treatment, as reported by Redgrave et al. (28). These observations were made on the frozen samples which were taken once before and twice after the D irrigation. These differences were not found in the same order of

Table X. Percent protein values used in the calculation of the curvilinear regression equations. Each value is the mean of four replications.

Location	Irrigation Treatment	N Rate lb/A 0	40	80	120	160	200	F a/	LSD .10
Manhattan	A B C D	11.28	10.25	11.15	12.18	13.18	13.73	**	.59
	- B C D b/	10.63	10.80	11.98	13.20	13.75	14.60	**	1.02
	A - C D	10.93	10.63	11.78	12.50	13.85	13.68	**	.74
	A B - D	10.70	10.50	10.83	11.90	13.20	13.93	**	.45
	A B C -	11.05	10.53	11.03	11.85	12.78	13.00	**	.50
	F	NS	NS	*	NS	NS	NS		
	LSD .10	---	---	.60	---	---	---		
	MEAN	10.92	10.54	11.35	12.33	13.35	13.79		
Dillon	A B C D	11.75	11.08	12.25	13.30	13.60	14.33	**	2.24
	- B C D	11.53	11.40	11.50	12.50	13.10	13.38	**	2.01
	A - C D	11.80	13.20	14.20	15.10	15.28	16.45	**	.99
	A B - D	11.38	11.55	12.38	13.65	15.53	16.05	**	1.59
	A B C -	12.18	10.90	11.45	13.38	14.38	14.80	**	1.15
	F	NS	**	*	*	**	**		
	LSD .10	---	.80	1.45	1.03	1.02	.95		

a/ * Significant at .10.
** Significant at .01.

b/ - indicates omitted irrigation.

NS Not significant.

magnitude, in the harvested grain. When irrigation regimes and N-rate treatments were analyzed separately, the 80 pounds per acre N-rate was the only rate that showed differences in grain protein percentages between the complete (ABCD) regime and a regime in which an irrigation was omitted, table X. When compared to the complete (ABCD) irrigation treatment at this N-rate, the lack of irrigation A (tillering) or B (boot) produced a higher protein content, the omission of C (milk) irrigation had lower protein and the minus D (dough) showed no difference. These relationships seem to hold over the range of N-rates studies with the exception that at the higher N-rates, the minus C (milk) irrigation seemed to be increasing in protein and the minus D (dough) irrigation tended to show a decrease when compared with the complete (ABCD) irrigation regime.

Due to the general lack of significant differences of grain protein percentage between irrigation treatments, a single equation has been used which relates grain protein percentage as a function of N-rate, table XI.

Dillon

Protein percentages at zero N-rate were not significantly different among irrigation treatments. At all other rates of N, there were differences among irrigation regimes, table X. A separate regression equation was developed for each irrigation treatment, table XI, and the slope of the equation calculated at each N-rate, table XII. When compared with the complete (ABCD) irrigation regime, the lack of the C (milk) stage irrigation showed the greatest rate of protein increase at the lower (120 pounds per acre or less) N-rates; then, as the N-rate was increased above 120

Table XI. Equations for the regression of grain protein percentage on N application rate for each irrigation treatment. X = N-rate ÷ 40.

Location	Irrigation Treatment	Regression Equation	r
Manhattan	a/	$Y = 10.90 - .93(X) + .73(X^2) - .09(X^3)$	.999
		$\frac{dy}{dx} = - .93 + 1.46(X) - .27(X^2)$	
		$\frac{d^2y}{dx^2} = 1.46 - .54(X)$	
Dillon	A B C D	$Y = 11.39 + .30(X) + .06(X^2)$	.946
	- B C D b/	$Y = 11.38 + .08(X) + .07(X^2)$	.960
	A - C D	$Y = 12.17 + .87(X)$	.982
	A B - D	$Y = 10.81 + 1.04(X)$	.973
	A B C -	$Y = 11.64 - .19(X) + .18(X^2)$	.913

Irrigation Treatment	dy/dx	d^2y/dx^2
A B C D	.30 + .12(X)	.12
- B C D	.08 + .14(X)	.14
A - C D	.87	---
A B - D	1.04	---
A B C -	-.19 + .36(X)	.36

a/ No significant difference between irrigation treatments at .10.

b/ - indicates omitted irrigation.

Table XII. Slopes of the regression of grain protein percentage on applied N-rate at selected N-rates.

Location	Irrigation Treatment	N Rate lb/A 0	40	80	120	160	200	Significant Difference a/
Manhattan	b/	-.93	.26	.91	1.02	.59	-.38	
Dillon	A B C D	.30	.42	.54	.66	.78	.90	
	- B C D	.08†	.22†	.36†	.50†	.64†	.78†	.06
	A - C D	.87†	.87†	.87†	.87†	.87†	.87	.04
	A B - D	1.04†	1.04†	1.04†	1.04	1.04	1.04	.48
	A B C -	-.19†	.17†	.53	.89†	1.25†	1.61†	.06

a/ A slope is significantly different (.10) from the ABCD treatment if the slope difference is greater than value shown.

b/ No significant difference between irrigation treatments at .10.

c/ - indicates omitted irrigation.

† Indicates which slopes are significantly different (at .10) from the complete (ABCD) treatment.

pounds per acre, the minus D (dough) irrigation showed the greatest rate of protein increase. Since a prime objective is to keep protein down below 12.5 percent, irrigation at these two (C and D) stages seemed to be very important with the C stage the most critical, table XIII. The high rate of protein increase when the B (boot) irrigation was omitted is quite probably related to the lack of yield response to applied N shown under this regime. A corrolary to this affect is shown with the minus A (tillering) irrigation treatment. Under this regime, the rate of protein increase was, at all N-rates, less than that of the complete (ABCD) regime and the yield was higher.

Reisenauer and Dickson (29) found that yield and protein were inversely related and Dubetz and Wells (8) showed that grain protein percentage increased with N-rate or increased moisture stress, with N-rate having the greatest affect.

Percentage Plump Kernels

A minimum of 80 percent plump kernels is required for western two-row barley to quality for malting grades (25,43). Plump kernels are those remaining above a 6/64 sieve (22).

Manhattan

Irrigation treatments did not significantly affect the percentage plump kernels, table XIV. This lack of an effect was probably caused by soil moisture not being low enough during the season to influence plumpness.