The effect of osmotic stress on growth characteristics of two spring wheat varieties
by Glenn Richardson

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:
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An osmotic stress of approximately seven atmospheres reduced both growth and water use for Both varieties Below that obtained when the stress approximated three quarters of an atmosphere. This was true whether the stress was imposed throughout the entire growth period or when stress was not imposed until tillering stage. The two varieties Behaved differently at different stages of growth. The Behavior of the two varieties was not always comparable Between the two crops which were grown under widely different day lengths and temperatures.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Two spring wheat crops were grown on drip cultures involving two varieties and two levels of osmotic stress. Growth characteristics and moisture use were determined for four growth periods for each crop. The first crop was grown in the spring and summer so that day lengths were normal for the crop at the location.

An osmotic stress of approximately seven atmospheres reduced both growth and water use for both varieties below that obtained when the stress approximated three quarters of an atmosphere. This was true whether the stress was imposed throughout the entire growth period or when stress was not imposed until tillering stage. The two varieties behaved differently at different stages of growth. The behavior of the two varieties was not always comparable between the two crops which were grown under widely different day lengths and temperatures.

INTRODUCTION

Production of small grain is a major source of income from dryland areas in the western states. Drought frequently limits the yield of these crops. To obtain a maximum crop yield from a limited moisture supply all stages of crop growth should be adjusted to make their maximum contributions to a final yield on a minimum of water. To obtain this objective, it is necessary to know how widely different varieties of a crop differ in their responses to water tensions at each stage of growth. From such information, it should be possible to adjust fertility level to the water level prevailing at seeding time and expected during the growing season. Information on how widely different genotypes of a crop respond to variable conditions at their different stages of growth should assist the plant breeder to develop crop varieties that will make more efficient growth on a limited moisture supply. Since moisture tension is a variable factor influencing plant growth, emphasis was placed on this variable during the study.

REVIEW OF LITERATURE

Water is a major material in which absorption by plant must exceed the amount retained as a plant constituent. Several hundred pounds of water are used for each pound of dry plant material produced. While the dry matter usually makes up less than 30% of the weight of green plants, the water contained in the plants is only a small proportion of that used for transpiration. Water deficiency is the most common factor that limits plant growth. The importance of water deficiency in plant growth has stimulated numerous research workers to study the relationship between water tensions and plant growth. Yet, satisfactory methods have not been devised whereby a specific soil moisture tension can be maintained.

Osmotic solutions have frequently been used to study plasmolysis of cells or to induce tensions which restrict water entry into plants. Numerous studies with saline soils demonstrate that an important influence of salt is to restrict water movement into the plant. The crops grown on soils with excessive salt concentrations demonstrate many symptoms of drought.

In an attempt to evaluate the role of water transmissions as a factor affecting root growth, Gingrich and Russell (1957) compared soil moisture tensions to osmotic stresses. They found root growth to be significantly greater for those roots grown with osmotic stresses.

Water diffuses to the root surface from the soil solution due to moisture gradients within the small volume of soil between roots. Thus, the mean tension exerted by a mass of soil is lower than the stress to which the roots are subjected. The use of osmotic stresses and plant culture equipment should keep the plant root at a fairly constant osmotic stress in order to study plant responses to stresses associated with drought.

The use of various media in solution for the desired osmotic stress has been shown to exhibit side effects to plant growth which are not clearly understood. Harris (1924) has shown the toxicity to be of a chemical nature. Taking into account the side effects of salts or other media, this is the most feasible method of inducing the desired drought effects. Pearson and Bernstein (1959) have particularly noted rice to show characteristics associated with drought when induced stresses were caused by salts in solution. Hayward and Spurr (1941) found that sulfate salts were more inhibitory to flax growth than chloride salts, and were equal in the ability to produce drought effects. Alfalfa was noted by Brown and Hayward (1956) to exhibit droughty appearances when submitted to salinized conditions. Ayers, et al, (1952) showed the yield of wheat was not reduced nearly as much when the drought conditions occurred at a late growth stage as when they occurred at an early growth stage.

Data for comparing wheat yields under dry land conditions where drought is a major factor in production reflect the yields of varieties but does not reflect desirable or undesirable growth characteristics for the interim growth periods. This study was designed to determine if differences occur between varieties at the various stages of growth.

METHODS

The study involved growing two widely different genotypes of spring wheat in nutrient media at two osmotic stresses. Plant growth was evaluated by periodic sampling and water use was determined by the difference between inflow and outflow on sand cultures.

The plants were grown on a coarse sand base in quart oil cans which had been coated with asphalt paint. The nutrients were provided by using a continuous drip culture technique. A stock bottle was used as the source of the appropriate solution for each pot. The solution was continuously syphoned from each stock bottle to the appropriate pot at a rate that exceeded evaporation and transpiration. A drainage hole was provided in each pot around which a small piece of copper tubing had been soldered and drainage was collected from each pot. The difference between inflow and outflow from the pot between sampling periods provided data on evapotranspiration. The pots were wetted with nutrient solution before the start of the experiment so that soil moisture storage was not a variable.

In addition to the planted pots, there were two pots left in each replication without plants growing in them. One pot had plant nutrient solution at high stress dripped on it at a rate in excess of evaporation and the other pot was similarly treated with low stress solution. The amount added to the stock bottle minus the amount of drainage was used to evaluate evaporation during growth periods. The loss attributed to evaporation was subtracted from the total use to give transpiration.

Hoagland's nutrient solution, as described by Eaton (1936), was used as a base solution. The base solution used for low osmotic stress developed an osmotic pressure equivalent to seventy-five hundredths atmospheres. High stress was obtained by adding calcium chloride and sodium chloride to the base solution. Each salt added three and one-quarter atmospheres of osmotic stress; thus, the solution used had a total stress of seven and one-quarter atmospheres of which seventy-five one hundredths atmosphere was developed from the nutrient solution. The proper amount of each salt used for this osmotic stress was determined from Agricultural Handbook 60, Diagnosis and Improvement of Saline and Alkalie Soils (1954).

The varieties used for this study were Thatcher and a short-strawed selection from a cross of (Norin 10 x Brevor 14) X Centana. Throughout the study this variety will be referred to as Japanese Dwarf. Both varieties are spring wheats.

A randomized block type of design was used for the study. This design allowed the planting of sixteen pots per replication plus two blank pots for measurement of evaporation and two pots for any side study. This randomized block was replicated three times. The individual pot location in each replication was selected by use of randomized tables. The pots were numbered one through twenty for each replication. Numbers one through eight were allocated the Thatcher variety; pots nine through sixteen grew the Japanese Dwarf variety. Pots seventeen and eighteen held Japanese Dwarf and Thatcher wheats respectively for side experiments. The last four pots of each of the two main series were used for high osmotic stresses for the two varieties. Pots nineteen and twenty were not planted and were used to measure evaporation.

Each pot was planted with ten seeds of the desired variety to a depth of one-half inch. After germination and emergence the seedlings were thinned back to five plants per pot. This procedure allowed for the uniform spacing and stand per pot.

Sampling dates were selected upon the basis of readily distinguished major plant growth stages. These stages were at tillering, between heading and blossoming, soft dough stage, and maturity. The pots sampled at each sampling date were picked according to a table of randomized numbers for each variety, treatment, and replication. The entire plant population on the appropriate pot was harvested on each sampling date.

Plant measurements on the sampling dates were taken from the harvested pots. These measurements were dry plant material weight, number of heads, number of tillers, and plant height. Also at each sampling date transpiration was determined as explained above.

The method of analysis for the collected data is the one employed by Snedecor (1946) on complex experiments. The shortest significant range mean separation, as used by Duncan (1955), was used to test differences between three or more means.

The study was conducted in two phases. The first phase was performed in a temperature-controlled greenhouse. The major portion of this phase compared growth characteristics between the varieties upon salinized and unsalinized cultures from germination to maturity. This phase was conducted from May 9, 1960, through August 12, 1960. A side experiment was also conducted during this phase, between varieties, when salinization occurred at the tillering stage. This was done in order to determine if the seven atmosphere stress was sufficient to cause drought effects when the varieties were salinized at a later date.

