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

K 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,

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

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.

Table XIII. Applied N-rate, pounds per acre, at which grain protein had increased to 12.5 percent. Calculated from regression equations.

Location	Irrigation Treatment	N Rate lb/A
Manhattan	a/	130
Dillon	A B C D	99.2
	- B C D b/	138.8
	A - C D	15.2
	A B - D	65.2
	A B C -	111.2

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

b/ - indicates omitted irrigation.

Table XIV. Values of percentage plump kernels used in the calculation of the 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	95.43	96.08	95.68	94.88	92.78	91.23	*	2.24
	- B C D b/	95.93	96.18	95.55	94.35	93.55	90.35	**	2.01
	A - C D	95.60	95.63	94.38	96.50	94.03	94.50	*	.99
	A B - D	96.15	95.25	94.63	94.95	92.95	92.45	*	1.59
	A B C -	95.85	95.83	95.95	94.70	93.78	93.05	*	1.15
	F	NS	NS	NS	NS	NS	NS		
	MEAN	95.79	95.79	95.24	95.08	93.42	92.32		
Dillon	A B C D	89.78	92.55	89.43	86.35	78.58	77.23	**	5.45
	- B C D	83.00	83.03	75.75	75.83	68.88	72.58	*	5.68
	A - C D	91.58	90.10	91.38	87.80	85.50	83.95	*	3.11
	A B - D	83.33	85.33	65.00	61.48	42.73	39.33	**	15.69
	A B C -	80.88	87.60	84.28	76.30	79.95	71.83	*	11.21
	F	NS	NS	**	*	**	**		
	LSD .10	---	---	9.6	19.9	17.6	16.8		

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

b/ - indicates omitted irrigation.

NS Not significant.

The values from the various irrigation treatments and replications were averaged and a regression equation developed from these values. The regression equations are given in table XV and the slope at each N-rate is given in table XVI. The slope shows that as the N-rate is increased beyond about 20 pounds per acre, percentage plump decreased. This effect became increasingly severe as N-rate was increased. However, plumpness was above 80 percent throughout the range of N-rates studied, table XVII.

Dillon

The effects of irrigation treatments on percentage plump were significant at this location, table XIV, at N-rates above 40 pounds per acre.

The equations for the regression of percentage plump kernels on N-rate are given in table XV. All irrigation treatments showed a decrease in percentage plump with increasing N-rate. Omitting the C (milk stage) irrigation caused the greatest rate of percentage plump decrease with increasing N-rate as shown by the slope values given in table XVI. A deficiency of soil moisture during the milk stage has also been shown in previous studies to decrease plumpness (32,33). This effect is possibly due to a lower rate of sugar translocation into the kernels, or a decrease in sugar production due to a decrease in net photosynthetic rate caused by moisture stress and subsequent stomatal closure.

Malting Barley Production Combinations

The N-rates at which protein had increased to 12.5 percent and plump kernel percentage had decreased to 80 percent are given in table XVIII.

Table XV. Equations for the regression of percentage plump a/ kernels on N application rate for each irrigation treatment. X = N-rate ÷ 40.

Location	Irrigation Treatment	Regression Equation	r
Manhattan	b/	$Y = 95.77 + .18(X) - .18(X^2)$	.989
		$\frac{dy}{dx} = .18 - .36(X)$	
		$\frac{d^2y}{dx^2} = -.36$	
Dillon	A B C D	$Y = 93.35 - 3.08(X)$	.910
	- B C D c/	$Y = 83.26 - 2.70(X)$	.985
	A - C D	$Y = 92.35 - 1.59(X)$	.934
	A B - D	$Y = 87.96 - 10.04(X)$	.966
	A B C -	$Y = 85.58 - 2.18(X)$	.726

Irrigation Treatment	dy/dx
A B C D	- 3.08
- B C D	- 2.70
A - C D	- 1.59
A B - D	-10.04
A B C -	- 2.18

a/ Plump kernels remain above a 6/64 sieve (22,43).

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

c/ - indicates omitted irrigation.

Table XVI. Slopes of the regression of percentage plump kernels on applied N-rate.

Location	Irrigation Treatment	N Rate lb/A 0	40	80	120	160	200	Significant Difference a/
Manhattan	b/	.18 -	.18 -	.54 -	.90 -	1.26 -	1.62	
Dillon	A B C D	- 3.08	- 3.08	- 3.08	- 3.08	- 3.08	- 3.08	
	- B C D c/	- 2.70	- 2.70	- 2.70	- 2.70	- 2.70	- 2.70	1.15
	A - C D	- 1.59	- 1.59	- 1.59	- 1.59	- 1.59	- 1.59	1.24
	A B - D	-10.04	-10.04	-10.04	-10.04	-10.04	-10.04	.95
	A B C -	- 2.18	- 2.18	- 2.18	- 2.18	- 2.18	- 2.18	1.19

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

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

c/ - indicates omitted irrigation.

