Sequential changes in some characteristics of two-row barley (Hordeum distichon L., VAR. Betzes) induced by differential irrigation and fertility regimes

by David John Vaughan Redgrave

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University

Abstract:
Two-row malting barley (Hordeum distichon L., VAR. Betzes) was grown under irrigation and N-P fertilization in southwestern Montana. The experiment was conducted to elucidate changes in the harvest grain which had been observed in previous experiments conducted in the same area. Irrigation application was keyed to the plant growth stage. Plant samples were collected periodically from the boot stage through harvest. A moisture stress caused changes in the gross plant weight, grain weight and grain protein percentage. The magnitude and direction of these changes was modified both by the fertility level under which the plant was growing and the growth stage of the plant when the stress was applied. The effects of a moisture stress during a given growth stage may not become evident until a later stage. Subsequent application of water did not provide a recovery from the deleterious effects of a prior moisture stress.

For the production of malting quality barley, it is essential that soil moisture supply be adequate during the tillering, boot and milk stages. A yield increase and protein decrease was noted when samples taken at the hard dough stage were compared to harvest samples. The magnitude of these changes needs further study and clarification.

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ABSTRACT

Two-row malting barley (Hordeum distichon L., VAR. Betzes) was grown under irrigation and N-P fertilization in southwestern Montana. The experiment was conducted to elucidate changes in the harvest grain which had been observed in previous experiments conducted in the same area. Irrigation application was keyed to the plant growth stage. Plant samples were collected periodically from the boot stage through harvest. A moisture stress caused changes in the gross plant weight, grain weight and grain protein percentage. The magnitude and direction of these changes was modified both by the fertility level under which the plant was growing and the growth stage of the plant when the stress was applied. The effects of a moisture stress during a given growth stage may not become evident until a later stage. Subsequent application of water did not provide a recovery from the deleterious effects of a prior moisture stress.

For the production of malting quality barley, it is essential that soil moisture supply be adequate during the tillering, boot and milk stages. A yield increase and protein decrease was noted when samples taken at the hard dough stage were compared to harvest samples. The magnitude of these changes needs further study and clarification.

INTRODUCTION

In 1965, field experiments were initiated in southwestern Montana, which were concerned with the nitrogen and phosphorus fertilization rates and irrigation regimes which would be necessary to produce high-quality, two-row malting barley. In 1966, three locations were used. These locations were near the towns of Manhattan, Dillon and Twin Bridges. The irrigation regimes were concerned with the timing of application of water based on the growth stage of the plant. These stages were the tillering, boot, milk and dough stages of development as defined by Feekes (14) and illustrated by Large (24) (Table II). During the 1966 season, plant samples were taken at the Manhattan and Dillon locations in an attempt to follow the changes that took place in the plant during the latter stages of development and how these changes were influenced by the fertility status and the soil moisture regime under which the plant was growing. Samples were taken by harvesting the entire plant at ground level for 3 feet in a row. Ten heads were selected from this sample; and the stems, leaves and heads were separated and frozen in the field using dry ice in order to stop metabolism as quickly as possible. These samples were then transported back to the laboratory and oven dried in a forced air oven at 65° C. The samples were analyzed for nitrogen and 1000-kernel weight was determined on the grain. On the basis of the information gained from that sampling, it appears that protein percentage of the kernels changes during the latter stages of growth and development. However, the changes that were noted in the protein percentage of the grain may be primarily a function of the amount of carbohydrates that were translocated into the kernel. This was indicated by the changes in 1000-kernel weight and the changes in the protein percentage. If 1000-kernel weight decreased, the protein percentage increased. As 1000-kernel weight increased with time, protein percentage tended to decrease. The present experiment was conducted in 1968 at Dillon, Montana, to further investigate these changes. Irrigation treatments were the same as those used previously. In addition to nitrogen treatment rates, various phosphorus rates were included. Plant sampling began at the boot stage and was accomplished by harvesting one meter of a row and subsequently separating the heads from the plants. The first set of samples was taken during the early boot stage before heads had emerged. The later samples all had heads. After the sample was taken, soil samples were taken from the area from which the plants had been removed. These soil samples will be analyzed for available phosphorus and nitrogen to determine the uptake and movement patterns of these materials under various irrigation treatments. In previous studies, it has been shown that the protein content and the yield of the grain are influenced by the nitrogen fertility under which the plant was growing as well as the irrigation regime. Thus, this thesis is concerned with the changes in the plant weight and the weight and protein content of the grain from boot stage to maturity and how these changes are influenced and modified by the nitrogen and phosphorus fertilizer application rate and the irrigation regime under which the plants were grown.