Since there were only enough pots for one sampling date on this side study (Treatment III), sampling occurred at maturity. However, water use measurements could be determined without plant sampling for the growth periods which occurred after tillering and prior to maturity. The data for plant height, final number of tillers, total heads, grain harvested, kernels per spikelet, and average kernal weight were compared with other treatments at maturity. Plant weight for this treatment is not compared with other treatments as there were no data for the interim periods.

The second phase of the study compared the growth characteristics when salinization occurred at tillering. The randomized block design with three replications was used as in the first phase of the study. This crop was grown between August 20, 1960, and January 8, 1961. From August 20 till late September the greenhouse evaporative cooler was in operation. From late September through January the greenhouse was heated. During the last month of the experiment the day length was lengthened to sixteen hours by the use of 250 watt incandescent lamps.

The sampling techniques and sampling stages were the same as those used in the earlier phase. Data analyses were also the same.

Table I - Treatments

Treatment I	Low osmotic stress from germination through harvest.
Treatment II	High osmotic stress from germination through harvest. 200 millequivalents NaCl and $CaCl_2$ on a combined electrical conductivity of 18 millimhos /cm.
Treatment III	Low osmotic stress prior to tillering time and high stress from tillering to maturity.

RESULTS AND DISCUSSION

This experiment consisted of growing two successive crops in the greenhouse on nutrient solutions as listed under methods and outlined in Table I. Since the first crop was grown under summer conditions with prevailing day lengths, and the second crop under fall and early winter conditions, the two phases of the study are discussed separately. The data for each crop are discussed by growth periods.

Comparative measurements of conductivities of the stock nutrient solutions and the drainage from the pots indicated a slight increase in conductivity as the solution passed through the pot. However, this increase did not reach statistically significant levels. Pearson and Bernstein (1959) found that the conductivity of nutrient solutions increased as water was used by caloro rice for evapotranspiration.

Data were analyzed by periods as the study progressed to guide the course of the experiment. Since the data were already available and give the statistical interpretation by periods it was believed to have sufficient value to remain a part of the thesis. In summarizing the data, statistical treatments were used which aided the interpretation of the data for the several periods.

First Crop

<u>First Growth Period</u> (Germination to tillering)

Data obtained during the first growth period for dry weight of plant material and water use are presented in Tables II and III. Preliminary experiments indicated that wheat emergence was delayed about one day

Table II -Gain in plant weight in gram during the first growth period (germination to tillering).

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	G. Total
Thatcher	1.137	1.502	1.450	4.089	.181	.220	.127	.528	4.617
Japanese Dwarf	1.552	.800	1.198	3.550	.142	.240	.150	.532	4.082
Total	2.689	2.302	2.648	7.639	.323	.460	.277	1.060	8.699

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.0040	.066
Varieties	1	.0238	.393
Treatments	1	3.6069	59.52***
Treatments x varieties	1	.0246	.466
Error	6	.0606	
Total	11	4.0266	

***Significant at 0.5%

Table III - Amounts of water used in milliliters through the first growth period.

	Treatment I Replications				Treatment II Replications				
Varieties	I	II	III	Total	I	II	III	Total	G. Total
Thatcher	440	787	654	1881	43	227	110	380	2261
Japanese Dwarf	453	799	321	1573	224	326	158	708	2281
Total	893	1586	975	3454	267	553	268	1088	4542

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	82,633	10.00**
Varieties	1	33	.0039
Treatments	1	466,496	54.46***
Treatments x varieties	1	33,709	4.079*
Error	6	8,263	
Total	11		

***Significant at 0.5%
**Significant at 2.5%
*Significant at 10 % level

under high stress. Consequently, Treatment II was planted a day earlier than Treatment I.

It was obvious throughout the growth period that the high osmotic stress seriously reduced growth. (See Figure 13) At the tillering stage the plants on Treatment I had produced eight to twenty times more growth than Treatment II. This difference was significant at the 0.5% level. There was no significant difference between replications or varieties and no interactions were found.

The total water use was considerably greater for Treatment I than for Treatment II and this difference was significant at the 0.5% level. The water use per gram of dry matter produced was much higher under Treatment II than for Treatment I (Table XX). The same table shows the water requirement to be similar for the two varieties under Treatment I, but Japanese Dwarf used much more water to produce a unit of dry matter than did Thatcher for Treatment II.

<u>Second Growth Period</u> (Tillering to soft dough)

The data for this period of growth are presented in Tables IV and V. The analysis of variance (Table IV) shows the replications to be different at the 2.5% level of significance, while the interaction, varieties, and treatments differed at the 0.5% level.

Averaging the two varieties, plants on Treatment I produced about ten times more plant material than plants on Treatment II. Thatcher produced about five and one-half times as much plant material on Treatment I as on Treatment II. A similar comparison for Japanese Dwarf produced a ratio of about sixteen to one, with Treatment I producing the most plant

Table IV - Gain in plant weight in grams during second growth period (tillering to heading).

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	G. Total
Thatcher	.862	.297	1.469	2.628	.141	.169	.154	.464	3.092
Japanese Dwarf	1.735	2.057	2.601	6.393	.066	.050	.261	.377	6.770
Total	2.597	2.354	4.070	9.021	.207	.219	.415	.831	9.862

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.40	8.0**
Varieties	1	1.13	22.60***
Treatments	1	5.58	116.00***
Treatments x varieties	1	1.23	24.60***
Error	6	.05	
Total	11		

**Significant at 2.5%
***Significant at 0.5% level

Table V – Amounts of water used in milliliters during second growth period.

	Treatment I Replications				Treatment II Replications				Treatment III Replications				
Varieties	I	II	III	Total	I	II	III	Total	I	II	III	Total	G. Total
Thatcher	411	437	352	1200	45	54	63	162	215	277	373	865	2227
Japanese Dwarf	642	563	677	1882	13	77	64	154	285	218	337	840	2876
Total	1053	1000	1029	3082	58	131	127	316	500	495	710	1705	5103

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	3,142	1.10
Varieties	1	24,305	8.54**
Treatments	2	318,783	111.9***
Treatments x varieties	2	26,705	9.38**
Error	10	2,847	
Total	17		

***Significant at 0.5%
**Significant at 2.5% level

MSR Mean separation showed a significant difference between all treatment means.

material. Japanese Dwarf produced about three times more plant material than Thatcher on Treatment I. On Treatment II, Thatcher produced about one-fourth more plant material than Japanese Dwarf. The plant yield for Treatment III is not available because this treatment was a minor study, as discussed under methods, and yields were obtained only at maturity.

For Treatment I, water use by Thatcher (Table V) was about eight times more than that for Treatment II, and about a fourth more water was used by Thatcher for Treatment I than Treatment III. Japanese Dwarf for Treatment II used about one-twelfth of the water used by Treatment I. When comparing varieties, Japanese Dwarf used about a third more water on Treatment I than II. The two varieties used about the same amount of water on each of Treatments II and III.

The analysis of variance illustrates the treatment differences as discussed above are significant at the 0.5% level, varieties at the 2.5% level, and the interaction at the 2.5% level of significance.

<u>Third Growth Period</u> (Heading to soft dough)

The gain in weight for this period is presented in Table VI. On Treatment I, Thatcher produced about three times more dry matter than Japanese Dwarf. Thatcher produced about one-fifth more plant material than Japanese Dwarf for Treatment II. Thatcher produced eleven times more dry plant matter on Treatment I than on Treatment II. Japanese Dwarf produced five times more plant material for Treatment I than for Treatment II.

The analysis of variance indicates these differences to be significant for treatments at the 0.5% level, for varieties at the 2.5% level,

Table VI - Gain in plant weight in grams during third growth period (heading to soft dough).

	Treatment I Replications				Treatment II Replications				
Varieties	I	II	III	Total	I	II	III	Total	G. Total
Thatcher	4.181	8.408	3.611	16.200	.227	.538	.811	1.576	17.776
Japanese Dwarf	2.189	.681	2.654	5.524	.553	.289	.339	1.181	6.705
Total	6.370	9.089	6.265	21.724	.780	.827	1.150	2.747	24.481

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	3.09	1.87+
Varieties	1	15.22	9.22**
Treatments	1	28.71	17.40***
Treatments x varieties	1	5.07	3.07+
Error	6	1.65	
Total	11		

+Significant at the 25% level
**Significant at the 2.5% level
***Significant at the 0.5% level

Table VII - Amounts of water used in milliliters during third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	1032	1992	1783	4807	70	71	209	350	521	978	744	1691	6848
Japanese Dwarf	808	2145	1759	4712	18	98	205	321	631	383	677	2243	7276
Total	1840	4137	3542	9519	88	169	414	671	1152	1361	1421	3934	14124

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	334,802	3.44*
Treatments	2	3,336,847	34.33***
Varieties	1	10,176	.10
Treatments x varieties	2	21,126	.22
Error	10	97,200	
Total	17		

***Significant at 0.5%
*Significant at 10% level

SSR Mean Separation[1]

Treatment I Treatment III Treatment II

[1]Underline shows nonsignificant difference between treatments

and for both interaction and replications to be significant at the 25% level.