Table XVII. Applied N-rate at which the percentage of plump a/ kernels had decreased to 80 percent. Calculated from regression equations.

Location	Irrigation Treatment	N Rate lb/A
Manhattan	b/	>200
Dillon	A B C D	172
	- B C D c/	48
	A - C D	>200
	A B - D	32
	A B C -	102

a/ Plump kernels remain above a 6/64 sieve (22,43).

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

c/ - indicates omitted irrigation.

Table XVIII. Irrigation treatment-N-rate combinations producing malting quality barley. a/ Maximum N-rate value calculated from regression equation.

Location	Irrigation Treatment	N Rate lb/A 0	40	80	120	160	200	Maximum	Quality Factor
Manhattan	b/	X	X	X	X			130	Protein
		X	X	X	X	X	X	>200	Plump
Dillon	A B C D	X	X	X				99	Protein
		X	X	X	X	X		17	Plump
	- B C D c/	X	X	X	X			139	Protein
		X	X					48	Plump
	A - C D	X						15	Protein
		X	X	X	X	X	X	>200	Plump
	A B - D	X	X					65	Protein
		X						31	Plump
	A B C -	X	X	X				111	Protein
		X	X	X				102	Plump

a/ 12.5 percent protein or less and at least 80 percent plump kernels.

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

c/ - indicates omitted irrigation.

Manhattan

The limiting factor on malting barley production at this location was protein percentage which had increased to 12.5 percent at the 130 pounds per acre N-rate. Plumpness was still above 80 percent at the maximum N-rate of 200 pounds per acre, table XVIII.

Dillon

At this location, the greatest adverse effects on quality were caused by the omission of the B (boot stage) irrigation, which affected protein percentage; and the omission of the C (milk stage) irrigation, which affected percentage plump, table XVIII.

The N-rate-irrigation regime combinations which produced barley meeting both protein and plumpness quality requirements are given in table XIX.

The following sections will be concerned with the economic analysis of the grain production levels previously presented under a varying price structure based on protein content.

Economic Analysis

Price Structure for Malting Barley

Under some contractual agreements, the price of malting barley changes with the protein content. One such arrangement is a price of $2.25 per hundred pounds for barley at 12.5 percent protein. If the protein is below 12.5 percent, the price increases at the rate of $.02 for each 0.1 percent decrease in protein. The maximum price is $2.75 per hundred pounds

Table XIX. Irrigation regime-N-rate combinations which produced barley of both 12.5 percent protein or less and at least 80 percent plump kernels. Maximum N-rate value calculated from regression equation.

Location	Irrigation Treatment	N Rate lb/A 0	40	80	120	160	200	Maximum	Quality Factor
Manhattan	a/	X	X	X	X			130	Protein
Dillon	A B C D	X	X	X				99	Protein
	- B C D b/	X	X					48	Plump
	A - C D	X						15	Protein
	A B - D	X						32	Plump
	A B C -	X	X	X				102	Plump

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

b/ - indicates omitted irrigation.

at 10.0 percent protein and decreases to \$2.25 per hundred pounds at 12.5 percent protein (10). This contrasts with a price for feed barley of \$1.83 per hundred pounds (10,26,44).

Value Equations

The regression equations for yield, table VIII, are total physical product equations in relation to applied N-rate for any given irrigation regime (16,21).

When the price of a unit of production is constant, then total physical product times price is equal to the total value product.

Total physical product $\cdot$ price = Total value product

or

Yield equation $\cdot$ price = Total value product equation

This equation will be:

$$\text{Total value product} = a + b(X) + c(X^2)$$

When the cost of the applied N is subtracted from the total value product equation, the result is a net value product equation as regards the value of the production in excess of the cost of the applied N. Since the cost of the N is a linear function of the amount applied, this can be subtracted from the total value product equation. At a cost of \$.13 per pounds of N, each 40 pound increment costs \$5.20. Subtracting \$5.20 (X) gives:

$$\text{Net value product} = a + b'(X) + c(X^2)$$

If it is assumed that all other production costs were constant over the range of applied N levels, then subtracting these costs from the net value product equation gives the profit equation:

$$\text{Profit} = a' + b'(X) + c(X^2)$$

The production costs would include the costs of P and K fertilizer, irrigation, planting and harvesting. When the price is a function of protein percentage, the same relationships are still true.