REVIEW OF LITERATURE

Many experiments have been conducted to investigate the relationships between plant growth and soil moisture supply. Kramer (23) has summed up the general results.

"In spite of an enormous amount of research on soil-plant-water relationships during the past half century, we are not yet certain what constitutes an adequate supply of water for the good growth of plants. Many of the results from research on the relationships between plant growth, crop yields and soil moisture have been inconclusive or even contradictory. This probably is because attention has been centered on one part of the soil-plant system. Too much emphasis has been placed on soil-water stress and too little on plant-water stress and on the reasons why water stress reduced plant growth."

One of the reasons for the disparity between the results is that many of these investigations have been conducted in such a way that irrigation timing was keyed to a given level of soil moisture. When the supply had been depleted to a predetermined level, additional water was applied. This approach ignores the fact that plants show a differential reaction to moisture stress depending upon the growth stage of the plant (31,32,36,37). Experimental results will then not be consistent unless the soil moisture depletion pattern and the plant development pattern were similar.

Combining the results of experiments with various small grain crops, a pattern emerged which leads to certain relationships.

The three major stages during the growth of a plant are tillering, head formation or flowering and grain filling (37). A moisture stress during tillering decreases the final yield due to the lower number of tillers produced (12). The lower vigor of the plants after an early moisture stress may be related to the decrease in P uptake which is limited under conditions of low soil moisture (13). N absorption is less affected by soil moisture content than is P (13). The subsequent growth and development of the plant is adversely affected by this lack of P during the early stages and increasing P supply or soil moisture at a later stage does not provide for complete recovery (5,6).

A limiting supply of soil moisture during the boot and flowering stages results in an increase in the protein percentage of the grain (38, 39). The critical nature of a moisture stress during the flowering period has been shown on corn (20,36,44), barley (31,3238) and grain sorghum (13). Some investigators have suggested that if a limited amount of water is available, such as with a supplemental irrigation system, then the most advantageous time for the application of this water is at the boot stage (18,27).

With barley, a moisture stress during the filling of the grain produces an increase in the protein percentage, a decrease in the yield and a decrease in the percentage plump kernels 1/ (10,34,37,38). It has been thought that yield and protein percentage for a given variety were related. But the concept that protein percentage changes are related to the dilution effect of carbohydrate accumulation has been questioned (32,38,40).

1/ Percent plump is defined as those kernels remaining above a sieve with openings 6/64 inch wide (1,24).

The application of N and P also affects the quantity of barley produced, the protein percentage, and the plumpness (26,32,37,42,43,45). Increasing the application rate of N and P increased the changes in the grain up to a point.

Usually, the effects of the N and P application are modified by the irrigation or soil moisture stress regime under which the plants were grown (19,32,37,38,41).

Under some conditions the effect of N application will mask the effects of the irrigation regime. At other times, the irrigation regime becomes the dominant factor (19,32).

Most of the foregoing results were observed by changing the N and P fertility status of the soil and modifying the soil moisture regime under which the plant was grown. The changes that were then observed in the harvested grain were attributed to the effects of the moisture stresses which were imposed at various growth stages.

Important as these results are, in many cases it is not known when the observed changes actually occurred. It has been assumed that the moisture stress during a certain growth stage affected its changes during that period, but this assumption may not be valid.

The need for a dynamic approach to irrigation research was well put by Harlan (16). "The factors affected by irrigation are so numerous and so involved that the final statement of yield per acre does not afford much basis for interpretation." He explains this feeling by adding, "The period during which the quantity of water or the application of water affects the size of the kernel is worth determining. 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."