The amounts of water used during this period are given in Table VII. Water use for Treatment III is also shown. Thatcher, on the low stress treatment, used almost fourteen times more water than on Treatment II, and about three times more water than on Treatment III. Japanese Dwarf used about fourteen times more water for Treatment I than for Treatment II and about two times more than on Treatment III. There was no difference between the varieties in water uptake during this period. The analysis of variance shows these differences between treatments and replications to be significant at the 0.5% and 2.5% levels respectively. The SSR mean separation shows the difference for water uptake between Treatments II and III was not significant at the 1% level. Table XX indicates Thatcher was the most efficient user of water for this period, requiring about one-third as much water on Treatment I as Japanese Dwarf to produce a gram of dry matter. For Treatment II about the same amounts of water were required to produce a gram of dry matter for both varieties. Plant height for the period is shown in Table VIII. For Treatment I Thatcher and Japanese Dwarf produced twice the height as for Treatment II. At this time Thatcher was a fifth taller than Japanese Dwarf on both treatments. The analysis of variance showed varieties to be significantly different at the 10% level of significance and the difference in plant height for treatments to be significantly different at the 0.5% level.

Also at this time Thatcher produced about a fifth more tillers than Japanese Dwarf (Table IX) for Treatment I. For Treatment II there was

Table VIII – Plant height at end of third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	G. Total
Thatcher	27	30	27	84	16	14	12	42	126
Japanese Dwarf	23	21	24	68	13	10	11	34	102
Total	50	51	51	152	29	24	23	76	228

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	2.0	.016
Varieties	1	48.0	3.84*
Treatments	1	481.0	38.48***
Treatments x varieties	1	8.0	.64
Error	6	12.5	
Total	11		

*Significant at 10%
***Significant at 0.5% level

Table IX - Number of tillers at end of third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	G. Total
Thatcher	20	28	17	65	6	5	3	14	79
Japanese Dwarf	17	17	18	52	4	4	5	13	65
Total	37	45	35	117	10	9	8	29	144

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	8	.92
Varieties	1	16	1.84*
Treatments	1	675	77.59***
Treatments x Varieties	1	15	1.72
Error	6	8.7	
Total	11		

*Significant at 10%
***Significant at 0.5% level

no difference between varieties. On Treatment II both varieties produced only about a fourth as many tillers as on Treatment I. The analysis of variance shows varieties and treatments to differ at the 10% and 0.5% levels of significance respectively.

Table X shows there is very little difference between the number of heads produced at this time between varieties at either salt level. Treatment II at this stage of growth reduced the number of heads produced to about a third as compared to Treatment I, and the difference is significant at the 0.5% level.

Fourth Growth Period (Soft dough to maturity)

Differences between the two varieties in dry matter production did not reach significant levels on any of the treatments in this growth period (Table XI). The difference between treatments shows Thatcher produced about twenty-five times more plant material for Treatment I than for Treatment II. Treatment III produced intermediate yields although the data are not presented. Japanese Dwarf produced forty-six times more plant material on Treatment I than on Treatment II, and again Treatment III yields were intermediate.

The analysis of variance indicates the treatments were significantly different at the 0.5% level. An SSR mean separation indicates these differences to be significant between each treatment at the 1% level.

Water uptake could not be measured during this period for Treatment II. A salty crust appeared on the cropped pots, preventing normal evaporation. Table XII includes only data gathered for Treatments I and

Table X - Number of heads at end of third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	G. Total
Thatcher	9	17	11	37	4	3	3	10	47
Japanese Dwarf	7	10	13	30	4	4	4	12	42
Total	16	27	24	67	8	7	7	22	89

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	6.5	.97
Varieties	1	2.0	.30
Treatments	1	169.0	25.22***
Treatments x varieties	1	7.0	1.44
Error	6	6.7	
Total	11		

***Significant at 0.5% level

Table XI - Gain in plant weight in grams during fourth growth period (soft dough to maturity).

Variety	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	G. Total
Thatcher	10.120	7.893	9.678	27.691	-.080	.604	.626	1.150	28.841
Japanese Dwarf	5.324	11.562	11.547	28.433	.071	.097	.442	.610	29.043
Total	15.444	19.445	21.225	56.124	-.009	.701	1.068	1.760	57.884

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	3.079	1.02
Varieties	1	.003	.001
Treatments	1	246.287	81.33***
Treatments x varieties	1	3.867	1.28
Error	6	3.028	
Total	11		

***Significant at 0.5% level

Table XII - Amounts of water used in milliliters during the fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	2623	2291	2860	7777	202	228	228	658	8435
Japanese Dwarf	1223	863	1608	3694	770	366	170	1306	5000
Total	3849	3154	4468	11471	972	594	398	1964	13435

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	100,137	1.40
Varieties	1	983,269	13.73**
Treatments	1	7,531,921	113.19***
Treatments x varieties	1	1,865,169	26.05***
Error	6	71,602	
Total	11		

**Significant at 2.5%
***Significant at 0.5% level

III. During this period Thatcher under Treatment I required almost twice as much water as Japanese Dwarf, but on Treatment III it used only half as much as the dwarf variety. Thatcher under Treatment I needed twelve times the amount of water it used for Treatment III, while Japanese Dwarf needed about three times more water for Treatment I than for Treatment III. Table XX indicates Thatcher on Treatment I needed less water than Japanese Dwarf for a unit of dry matter production.

Treatments II and III reduced plant height of Thatcher for this period by two fifths and a sixth respectively over Treatment I. The Japanese Dwarf height was reduced by one half on Treatment II below those of Treatments I and III. The statistical differences between treatments were significant at the 10% level. There was no statistical difference between varieties. The SSR mean separation shows this difference to occur between all treatments. This data is shown in Table XIII.

Table XIV presents the total number of tillers and analysis of variance for tillers at harvest. Thatcher produced the most tillers on all treatments. For Treatment I, Thatcher produced about six times more tillers than Treatment II and about three times more than Treatment III. Japanese Dwarf produced about four-fifths as many tillers as Thatcher for Treatment I, a slight reduction on Treatment II, and about half as many tillers on Treatment III. The dwarf variety produced a sixth as many tillers on Treatment II and a third as many on Treatment III as on Treatment I. The analysis of variance indicates that treatment and variety differences on total tillers were significant at the 0.5% level.

Table XIII - Plant height at harvest.

	Treatment I Replications				Treatment II Replications				Treatment III Replications				
Varieties	I	II	III	Total	I	II	III	Total	I	II	III	Total	G. Total
Thatcher	27	26.5	24	77.5	15	15	15.5	45.5	23	22	23	68	191.0
Japanese Dwarf	20.5	23.0	21	64.5	12	10	11.0	33.0	21	21	20	62	159.5
Total	47.5	49.5	45	142.0	27	25	26.5	78.5	44	43	43	130	350.5

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.5	.0085
Varieties	1	54.5	.93
Treatments	2	189.5	3.24**
Treatments x varieties	2	.9	.0154
Error	10	58.5	
Total	17		

**Significant at 10% level

SSR Mean Separation[1]

<u>Treatment I Treatment III</u> Treatment II

[1]underline shows nonsignificance between treatments at 1% level

Table XIV - Total number of tillers at harvest.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	29	29	37	95	5	5	5	15	11	15	13	39	149
Japanese Dwarf	20	27	29	76	4	3	6	13	7	7	7	21	110
Total	49	56	66	171	9	8	11	28	18	22	20	60	259

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	16.5	2.62+
Varieties	1	84.0	13.33***
Treatments	2	938.5	148.97***
Treatments x varieties	2	15.5	2.46+
Error	10	6.3	
Total	17		

+Significant at 25%
***Significant at 0.5% level

SSR Mean Separation shows significant differences between all treatments

Replications and the interactions were significant at the 25% level. The SSR mean separation shows that the effect of treatments on tiller production was significant at the 1% level.