Under the price structure for two-row malting barley, mentioned previously, the total price per hundred pounds is $2.25 plus the protein incentive of $.02 for each one-tenth below 12.5 percent or $.20 for each percent decrease.

$$\text{Price} = \$2.25 + \{(12.5 - \text{protein percentage}) \cdot \$.2\}$$

The regression equations giving protein percentage as a function of applied N-rate for each irrigation regime have been presented in table XI. Using these equations, the price relationship becomes:

$$\text{Price} = \$2.25 + \{(12.5 - (a + b(X) + c(X^2))) \cdot \$.2\}$$

and multiplying this price relationship by the appropriate yield equation gives the total value product equation:

Yield equation $\cdot$ price equation = Total value product equation

Subtracting the cost of the applied N results in the net value equation as regards the variable cost of applied N which is $5.20 per X unit (X = 40 lb/A N).

The net value equations are given in table XX. The reason for the large magnitudes of the exponents is that these equations are the products of the yield equations and the percentage protein equations which in many cases were quadratic or cubic.

Table XX. Net value product equations based on gross value as a function of protein percentage and N cost at \$5.20/X unit. X = N-rate ÷ 40.

Location	Irrigation Treatment	Net Value Product Equation
Manhattan	a/	$Y = 56.74 + 20.30(X) - 3.96(X^2) - .98(X^3) + .28(X^4) - .02(X^5)$
Dillon	A B C D	$Y = 52.46 - 16.09(X) + 10.62(X^2) - 1.34(X^3) - .01(X^4) + .01(X^5)$
	b/ - B C D	$Y = 43.04 + 7.21(X) - .34(X^2) - .07(X^3)$
	A - C D	$Y = 46.31 - 8.68(X)$ c/
	A B - D	$Y = 49.84 + 1.69(X) - 2.40(X^2) + .12(X^3)$
	A B C -	$Y = 61.55 - 8.62(X) + 4.93(X^2) - .75(X^3) - .10(X^4) + .01(X^5)$

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

b/ - indicates omitted irrigation.

c/ No yield response. Price decreases as protein increases.

Value of Production

Maximum economical production is at the applied N-rate where the slope of the net value equation is zero. 2/ This relationship may not hold true because of the protein percentage maximum and plumpness percentage minimum requirements imposed on malting two-row barley. When these values are exceeded, the equation becomes discontinuous and the price would be based on the value of feed barley.

The N-rate for each irrigation regime which produced the maximum yield of acceptable barley is given in table XVIII. It has been shown that as N-rate increased, both the yield per acre and percent protein increased. Which will return the maximum value per acre: (1) high yield or (2) low protein percentage? In other words, when is the value of the yield increase, by increasing N-rate, offset by the price decrease caused by the associated increase in protein percentage?

The net value per acre at the maximum N-rate producing malting quality barley was calculated. In addition, the slope of the net value equation was also calculated at this maximum point, table XXI. If the slope is positive, then net value is increasing. If it is negative, then a greater net value can be gained by producing at a lower N-rate. This means the decrease in yield by lowering N-rate is more than compensated

---

2/ The point of zero slope can be found by setting the first derivative equal to zero and solving for the roots. Methods of solving equations greater than quadratic are given by Hilderbrand (17). These methods are quite tedious and it is possible that more than one solution exists over the range of positive values of X. Instead, the equations were evaluated by solving at .1 increments of X using a digital computer.

for by the increase in value per hundred pounds which results from a protein percentage below 12.5 percent.

Manhattan

The price incentive based on low protein percentage was sufficient to return a higher value per acre at less than maximum yield as shown by the slope at the maximum yield point. The value per acre at the point of maximum yield of malting quality barley was $71.23 at 130 pounds N per acre. Decreasing the N-rate to 80 pounds per acre returned $77.50, table XXI.

The decrease in yield, 4000 pounds per acre at 130 pounds N to 3500 at 80 pounds N, did not result in less value due to the price increase, per hundred pounds, which resulted from protein decreasing from 12.5 to 11.2 percent.

Dillon

The complete (ABCD) and minus A (tillering) irrigation treatments showed values of $57.83 and $51.10 at the highest N-rates which produced malting quality two-row barley, table XXI. The slopes of the net value equations for these irrigation regimes indicate that if quality had not been limiting, a higher net value could have been obtained. The limiting factor with the complete (ABCD) treatment was protein percentage and with the minus A (tillering) treatment the decrease in plumpness percentage limited production, table XVIII.

Omitting the B (boot) irrigation showed a return of $42.83 at 15 pounds of N per acre, which was the point where protein had increased to

Table XXI. Net value, dollars per acre, at maximum N-rate producing malting quality barley and a maximum net value per acre. a/ b/

Location	Irrigation Treatment	Maximum N Rate lb/A	Value at Maximum N Rate	Slope of Net Value Equation	Maximum Value	N Rate lb/A
Manhattan	c/	130	71.23	- 9.62	77.50	80
Dillon	A B C D	100	57.83	12.36		
	- B C D d/	48	51.10	6.12		
	A - C D	15	42.83	- 8.68	46.31	0
	A B - D	32	49.72	- 1.91	50.14	16
	A B C -	102	56.21	- 2.25	61.55	0

a/ Net value as regards cost of applied N only.

b/ 12.5 percent protein or less and at least 80 percent plump kernels.