The general growth pattern of barley is an increase in the weight of the plants until two to three weeks before harvest after which the weight declines (7,17). Moisture stress affects the development of the plant by decreasing the rate of dry matter production and altering the translocation pattern of carbohydrates into the developing grain. The effect of moisture stress during grain development is a decrease in the rate of grain weight accumulation up until the hard dough stage, after which the pattern changes (7,11). Some reports indicate that a decrease in grain weight occurs between the hard dough stage and harvest (11,22), and an increase or no change during this period has also been reported (21,29).

The changes in the protein percentage of the grain during the latter stages of growth are also variable with increases (16), no change (11), and decreases (22) being reported.

Some of the variability in the reported protein changes may be due to the difference in protein content between the main and secondary growths. In wheat it has been shown that the protein content of the main crop grain can be lower than that of the secondary, and this effect seems to be modified by the moisture status during ripening (30).

Of the recent reports, the most comprehensive is the one by Krall (22) who reports that for barley the general pattern is for the yield to decline from hard dough to harvest and the protein percentage to increase during the same period. The magnitude of these changes was influenced by the variety of barley grown and was further modified both by the differences in environment during the ripening stages and by whether the crop was grown under dryland conditions or irrigation.

The reasons for the research on moisture stress effects and irrigation regime as they influence plant growth have been well stated by Richards and Wadleigh (35), "A knowledge of the relation of crop response to the soil-moisture status is a primary consideration in establishing the most economical over-all management plan."

This research project was initiated with the hope of adding to this knowledge.

MATERIALS AND METHODS

Location

The field plots were located in southwestern Montana approximately 5 miles north of Dillon. The experimental area is on the southern part of the Bureau of Reclamation's East Bench Project of the Beaverhead River. The area was adjacent to and above the main canal of the project at approximately 45°15'N and 112°33'W with an elevation of 5200 feet and a uniform slope to the north of less than 1 percent.

Soil

The soil, Avalanche silt loam, is classified as a Borrolic Calciothid. A profile description of this series is given in Table XIX.

During the initial site inspection, three areas were sampled at depths of 0-6 inches, 0 to 1 foot and then at 1-foot intervals down to 6 feet. The analysis data for these samples are given in Table XVIII.

Plot Layout and Design

The experimental design was a split plot with the irrigation plots as the main treatment and the fertilizer treatments placed on the subplots.

Replications were oriented in the N-S direction. The irrigation strips were oriented in the E-W direction and randomized within each replication. The fertilizer strips were randomized separately within each irrigation strip. Each irrigation strip was 85 x 25 feet (25.9 x 7.6m) and subdivided into 12 fertilizer strips which were 25 feet (7.6m) long and 7 feet wide (2.1m).

Statistical Analysis

The statistical analysis was done according to the computational formulas given by Cochran and Cox (8). The analysis of variance provides two error terms designated E_a and E_b. Error A was used to calculate F ratios for the A level treatment, irrigation treatments in this design; and error B was used for the F ratio of the fertilizer rates and the interaction effects. All calculations were performed using a Sigma 7 Computor.

Fertilizer Rates and Materials

Fertilizer was hand applied to each plot and then lightly disced from the south. This provided approximately a six centimeter incorporation. Ammonium nitrate (33.5-0-0), concentrated superphosphate (0-45-0) and muriate of potash (0-0-60) materials were used. Fertilizer rates were calculated in pounds per acre to provide compatability with previous experiments related to this study.

Nitrogen rates were 0, 50, 100, 150 and 200 lbs/A of N; Phosphorus rates were 0, 40 and 80 lbs/A of P; Potassium rates were 0 and 40 lbs/A of K. Table I gives the rates of N, P and K for each fertilizer treatment.