Table XV illustrates that Thatcher produced a fifth more heads with grain on Treatment I and a third more heads on Treatment III than Japanese Dwarf. On Treatment II the number of heads produced was about the same for both varieties. On Treatment I, Thatcher produced about six times more heads than on Treatment II, and about three times more heads than on Treatment III. The analysis of variance indicates there was a differ-

tile heads between both varieties and treatments

ificance. Replications differed at the 2.5%

produced during this phase by both varieties

l Bernstien (1959) attribute the sterile heads

erature and humidity. A larger number of the

ced from tillers making a late appearance in the

e fewer of these sterile heads produced for

an for Treatment I. The analysis of variance for

this data demonstrates the difference for varieties to be significant at the 25% level, while the interaction was significant at the 10% level. The influence of treatments on sterile heads was significantly different at the 0.5% level. The SSR mean separation indicates Treatments II and III were not significantly different; however, Treatment I differed from Treatments II and III at the 1% level of significance.

Both varieties produced about the same weight of grain for all

Table XV - Number of heads producing grain.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	26	26	31	83	4	5	5	14	9	12	13	34	131
Japanese Dwarf	15	21	23	59	4	3	6	13	7	7	7	21	93
Total	41	47	54	142	8	8	11	27	16	19	20	55	224

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	17.5	5.46**
Varieties	1	82.0	25.63***
Treatments	2	600.0	187.50***
Treatments x varieties	2	71.5	22.34***
Error	10	3.2	
Total	17		

**Significant at 2.5%
***Significant at 0.5% level

SSR Mean Separation shows significance at the 1% level between all treatments.

Table XVI - Number of heads without grain.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	8	4	6	18	0	0	0	0	1	1	1	3	21
Japanese Dwarf	1	5	2	8	1	0	1	2	1	0	1	2	12
Total	9	9	8	26	1	0	1	2	2	1	2	5	33

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.17	.08
Varieties	1	4.50	2.23+
Treatments	2	23.50	10.16***
Treatments x varieties	2	10.75	5.32**
Error	10	2.02	
Total	17		

+Significant at 25%
**Significant at 10%
***Significant at 0.5% level

SSR Mean separation, 1% level[1]

Treatment I   Treatment II   Treatment III

[1]underline shows nonsignificance between treatments

treatments (Table XVII), but Treatments II and III seriously reduced yields. The analysis of variance illustrates the difference between treatments for grain yield to be significant at the 0.5% level and the interaction to be significant at the 25% level. The SSR mean separation indicates there was a significant difference between all treatments at the 1% level.

The average number of kernels per spikelet is presented in Table XVIII. Thatcher produced fewer kernels per spikelet on Treatments II and III than on Treatment I, while only Treatment II influenced the kernels per spikelet on Japanese Dwarf. The dwarf variety produced slightly more kernles per spikelet than Thatcher for Treatment I and a fifth more kernels than Thatcher for Treatments II and III. The analysis of variance illustrates the varieties were significantly different in kernels produced per spikelet at the 2.5% level and treatments were significantly different at the 0.5% level. The SSR mean separation indicates there was no significant difference between Treatments I and III; however, Treatments I and III were significantly different from Treatment II at the 1% level.

Table XIX presents the data for the average kernel weight. There were no differences between varieties for kernel weight. Treatment II reduced kernel weight by about a third over Treatment I, whereas the reduction associated with Treatment III was considerably less. The analysis of variance indicates that the influence of treatments on kernel weight were significantly different at the 2.5% level but other comparisons were not significantly different. The SSR mean separation

Table XVII - Weight in grams of grain at harvest.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	4.75	5.61	3.64	14.00	.14	.27	.15	.56	2.15	2.25	1.46	5.86	20.42
Japanese Dwarf	3.16	4.64	5.65	13.45	.18	.19	.34	.71	1.88	.76	1.42	4.06	18.22
Total	7.91	10.25	9.29	27.45	.32	.46	.49	1.27	4.03	3.01	2.88	9.92	31.64

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.09	.15
Varieties	1	.26	.44
Treatments	2	28.65	48.56***
Treatments x varieties	2	1.17	1.98+
Error	10	.59	
Total	17		

+Significant at 25%
***Significant at 0.5% level

SRS Mean Separation shows significant difference at 1% level between all treatments.

Table XVIII - Number of kernels per spikelet.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	1.8	1.9	1.5	5.2	1.1	1.4	1.2	3.7	1.5	1.7	1.6	4.8	13.7
Japanese Dwarf	1.9	1.9	1.8	5.6	1.7	1.6	1.4	4.7	2.1	1.7	1.9	5.7	16.0
Total	3.7	3.8	3.3	10.8	2.8	3.0	2.6	8.4	3.6	3.4	3.5	10.5	29.7

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.035	1.59
Varieties	1	.150	6.82**
Treatments	2	.290	13.18***
Treatments x varieties	2	.010	.45
Error	10	.022	
Total	17		

**Significant at 2.5%
***Significant at 0.5% level

SSR Mean Separation[1]

Treatment I   Treatment III   Treatment II

[1] underline shows nonsignificance between treatments at 1% level

Table XIX - Average kernel weight.

Varieties	Treatment I Replications I	II	III	Total	Treatment II Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	.014	.016	.013	.043	.012	.010	.006	.025	.011	.013	.014	.038	.109
Japanese Dwarf	.016	.015	.015	.046	.007	.010	.012	.029	.013	.008	.013	.034	.109
Total	.030	.031	.028	.089	.019	.020	.018	.057	.024	.021	.027	.027	.218

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.000000025	.0044
Varieties	1	0.0	0.0
Treatments	2	.000042725	7.48**
Treatments x varieties	2	.000002665	4.00*
Error	10	.000005709	
Total	17		

**Significant at 2.5% level
*Significant at 10% level

SSR Mean Separation signficantly different at the 1% level for all treatments

Table XX - Summary of water use per gram of dry matter produced during the different growth periods.

Growth period	Varieties	Treatments I	II	III
I				
	Thatcher	460	720	
	Japanese Dwarf	443	1313	
II				
	Thatcher	457	349	
	Japanese Dwarf	294	408	
III				
	Thatcher	295	222	
	Japanese Dwarf	833	274	
IV				
	Thatcher	281		380
	Japanese Dwarf	656		110

Mean water use for growth period

illustrates there was a difference between treatment means of kernel weight at the 1% level.

Summary Figures and Tables

Figure 1 demonstrates the plant growth pattern for the two varieties. During the plant life cycle both varieties produced similar growth. Thatcher produced less growth from tillering to heading than Japanese Dwarf for Treatment I, but more growth from heading to soft dough. This was associated with tiller development and contributed to the greater plant weight produced by Thatcher during the later stages of growth. Thatcher produced more plant material after tillering than Japanese Dwarf. Under Treatment II Japanese Dwarf produced more plant material after heading than Thatcher.

Figure 2 graphically presents water use by the two varieties throughout the growth of the crop. Thatcher under Treatment I used more water than Japanese Dwarf through the life cycle, except prior to and shortly after the soft dough stage. Thatcher took up more water than Japanese Dwarf for Treatment III but on Treatment II Japanese Dwarf required the larger amount of water.

Figure 3 graphically presents water use and plant growth for Japanese Dwarf throughout the growth cycle. The water use pattern is closely related to plant growth for the first two growth periods. From tillering to heading, water use is comparatively high in relation to growth, while from heading to maturity it is relatively low. The relationship between water use and plant growth for Thatcher (Figure 4) was fairly consistent in the growth periods.