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

d/ - indicates omitted irrigation.

12.5 percent. A higher value, \$46.31, occurred at zero N. This is due to the lack of yield response shown by this irrigation regime and the increase in protein percentage which resulted in a continuous decrease in the value, per hundred pounds, of the grain produced.

With the minus C (milk) irrigation treatment, yield maximum was limited by plumpness percentage, table XVIII. The slope of the net value at the maximum point was negative indicating that a higher value could have been obtained at a lower N-rate. This treatment gave a maximum return of \$50.14 at 16 pounds N per acre.

Omitting the D (dough) irrigation gave a return of \$56.21 at 102 pounds of N at which point plumpness percentage limited production. The slope was also negative for this treatment. The maximum return was \$61.55 at zero N.

SUMMARY AND CONCLUSIONS

Betzes barley, a two-row malting variety approved by the Malting Barley Improvement Association (26), was grown under irrigation at two locations in southwestern Montana, near Manhattan and near Dillon, during the 1966 season. The purpose of the experiment was to determine the affects on the yield and quality (protein and plump kernel percentages) of various levels of N fertilization (0 to 200 pounds per acre) and different irrigation regimes. Water was applied or witheld at each of four plant growth stages: tillering, boot, milk and hard dough. These stages have been defined by Feekes (11) as stages 3, 10.0-10.1, 10.5.2-10.5.4, and 11.2-11.3, respectively, and are illustrated by Large (20).

Manhattan

No significant difference (at .10) was found among irrigation treatments as regards the effects on yield and percentage plump kernels. This was probably caused by rain during the season and the subirrigation that may have occurred which together essentially eliminated the effects of omitting an irrigation stage. Protein percentages were different among irrigations only at the 80 pound N-rate.

Increasing N application rate increased yield from 2200 pounds per acre at zero N up to 4150 pounds per acre at 180 pounds N. Protein increased from 10.9 to 13.3 percent and plumpness decreased from 95.8 to 92.2 percent with increasing N application rate. Protein was the factor that limited production of malting quality barley at this location.

Dillon

The irrigation regimes showed differential affects on yield, protein percentage and percentage plump kernels. In general, yield and protein percentage were increased and percentage plump decreased with increasing N-rates; but these changes were modified by the different regimes. When compared with the complete set of irrigations (tillering, boot, milk and hard dough stages) the omission of the boot stage (B) irrigation caused a rapid increase in protein content with increasing N-rate and did not show any yield response. The lack of the milk stage (C) irrigation showed the greatest rate of decrease in percentage plump kernels and a low yield response to applied N. Omission of the dough stage (D) irrigation had a pattern of change in yield, protein percentage and percentage plump kernels that was similar to the complete set of irrigations.

The best yield response to applied N was with the omission of the tillering stage (A) irrigation. This effect is not fully understood as tillering is a major component of yield and presumably would be inhibited by a moisture stress at the tillering stage. The area was reseeded once because of stand variability and all plots received two light germination irrigations. The yield response of the minus A treatment may have been due to higher soil temperature on those plots which did not receive irrigation or it may be related to less downward movement of the applied N, when less water was applied, and its subsequent greater availability to the plant at this period.

The cause of this yield response should be investigated. Many farmers have reported adverse affects of an early irrigation "in some years". 3/ Perhaps the best irrigation regime would consist of a pre-plant application, omission of the tillering irrigation, and then an irrigation after tillering and again at the milk stage. If the location of the applied N is important at a particular growth stage, the amount of water applied prior to this time should be controlled to concentrate the applied N at the depth where the roots of the plant would be located during this stage.

Production Alternatives

The value of the barley produced at both locations was calculated at each applied N-rate. Two prices were used: (1) the price of malting two-row barley which is based on the protein percentage and (2) the price of feed barley. The values per acre are given in table XXII.

Manhattan

The net return based on malting barley prices was greater than the feed barley value at all N-rates which produced malting quality barley. Protein percentage limited the N-rate at which malting quality barley could be produced. At N-rates above 80 pounds per acre the increase in the protein percentage decreased the price of malting quality two-row barley sufficiently so that even with the yield increase the value per acre was decreased.

3/ C. M. Smith, Professor, Montana Extension Service, Montana State University, Bozeman. Personal communication.

Table XXII. Value of barley production when sold for malting or feed uses.