Irrigation Treatments

Irrigation water was applied at four times during the growing season. The application was timed by the growth stage of the plants. The stages were A, tillering; B, boot; C, milk; and D, dough. These stages have been designated by Feekes (14) as A, stage 3; B, stage 10.1; C, stage 10.5.4; and D, stage 11.3 and have been illustrated by Large (24). The irrigation treatments are outlined in Table II.

Table I. Fertilizer Application Rates.

Treatment	Rate in Pounds/Acre 1/		
	N	P	K
1	0 (0) 2/	0 (0)	0 (0)
2	0 (0)	0 (0)	40 (45)
3	0 (0)	40 (45)	40 (45)
4	0 (0)	80 (90)	40 (45)
5	50 (56)	40 (45)	40 (45)
6	100 (112)	0 (0)	40 (45)
7	100 (112)	40 (45)	40 (45)
8	100 (112)	80 (90)	40 (45)
9	150 (168)	40 (45)	40 (45)
10	200 (224)	0 (0)	40 (45)
11	200 (224)	40 (45)	40 (45)
12	200 (224)	80 (90)	40 (45)

1/ N-(NH_4NO_3 33.5-0-0); P-($Ca(H_2PO_4)_2$ 0-45-0); K-(KCl 0-0-60).

2/ Kg/ha.

Table II. Plant stages used to time application of irrigation water.

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 (24).

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

The irrigation treatments consisted of omitting one of the irrigation stages. Thus including the treatment receiving all of the irrigations, five irrigation treatments were used.

A sprinkler irrigation system was used to apply the water with four sprinklers in an irrigation strip. These sprinklers were connected to a 3-inch diameter main line and were run until 3 inches of water had been applied to the irrigation strip. The amount of water applied was measured by placing two or three small cans in each irrigation strip. The date of each irrigation is given in Table III.

Seeding

The area was seeded June 14, 1968, with certified betzes barley (*Hordeum distichon* L. (3)) at a rate of 100 pounds per acre using a seven-row (one-foot spacing) press wheel seeder. Seeding was done in a N-S direction. About a week after seeding, heavy rain partially filled in each row furrow so that when the plants began to emerge, some of them were buried quite deeply--as much as 2 to 2 1/2 inches. When the plants began to emerge, this meant that the first leaf, rather than the coleoptile, was attempting to emerge through the soil cover. This was one of the factors resulting in a low stand density on row 5 and a spotty stand on some of the other rows. The plants did not emerge well, and many did not emerge at all.

Periodic Plant Samples

Each fertilizer strip consisted of seven rows running for 25 feet

Table III. Dates of Irrigation.

Date	Irrigation	Plant Stage
July 15	A	Tillering
August 6 and 7	B	Boot
September 9	C	Milk
October 5	D	Hard Dough

(7.6m) in the N-S direction. The rows were numbered from the west side of the plot. After the A stage (tillering) irrigation, a stand survey was made to determine how the plot would be divided for periodic sampling and harvest. At this time, row 5 had a very low stand density. Row 5 was completely removed in all plots, and row 6 was used for periodic sampling. The periodic samples consisted of 1 meter of row with approximately 10 to 15 centimers between successive samples. A 5-meter row sample was taken from row 4 to provide a harvest sample which would be compatable with the periodic samples of row 6. Rows 1 and 4 became the borders for rows 2 and 3 which were used for harvest samples and neutron access tubes. The plants were partially air dried in the field and subsequently oven dried in a forced air oven at 60°C. After oven drying, the grain-bearing heads were hand separated. The stems and leaves were ground in a Wiley mill in preparation for chemical analysis. The heads were weighed, counted and threshed; and the grain weighed. The grain was also ground in a Wiley mill.

Periodic Soil Samples

After the plants were removed, a soil sample was taken from the sampling area. Two samples were taken at the 0-6 inch depth and combined; other samples were taken from the 0-1 foot, 1-2 foot and 2-3 foot depths. All of the samples were taken with a King tube. The samples were placed on a 9-inch paper plate in the plot until air dry, were then bagged and subsequently oven dried in a forced air oven at 65°C.

After drying, the samples were sieved through a number 10 sieve (0.078 inch openings).