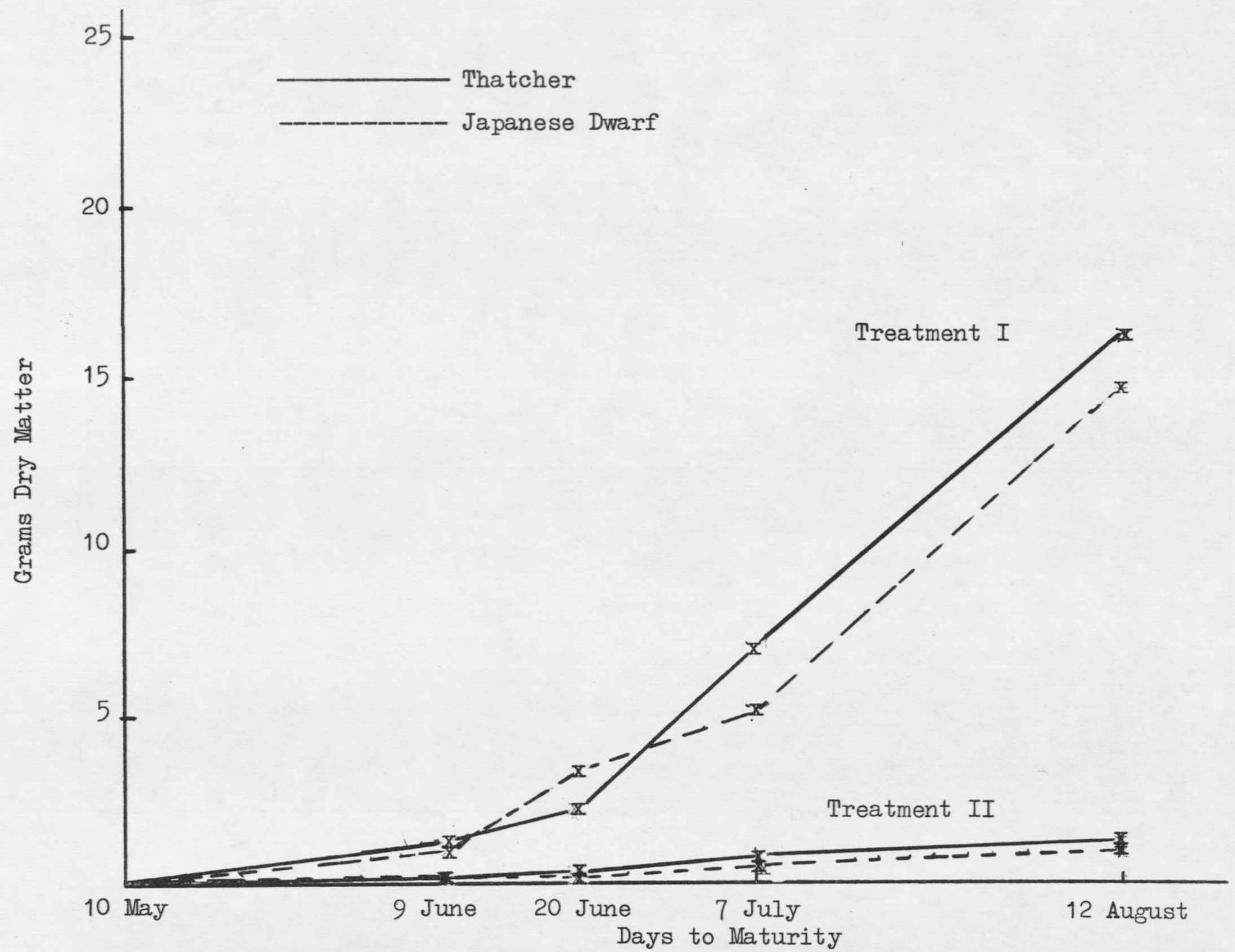


Figure 1. Summary of plant growth in relation to time.