Location	Irrigation Treatment	Use of Barley	Net Values Dollars/A a/ N lb/A 0	40	80	120	160	200	Limiting b/ Quality Factor
Manhattan	c/	Malting	56.74	72.36	77.50	73.36	---	---	Protein
		Feed	40.41	48.80	53.94	55.82	54.45	49.80	
Dillon	A B C D	Malting	52.46	45.64	52.06	---	---	---	Protein
		Feed	38.83	31.97	32.53	35.27	35.00	26.43	
	- B C D	Malting	43.04	49.85	---	---	---	---	Plumpness
		Feed	31.82	36.01	40.20	44.39	48.58	52.76	
	A - C D	Malting	46.31	---	---	---	---	---	Protein
		Feed	36.58	31.38	26.18	20.98	15.78	10.58	
	A B - D	Malting	49.84	---	---	---	---	---	Plumpness
		Feed	35.25	36.67	35.94	33.06	28.04	20.87	
	A B C -	Malting	61.55	57.02	56.81	---	---	---	Plumpness (102 lb. N)
		Feed	46.50	41.78	41.83	42.56	39.83	29.49	Protein (111 lb. N)

a/ Net value with regard to cost of N only. N cost = $.13/lb.
Malting barley value = variable price based on protein. See page
Feed barley value = $1.83/100 lb.

b/ Malting barley, maximum 12.5 percent protein and minimum 80 percent plump.

c/ No significant difference (at .10) between irrigation treatments.

Dillon

When compared with the complete (ABCD) irrigation regime, omission of the B (boot) or C (milk) stage irrigations did not constitute practical irrigation regimes for the production of malting or feed barley.

Irrigation at the A (tillering), B (boot) and C (milk) stages seemed to be essential for the production of malting quality two-row barley or feed barley. Economical yields of feed barley were produced at higher rates of N than the rates at which malting quality barley was produced. Irrigation regime and N-rate should be carefully balanced as the highest return per acre can be obtained if the grain quality will meet malting barley standards.

APPENDIX

Table XXIII. Moisture use at the Manhattan location. Inches of water used, 0 - 6.5 feet.

Irrigation Treatment	N Rate	A → B a/	B → C	C → D	Total
A B C D	0	4.51	.95	3.76	9.22
	80	4.43	.98	4.33	9.72
	160	3.92	1.07	4.72	9.71
Average		4.29	1.00	4.27	9.56
- B C D b/	0	1.45	1.49	4.32	7.26
	80	.50	1.55	4.87	6.92
	160	1.59	1.66	4.77	8.02
Average		1.18	1.57	4.65	7.40
A - C D	0	2.26	.83	4.19	7.28
	80	4.64	.72	3.95	9.31
	160	3.50	.83	4.41	8.74
Average		3.47	.83	4.18	8.44
A B - D	0	2.47	1.59	2.20	6.26
	80	3.04	1.90	2.96	7.90
	160	3.00	1.95	3.29	8.24
Average		2.84	1.81	2.82	7.47
A B C -	0	3.65	1.18	2.65	7.48
	80	3.46	1.54	3.78	8.78
	160	3.69	1.65	4.64	9.98
Average		3.60	1.46	3.69	8.75

a/ A → B usage between A and B irrigations.

b/ - indicates omitted irrigation.

Table XXIV. Moisture use at the Dillon location. Inches of water used, 0 - 4.5 feet.

Irrigation Treatment	N Rate	A → B a/	B → C	C → D	Total
A B C D	0	2.88	1.67	3.52	8.07
	80	2.96	1.46	3.76	8.18
	160	3.59	1.93	3.28	8.80
Average		3.14	1.69	3.52	8.35
- B C D b/	0	1.57	1.44	2.75	5.76
	80	2.78	1.85	3.71	8.34
	160	2.82	2.05	4.28	9.15
Average		2.39	1.78	3.58	7.75
A - C D	0	2.53	1.12	2.96	6.61
	80	2.65	.71	3.17	6.53
	160	3.01	.92	3.60	7.53
Average		2.73	.92	3.24	6.89
A B - D	0	2.74	1.53	1.31	5.58
	80	3.44	1.78	1.13	6.35
	160	3.60	1.96	.90	6.46
Average		3.26	1.76	1.11	6.13
A B C -	0	2.94	1.57	3.15	7.66
	80	2.99	1.85	3.58	8.42
	160	2.91	1.56	3.78	8.25
Average		2.95	1.66	3.50	8.11

a/ A → B usage between A and B irrigation.

b/ - indicates omitted irrigation.

Table XXV. Analysis of variance. Manhattan, 1966.