Nitrogen Analysis

Nitrogen (NH_3) was determined using the Kjeldahl procedure with the boric acid modification as outlined in the American Association of Cereal Chemists method 46-12 (2). Methyl Red and Bromocresol Green indicator was used and the received solution back titrated using a sodium acid sulphate ($NaHSO_4 \cdot H_2O$) solution as suggested by Reeder and Patton (33). The normality of the acid was adjusted so that a 0.4 gram sample of grain or plant material required 10-25 ml. of solution for back titration. This solution was 0.1142 normal. The entire procedure was calibrated by using samples of ammonium oxalate. Grain protein percentage was calculated by multiplying percent N by 6.25 (1,2).

1000-Kernel Weight

A 15-gram subsample of the grain was used to measure kernel weight. The number of kernels in the subsample was determined with an electronic seed counter. If the grain sample was less than 15 grams, then the entire sample was used. The number of seeds in a 15-gram sample varied from 500 to 800. It was not possible to do a sieve analysis on the grain due to the small sample size.

Neutron Readings

Aluminum neutron access tubes were installed in replications 3 and 4 on selected treatments. These tubes were installed between rows 2 and 3 in an area which was judged to have a good stand. Soil samples were taken for moisture content determination at the same time as the installation of the neutron tubes and subsequently air dried in a forced air oven at 110°C. Readings that were taken with a Nuclear Chicago Neutron Meter were used in conjunction with these moisture samples to provide a calibration curve.

Precipitation Data

Precipitation was recorded at the Dillon Airport. The weather station at this airport is part of the Environmental Science Services Network. The station is located approximately 1.5 miles north of the experimental area. The data is given in Table XX.

RESULTS AND DISCUSSION

The size of the error terms in the analysis of variance indicated a large amount of variability between and within replications. This variation was probably caused by the nonuniform stand and was aggravated by the small sample size of one meter of row. The results of the statistical analysis for the various factors measured is given in Table XVII. A perusal of the treatment means will show that differences between treatments exist and are significant at .10 as shown by the LSD values. These differences are sometimes not reflected in a significant F value for the treatment effect. This discussion will present the major trends shown in the data. If a change was consistent between treatment and times of sampling, then this effect was considered as real without resorting to rigid statistical proof of this reality.

Total Plant Weight

The total dry weight of the plants from a meter of row showed the most rapid increase between the tillering and boot stages. The weight continued to increase until the hard dough stage, and then showed a decrease at harvest. The magnitude of these changes was influenced by the irrigation regime. Figure 1 shows the weight of plants as a function of time for the complete irrigation treatment (ABCD). The total weight increased rapidly between the boot and milk stages. The rate of dry matter accumulation slowed down between the milk and hard dough stages and then showed a decrease until harvest time. Subtracting the weight of grain from the total weight showed a similar increase between the boot and milk stages; but then between the milk and hard dough stages, the rate of accumulation