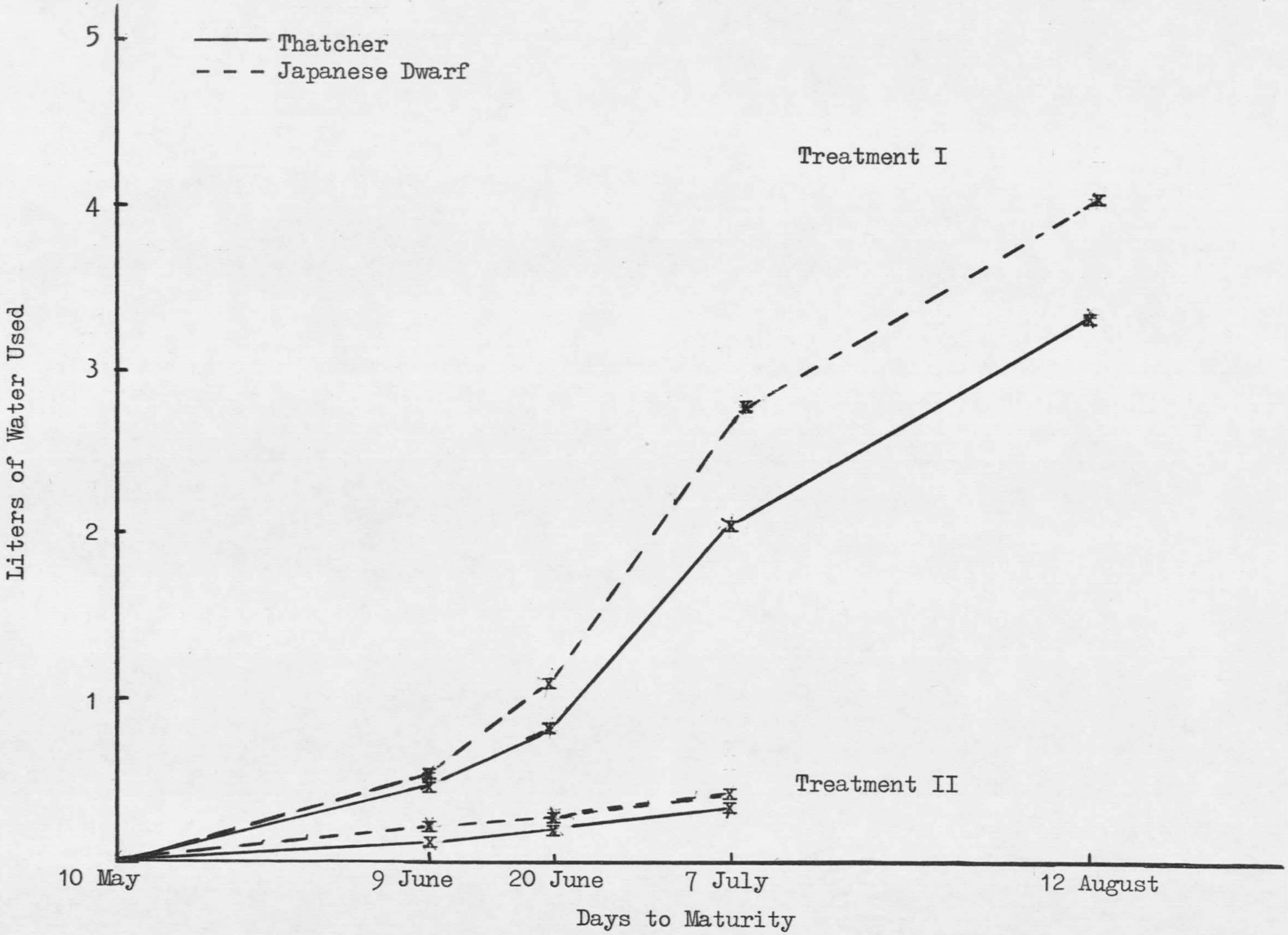


Figure 2. Summary of water use in relation to time

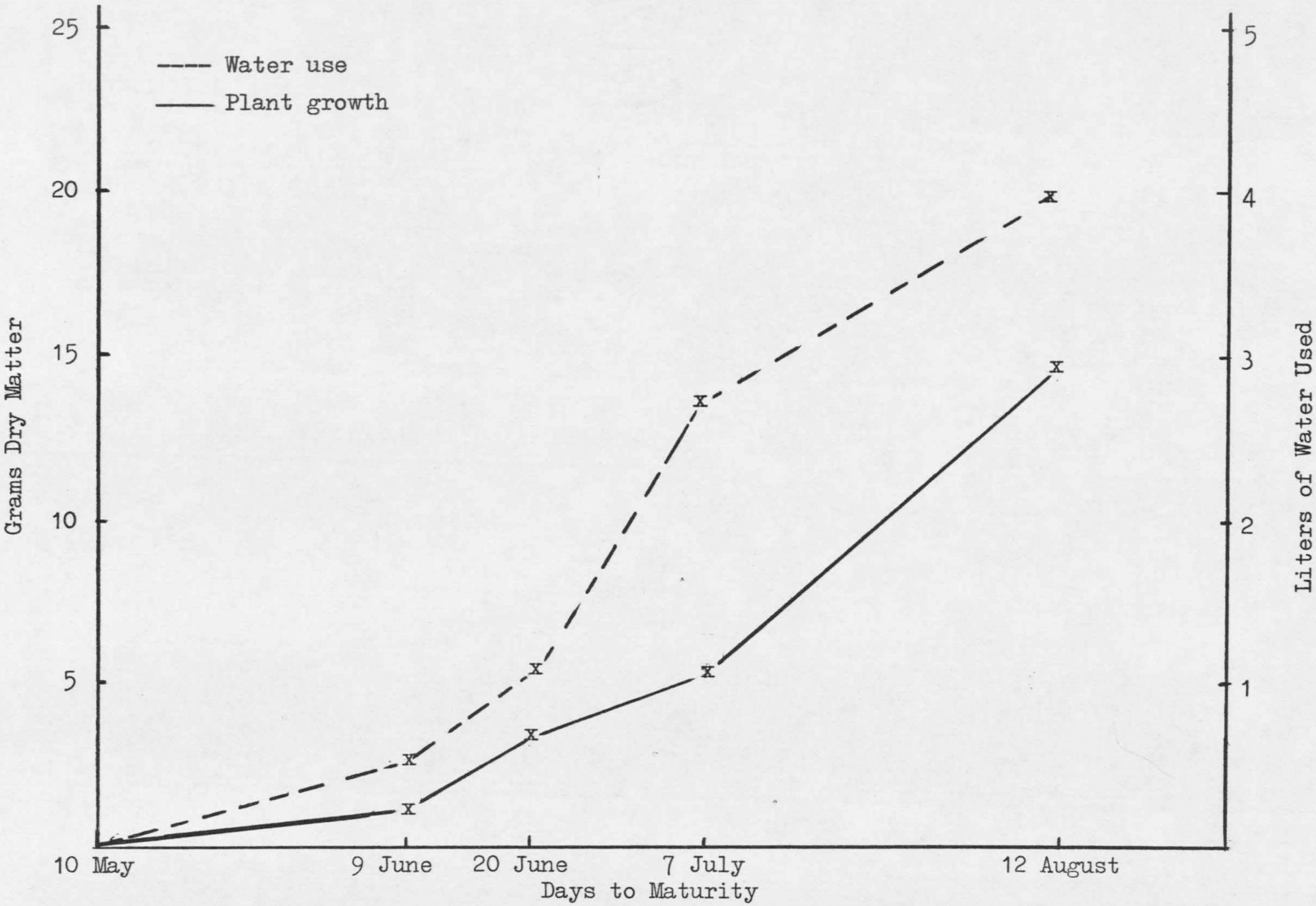


Figure 3. Comparison of water use and plant growth for growth periods, Japanese Dwarf. Treatment I.

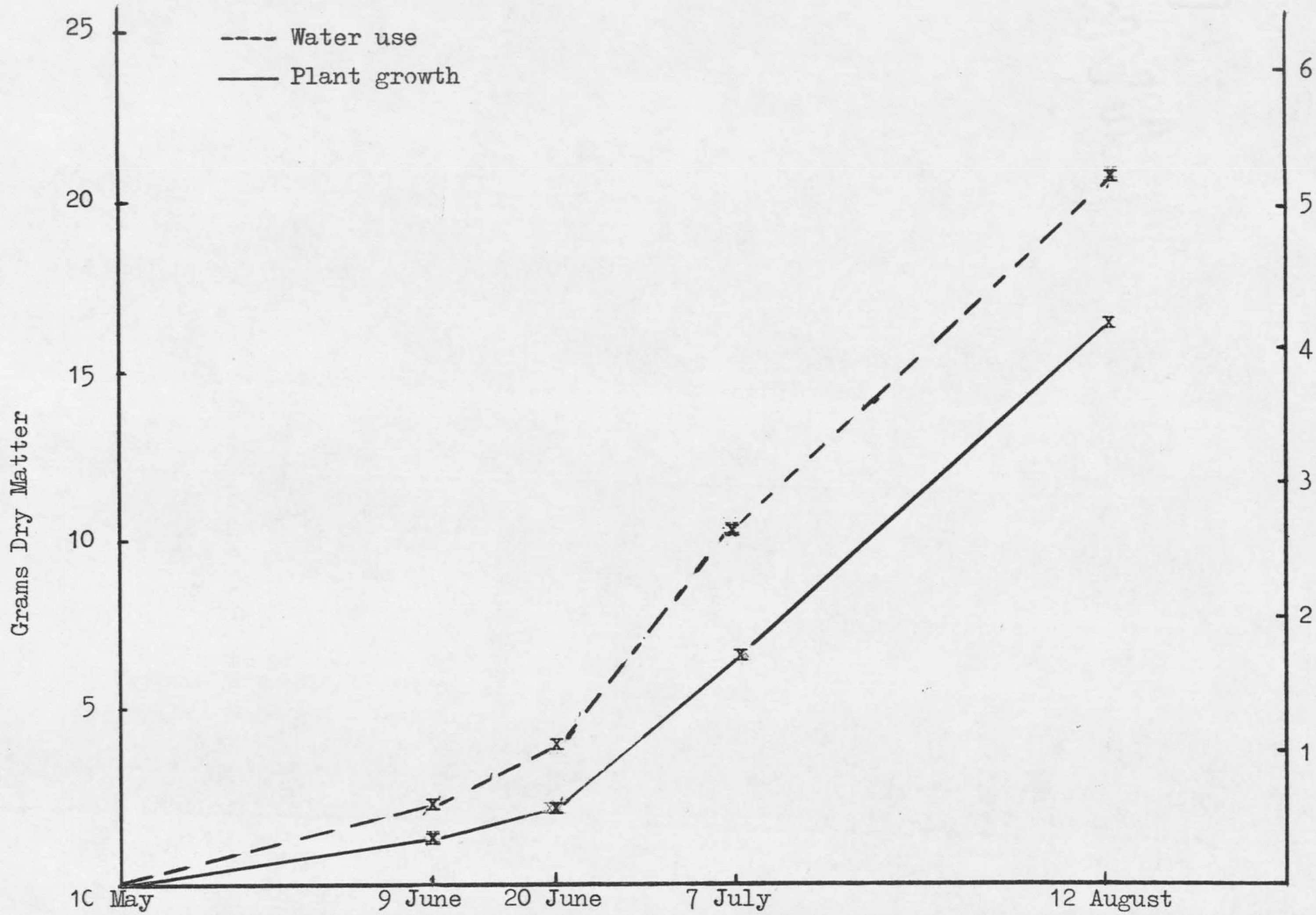


Figure 4. Comparison of water use and plant growth for the growth periods, Treatment I, Thatcher

Figures 5 and 6 show a close relationship on Treatment 2 between plant growth and water use up to soft dough stage. From soft dough stage to heading the data secured for evapotranspiration did not exceed evaporation.

Table XXI summarizes the growth data for the various growth periods and provides statistical interpretation. It illustrates that during the crop cycle both varieties produced equal amounts of plant materials for each treatment. In general growth during the later periods exceeded that during the early periods, and this accounts for the significant difference between periods. The high stress treatment reduced yield to approximately one-tenth of that obtained on the low stress treatment, and this difference is significant at the 0.5% level. There was no interaction between treatments and varieties, but the varieties grew differently in the different periods with significance at the 2.5% level. The treatments induced different growth in the different periods with significance at the 0.5% level. The Treatment x Variety x period interaction was significant at the 2.5% level.

Water used for the different periods is similarly summarized in Table XXII. Water use for the fourth growth period is not given because, as previously discussed, the measured values did not exceed evaporation. The low level of significance obtained between replications for water use was probably associated with proximity to the evaporative cooler used in the greenhouse. Periods and treatments influenced water use at the 0.5% level of significance and the Period x Treatment interaction was also significant at the same level.