	Source	df	Mean Squares Yield	Protein Percentage	Plump Percentage
	Replication	3	951300.0	1.289	4.10
	Irrigation	4	562850.0	2.382	3.05
	Error A	12	225775.0	1.407	5.89
	Fertilizer	5	11701100.0	35.336	40.34
	Error B	15	437440.0	.681	3.33
	Interaction	20	394095.0	.477	2.80
	Error C	60	434213.3	.369	2.51
Irrigation					
A B C D	Replication	3	641830.0	2.259	10.170
	Fertilizer	5	3235636.0	6.950	14.736
	Error	15	435841.3	.341	4.899
- B C D a/	Replication	3	375093.0	1.576	11.287
	Fertilizer	5	2557466.0	10.515	19.108
	Error	15	93198.0	1.022	3.943
A - C D	Replication	3	288096.7	2.125	2.817
	Fertilizer	5	4517496.0	6.551	3.622
	Error	15	529871.3	.533	.957
A B - D	Replication	3	286046.7	.689	.793
	Fertilizer	5	2816526.0	8.261	8.886
	Error	15	242277.3	.199	2.468
A B C -	Replication	3	158043.3	.830	1.957
	Fertilizer	5	2088490.0	4.101	5.750
	Error	15	200310.0	.245	1.287
Fertilizer b/					
0	Replication	3	367856.3	.189	.82
	Irrigation	4	35423.8	.278	.32
	Error	12	23425.8	.451	.66

Table continued...

Table XXV, continued:

	Source	df	Mean Squares: Yield	Protein Percentage	Plump Percentage
Fertilizer					
40	Replication	3	97830.0	.333	.58
	Irrigation	4	116767.5	.161	.28
	Error	12	144258.3	.484	.85
80	Replication	3	979223.3	1.474	1.82
	Irrigation	4	244382.5	.993	1.92
	Error	12	543540.0	.227	1.56
120	Replication	3	134253.3	1.978	1.05
	Irrigation	4	132215.0	1.225	2.75
	Error	12	158998.3	.670	2.57
160	Replication	3	565140.0	.103	10.00
	Irrigation	4	47982.5	.794	1.15
	Error	12	34714.2	.955	4.36
200	Replication	3	11246.7	.924	6.34
	Irrigation	4	1229160.0	1.554	10.38
	Error	12	442895.8	.758	8.53

a/ - indicates omitted irrigation.

b/ N-rate in pounds per acre.

Table XXVI. Analysis of variance. Dillon, 1966.

	Source	df	Mean Squares		
			Yield	Protein Percentage	Plump Percentage
	Replication	3	3248236.6	1.829	426.00
	Irrigation	4	3996745.0	15.579	2319.68
	Error A	12	532940.8	.919	339.10
	Fertilizer	5	3438626.0	46.366	1440.70
	Error B	15	204169.3	1.611	102.38
	Interaction	20	511739.5	1.485	207.83
	Error C	60	172196.2	.639	83.45
Irrigation					
A B C D	Replication	3	985580.0	1.574	70.94
	Fertilizer	5	833986.0	6.044	266.22
	Error	15	350720.0	.817	28.95
- B C D a/	Replication	3	1318190.0	.297	44.34
	Fertilizer	5	3712610.0	3.088	127.51
	Error	15	123048.0	.499	31.51
A - C D	Replication	3	1002579.3	2.142	19.63
	Fertilizer	5	84716.8	10.940	40.31
	Error	15	184920.5	1.078	9.42
A B - D	Replication	3	1868626.6	.872	1184.42
	Fertilizer	5	381180.0	16.137	1511.44
	Error	15	143111.3	.772	240.20
A B C -	Replication	3	215066.7	.618	491.45
	Fertilizer	5	473296.0	10.097	334.51
	Error	15	91190.7	1.000	122.61
Fertilizer b/					
0	Replication	3	792177.7	.222	8.73
	Irrigation	4	448573.0	.371	87.33
	Error	12	175420.8	.484	54.26

Table continued...

Table XXVI, continued:

	Source	df	Mean Squares Yield	Protein Percentage	Plump Percentage
Fertilizer					
40	Replication	3	597886.0	1.073	158.01
	Irrigation	4	245690.0	3.365	56.79
	Error	12	127265.6	.403	29.33
80	Replication	3	518490.0	.803	146.59
	Irrigation	4	653075.0	4.966	472.77
	Error	12	157310.0	1.327	58.17
120	Replication	3	620970.0	1.126	114.04
	Irrigation	4	776747.5	3.602	608.72
	Error	12	334919.2	.673	249.69
160	Replication	3	705510.0	2.227	221.60
	Irrigation	4	2102947.5	4.359	1055.44
	Error	12	283099.2	.660	194.30
200	Replication	3	1044016.6	4.433	270.11
	Irrigation	4	2328305.0	6.341	1124.70
	Error	12	315974.2	.565	178.04

a/ - indicates omitted irrigation.

b/ N-rate in pounds per acre.

Table XXVII. Soil Description - Manhattan.

Manhattan series. Calcisols of the chestnut soils zone, developed in sandy alluvial deposits in valleys of the Northern Rocky Mountains.

Distinctive characteristics:

1. Moderately thick, very dark grayish brown sandy loam. A1 or Ap, normally leached of lime but becomes calcareous with tillage.
2. A distinct or prominent Cca horizon of accumulated and segregated lime.