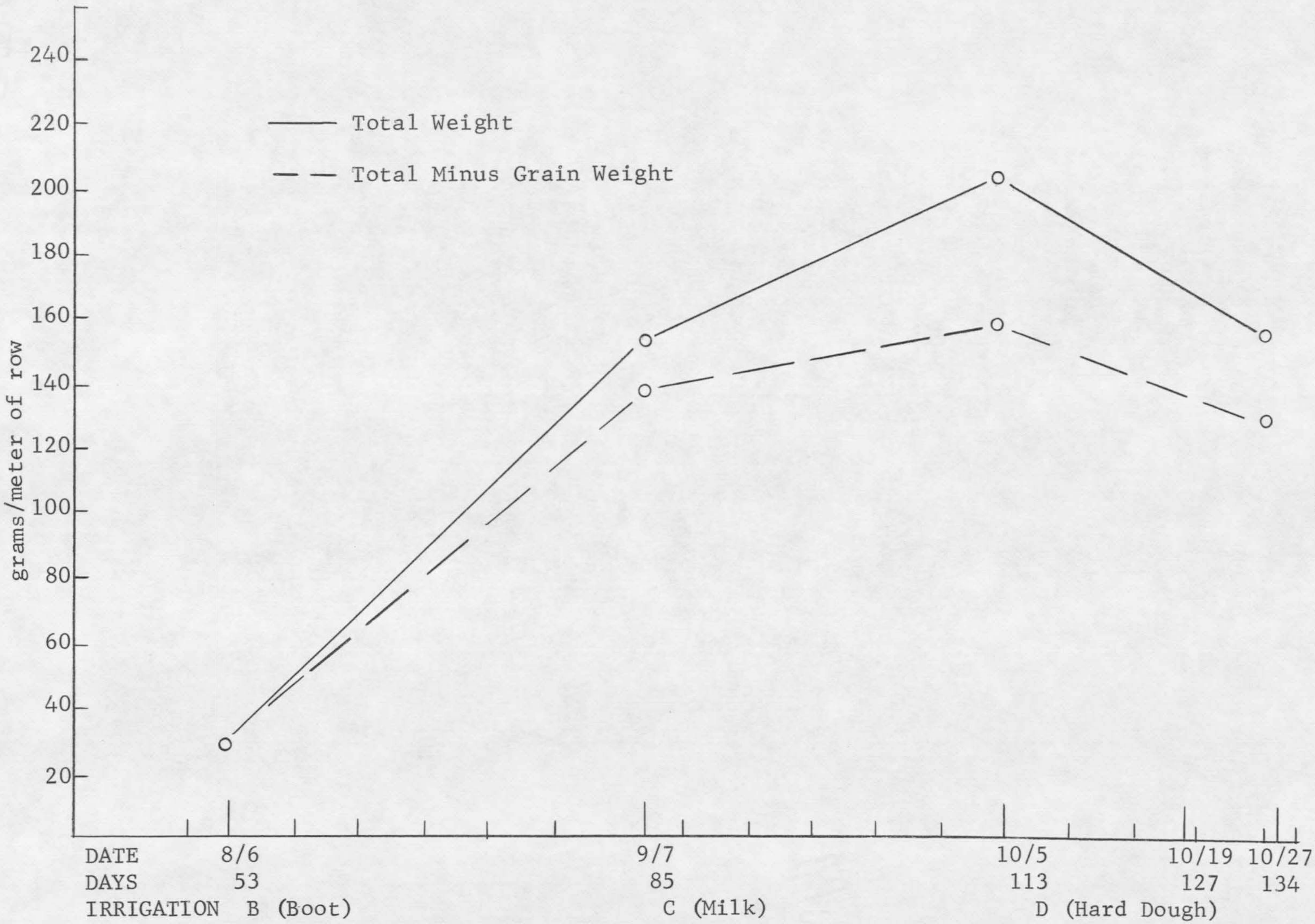

Figure 1. Dry weight of plants. Means for irrigation treatment 1-(ABCD).

of vegetative material decreased markedly. In fact, it became almost negligible. The same pattern is shown with the -A irrigation regime, as given in Figure 2. The rate of vegetative material increase was lower between the boot and milk stages when the A irrigation was omitted, was approximately the same between milk and hard dough stages, and then showed a decline to harvest similar to the complete regime. The weight of vegetative material for the -A irrigation regime was lower throughout the season then the complete, and yet the rate of change was very similar. This seems to indicate that the major effect of omitting the A irrigation was to reduce plant growth during the early stages. This decrease was evident through harvest time, even though the -A irrigation treatment subsequently received the B, C and D irrigations. Application of water at the later stages of growth did not overcome the adverse effects of water stress during the tillering stage.

The effectsof omitting the B irrigation, compared with the complete irrigation treatment, are shown in Figure 3. Omitting this irrigation caused the rate of dry matter accumulation to be markedly less between the milk and hard dough stages in comparison with the complete irrigation treatment. As would be expected, the rate of dry matter accumulation between the boot and milk stages was less when water was omitted at the boot stage. This effect also carried over when water was applied at the later stages. Even the application of water at the milk stage did not cause an increase in the weight of the plants.