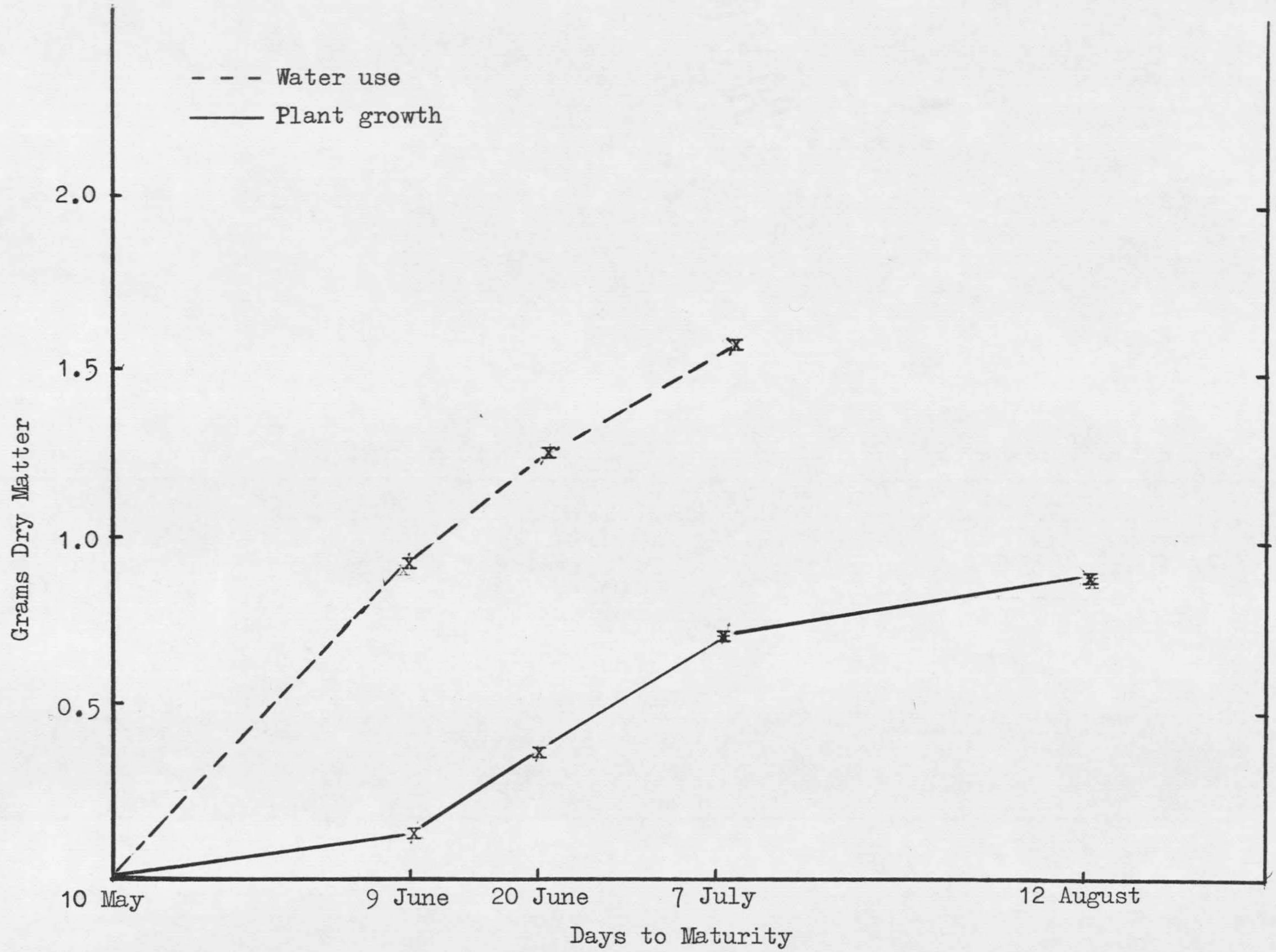


Figure 5. Plant growth and water use for the growth periods, Treatment II, Thatcher.

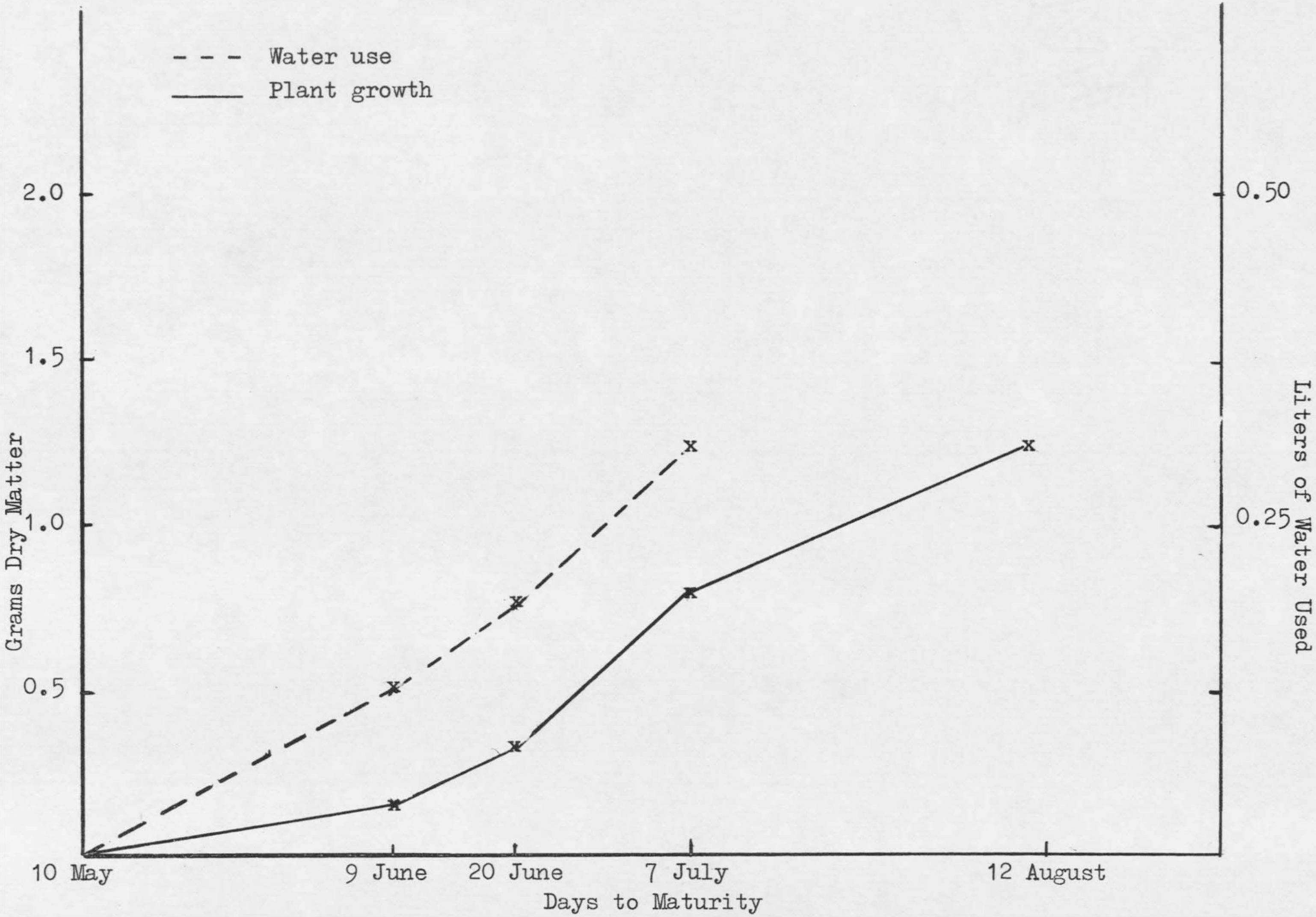


Figure 6. Plant growth and water use for the growth periods, Treatment II, Japanese Dwarf.

Table XXI - Plant growth interactions for treatments, varieties, and periods.