Soil Profile:		Manhattan fine sandy loam (under cultivation)
Ap	0- 9"	Greyish brown (10YR 5/2) fine sandy loam; 10YR 3/2 moist; weak medium and fine granular structure; soft and very friable; calcareous; few scattered pebbles; abrupt boundary.
Cca1	9-15"	Light brownish grey (10YR 6/2) sandy loam; 10YR 4/2 moist; massive structure; slightly hard, very friable; strongly calcareous with some soft white lime nodules; some small gravels with lime coating. Clear boundary.
Cca2	15-21"	Light brownish grey (10YR 6/2) loam or sandy loam; 10YR 5/2 moist; massive structure; hard, friable, slightly sticky and slightly plastic; very strongly calcareous, some angular gravels with lime coatings. Gradual irregular boundary.
C3	21-29"	Light gray (10YR 7/2) loamy sand; 10YR 5/2 when moist; massive; soft and very friable; very strongly calcareous with lime disseminated except for light coatings on small gravels; gradual boundary.

Table continued...

Table XXVII, continued:

Soil Profile:		Manhattan fine sandy loam (under cultivation)
C4	29-60"	Very pale brown (10YR 7/3) sandy loam; 10YR 5/3 moist; massive; soft, very friable; very strongly calcareous; lime disseminated except for light coatings on small gravels.

NOTE: During the installation of the neutron access tubes, a thin layer, 3-5 inches, of closely packed silt was noted at depths of 4-5 feet. This layer was quite dense and could be sufficiently impervious to impede internal drainage resulting in a perched water table with irrigation.

Table XXVIII. Soil Description - Dillon

Avalanche series. Calcisols of the brown soils zone developed in strongly calcareous alluvium in valleys of the northern Rocky Mountain Region.

Distinctive characteristics:

1. Poorly graded character of the parent material with a high silt content, low content of sands and clay and few to common gravels.
2. Thin, light-colored A1 horizon.
3. Distinct or prominent very thick Cca or Dca horizon.

Soil Profile:		Avalanche silt loam (under cultivation)
Ap	0- 7"	Pale brown (10YR 7/3) silt loam; 10YR 5/3 moist; massive structure, slightly hard, very friable, nonsticky and slightly plastic; very calcareous; abrupt smooth boundary.
Cca	7-24"	Brown (10YR 7/2) silt loam with a few gravels; 10YR 4.5/2 moist, moderately coarse prismatic breaking to moderately coarse medium blocks,slight hard, very friable, nonsticky and slightly plastic; very calcareous; clear wavy boundary.
Dca	24-50"	Very pale brown (10YR 7/3) to white (10YR 8/2) silt loam with some angular gravels. 10YR 5.5/3 to 10YR 6/3.5 moist; massive structure; soft, very friable, nonsticky and slightly plastic; extremely calcareous with thin lime coats on gravels.

LITERATURE CITED

1. American Society of Brewing Chemists. 1958. Methods of analysis. Sixth Ed., Madison, Wisc.

2. Association of Official Agricultural Chemists. 1960. Official methods of analysis. Ninth Ed., Washington, D. C.

3. Bailey, L. H. 1949. Manual of cultivated plants. The MacMillan Co., New York. p. 145.

4. Bauer, A., Young, R. A., and Ozbun, J. L. 1965. Effects of moisture and fertilizer on yields of spring wheat and barley. Agron. Jour. 57:354-356.

5. Blaney, H. F. and Criddle, W. D. 1950. Determining water requirements in irrigated areas from climatological and irrigation data. USDA, SCS Tech. Pub. 96.

6. Cochran, W. G. and Cox, G. M. 1957. Experimental designs. John Wiley and Sons. New York. p. 306-308.

7. Den Hartog, G. T. and Lambert, J. W. 1953. The relationships between certain agronomic and malting quality characteristics of barley. Agron. Jour. 45:208-212.

8. Dubetz, S. and Wells, S. A. 1965. Yield and quality of greenhouse-grown betzes barley as affected by water and fertilizers. Can. Jour. Plant Sci. 45:437-442.

9. Eck, H. V. and Fanning, C. 1961. Placement of fertilizer in relation to soil moisture supply. Agron. Jour. 53:335-338.

10. Extension Service, Montana State University. 1966. Malting barley in Montana. Circular 293.

11. Feekes, W. 1941. De tarwe en haar milieu. Vers XVII. Tech. Tarwe Comm. Gronigen. p. 560-561.

12. Hanks, R. J. and Tanner, C. B. 1952. Water consumption by plants as influenced by soil fertility. Agron. Jour. 44:98-100.

13. Harlan, H. V. and Anthony, S. 1921. Effect of time of irrigation on kernel development of barley. Jour. Agri. Res. 21:29-45.

14. Harris, F. S. 1916. The irrigation of wheat. Utah Agri. Exp. Sta. Bul. 146.

15. ———————— and Butt, M. I. 1920. The duty of water in Cache Valley, Utah. Utah Agri. Exp. Sta. Bul. 173.

16. Heady, E. O. 1952. Economics of agricultural production and resource use. Prentice-Hall, Inc. New Jersey. 850 p.

17. Hilderbrand, F. B. 1956. Introduction to numerical analysis. McGraw-Hill C., Inc. New York.

18. Hutcheon, W. L. and Paul, E. A. 1966. Control of the protein content of thatcher wheat by nitrogen fertilization and moisture stress. Can. Jour. Soil Sci. 46:101-108.

19. Jenne, E. A., Rhoades, H. F., Yien, C. H. and Howe, O. W. 1958. Changes in nutrient element accumulation by corn. Agron. Jour. 50:71-74.

20. Large, E. C. 1954. Growth stages in cereals: Illustration of the Feekes scale. Plant Path. 4:128-129.

21. Leftwich, R. H. 1966. The price system and resource allocation. Holt, Rinehart and Winston. New York. 369 p.

22. Lejeune, A. J. and Parker, J. H. 1953. Guide to premiums for high quality malting barley. Midwest Barley Improvement Association. Milwaukee, Wisconsin.

23. ——————— and ——————. 1954. Effects of field application of commercial fertilizers on malting quality of barley. Amer. Soc. Brew. Chem. Proc.

24. Luebs, R. E. and Laag, A. E. 1967. N effect on leaf area, yield and N uptake of barley under moisture stress. Agron. Jour. 59:219-222.

25. Malting Barley Improvement Association. 1967. Malting barley handbook. Milwaukee, Wisconsin.

26. Montana Agricultural Experiment Station. 1964. Prices received and prices paid by Montana farmers and ranchers, 1960-1962. Bul. 587.

27. Montana Agricultural Experiment Station. 1966. Grain and oil seed crop varieties for Montana. Circular 240.

28. Redgrave, D. J., Smith, C. M. and Ferguson, A. H. 1967. Malting barley: Changes caused by irrigation timing and N. Agron. Abstracts. 59:110.

29. Reisenauer, H. M. and Dickson, A. D. 1961. Effects of N and S fertilization on the yield and malting quality of barley. Agron. Jour. 53:192-194.

30. Richards, L. A. and Wadleigh, C. H. 1952. Soil water and plant growth, Chapter, in Soil physical conditions and plant growth. Academic Press, Inc. New York. p. 73.

31. Robins, J. S. and Domingo, C. E. 1953. Some effects of severe soil moisture deficits at specific growth stages in corn. Agron. Jour. 45:618-621.

32. Smith, C. M., Peace, R. D. and Jackson, M. 1962. Produce quality betzes barley with fertilization and water management. Montana Farmer-Stockman. Vol. 49, No. 12. p. 10.

33. ————————, Ferguson, A. H. and Howard, S. W. 1966. 100 Bushels of barley per acre on new land. Montana Farmer-Stockman. Vol. 53, No. 12. p. 21.

34. ———————— and Watson, C. A. 1966. Yield, protein and kernel size of two-row malting barley as influenced by fertilizers and water management. Agron. Abstracts. 58:83.

35. Snedecor, G. W. 1956. Statistical methods. Iowa State College Press. p. 461.

36. Sosulski, V. M. and Bendelow, V. M. 1964. The effect of irrigation on the agronomic and malting characteristics of barley. Can. Jour. Plant Sci. 44:509-514.

37. Stanberry, C. O. 1965. Nitrogen boosts barley profits. Plant Food Review. Fall, 1965. p. 14-16.

38. ———————— and Lowrey, M. 1965. Barley production under various nitrogen and moisture levels. Agron. Jour. 57:31-34.

39. Steele, G. D. and Toorie, J. H. 1960. Principles and procedures of statistics. McGraw-Hill Co., Inc. New York. 481 p.

40. Swanson, E. R. and Tyner, E. H. 1965. Influence of moisture regime on optimum nitrogen levels and plant population for corn: A game theoretic analysis. Agron. Jour. 57:360-364.

41. Tempest, J. W. and Snelson, W. H. 1930. Irrigated practice and water requirements for crops in Alberta. Dept. Interior Can., Irri. Series Bul. 7.

42. Thorne, D. W. and Peterson, H. B. 1954. Irrigated soils: Their fertility and management. The Blakiston Co., Inc. New York. p. 55.

43. U. S. Dept. of Agric. 1964. Official grain standards of the U. S. USDA Cons. and Mkt. Serv., Grain Div. Washington, D. C.

44. U. S. Dept. of Agric. 1967. Agricultural statistics. USDA Periodical Pub. Washington, D. C.