Stress and variety

Periods	1	2	3	4	Avg.
	Grams	Grams	Grams	Grams	Grams
low					
Thatcher	4.1	2.6	16.2	27.7	12.6
Japanese Dwarf	3.6	6.4	5.5	28.4	11.0
Average	3.8	4.5	10.8	28.1	11.8
high					
Thatcher	.5	.8	1.6	1.1	1.0
Japanese Dwarf	.5	.5	1.2	.6	.7
Average	.5	.7	1.3	.9	.9

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	1.427	1.23
Varieties	1	1.310	1.13
Periods	3	43.425	37.56***
Treatments	1	160.136	138.53***
Treatments x varieties	1	.635	.60
Varieties x periods	3	4.431	3.83**
Treatments x periods	3	41.255	35.69***
Treatments x varieties x periods	3	5.145	4.45**
Error	30	1.156	
Total	47		

***Significant at 0.5%
**Significant at 2.5% level

Table XXII - Water use interactions for three growth periods.

Stress and Variety

Periods:	1	2	3	Avg.
	Liters	Liters	Liters	Liters
low				
Thatcher	1.8	1.2	4.8	2.6
Japanese Dwarf	1.6	1.9	4.7	2.7
Average	1.7	1.6	4.8	2.7
high				
Thatcher	.3	.2	.4	.5
Japanese Dwarf	.7	.2	.3	.6
Average	.5	.2	.4	.6

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	243,657	4.37*
Varieties	1	9,025	.16
Periods	2	1,101,944	19.74***
Treatments	1	5,428,900	97.28***
Treatments x varieties	1	3,891	.07
Treatments x periods	2	1,099,547	19.70***
Varieties x periods	2	15,128	.27
Treatments x varieties x periods	2	34,868	.62
Error	22	55,087	
Total	35		

***Significant at 0.5%
*Significant at 10% level

Second Crop

The second phase of the experiment was conducted in the fall and early winter of 1961-62 and under different temperature, humidity, and light regimes than the previous portion of the study. The combined effects of these unmeasured variables tend to cause some growth stages to be prolonged for both varieties. This phase of the study involved Treatments I and III. The data is again discussed according to growth periods.

First Growth Period (Germination to tillering)

During this period there was no treatment variable since osmotic stress was not applied until the tillering stage. Table XXIII shows there was no significant difference between plant weights for varieties or replications during this period.

There was no difference between varieties for water use at this time. The analysis of variance in Table XXIV shows there is no significant difference between varieties, but replications were significantly different at the 25% level. According to Table XLVI, Japanese Dwarf made more efficient use of water than Thatcher for the period.

Second Growth Period (Tillering to heading)

Salinization for the desired osmotic stress was induced at the beginning of this growth period. Table XXVI exhibits the data collected for plant weight gain for the period. Thatcher produced about six times more plant material for Treatment I than for Treatment III, whereas the corresponding difference for Japanese Dwarf was only slight. Thatcher produced three times more plant material than Japanese Dwarf

Table XXIII. - Gain in plant weight in grams during the first growth period (germination to tillering).

Varieties	Treatment I Replications I	II	III	Total
Thatcher	.352	.382	.459	1.193
Japanese Dwarf	.420	.309	.432	1.152
Total	.772	.691	.882	2.345

Analysis of variance

Variation due to	d.f.	Mean Square	Cal.F
Replications	2	.0045	.70
Varieties	1	.008	1.30
Error	2	.0058	
Total	5		

No significant difference at any level

Table XXIV -- Water used in milliliters for the first growth period.

Varieties	Replications I	II	III	Total
Thatcher	205	219	295	719
Japanese Dwarf	210	185	238	633
Total	415	404	533	1352

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	2257	5.45*
Varieties	1	1232	2.48
Error	2	497	
Total	5		

*Significant difference at 25% level

Table XXV - Plant height in inches at end of first growth period.

Varieties	Treatment I Replications I	II	III	Total
Thatcher	13	14	13	40
Japanese Dwarf	13	13	13	39
Total	26	27	26	79

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.25	2.50
Varieties	1	.30	3.00+
Error	2	.10	
Total	5		

+Significant at 25% level

Table XXVI - Gain in plant weight in grams during the second growth period (tillering to heading)

	Treatment I				Treatment III				
	Replications				Replications				
Varieties	I	II	III	Total	I	II	III	Total	G. Total
Thatcher	8.54	9.57	11.01	29.12	2.03	2.04	1.23	5.30	34.42
Japanese Dwarf	2.90	3.58	3.29	9.77	2.79	2.90	1.54	7.23	17.00
Total	11.44	13.15	14.30	38.89	4.82	4.94	2.77	12.53	51.42

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.42	.56
Varieties	1	24.29	32.39***
Treatments	1	57.91	77.21***
Treatments x varieties	1	38.71	51.61***
Error	6	.75	
	11		

***Significant at 0.5% level

for Treatment I. Under Treatment III Japanese Dwarf produced slightly more plant material than Thatcher.

Figure 7 indicates Japanese Dwarf reached this stage of growth twenty-four days earlier than Thatcher, and the difference in yield may be at least partially associated with the length of the growth period. The analysis of variance demonstrates these differences for treatments, varieties, and the interaction to be significant at the 0.5% level.

Water use for this period is presented by Table XXVII. Thatcher wheat required about four times more water for Treatment I than Treatment III and Japanese Dwarf needed about a tenth less water for Treatment III than for Treatment I. Thatcher used four times more water than Japanese Dwarf under Treatment I, but this difference is associated with a large difference in growth. Table XLVI indicates Japanese Dwarf to be the most efficient user of water for both treatments. Thatcher required almost twice as much water to produced a gram of dry matter as Japanese Dwarf on Treatment III. The analysis of variance indicates water use for this period to be significantly different between varieties and treatments at the 0.5% level and the interaction was significant at the same level.

Table XXVIII presents data for plant height at the end of this period. Thatcher is significantly taller at the 10% level than Japanese Dwarf.

Thatcher produced about three times more tillers at the end of this period on Treatment I than Japanese Dwarf (Table XXIX) and there was no difference between varieties for tiller production for Treatment

Table XXVII - Water use in milliliters for the second growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	5177	6722	6252	18,151	1649	1650	1612	4911	23,062
Japanese Dwarf	1697	1289	1604	4,590	1502	942	1255	3699	8,289
Total	6874	8011	7856	22,741	3151	2592	2867	8610	31,351

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F.
Replications	2	34,821	.14
Varieties	1	18,186,794	81.19***
Treatments	1	6,640,430	27.69***
Treatments x varieties	1	22,703,130	94.68***
Error	6	239,798	
Total	11		

***Significant at 0.5% level

Table XXVIII - Plant height in inches at end of second growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	26	26	27	79	18	18	20	56	135
Japanese Dwarf	24	19	24	67	20	24	16	60	127
Total	50	45	51	146	38	42	36	116	262

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	0	
Varieties	1	6	.69
Treatments	1	75	8.62**
Treatments x varieties	1	21	2.41^{+}
Error	6	8.7	
Total	11		

**Significant at 10%
$^{+}$Significant at 25% level

Table XXIX – Number of tillers at end of second growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	36	32	26	94	7	7	7	21	115
Japanese Dwarf	10	7	12	29	5	10	5	20	49
Total	46	39	38	123	12	17	12	41	164

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	4.5	.30
Varieties	1	36.3	30.76***
Treatments	1	361.0	30.59***
Treatments x varieties	1	541.0	45.85***
Error	6	11.8	
Total	11		

***Significant at the 0.5% level

III. Thatcher produced about four times more tillers on Treatment I than on Treatment III, but for Treatment III Japanese Dwarf reduced tiller production to only one-third below Treatment I. The analysis of variance shows the varieties, treatments, and the interaction to be significantly different at the 0.5% level of significance.

The number of heads produced for this period is presented by Table XXX. The analysis of variance indicates there is no difference between varieties, replications, treatments, and the interaction at any level of significance. Comparisons of number of heads at this stage may not be logical since heading was not complete.

Third Growth Period (Heading to soft dough)

The gain of plant material for this period is exhibited by Table XXXI. Thatcher produced twenty-three times more plant material for Treatment I than Treatment III, while Japanese Dwarf produced only about four times more plant material on Treatment I. Figure 7 illustrates Thatcher needed forty-three days to complete this stage as compared to twenty-four days for Japanese Dwarf on Treatment I. Day length probably influenced the length of the plant growth period at this time for Thatcher more than for Japanese Dwarf. Figure 7 shows this growth period started at a later date than the similar period for Japanese Dwarf. However, for Treatment I, Thatcher produced approximately six times the amount of plant material Japanese Dwarf produced.

Figure 7 also illustrates that Japanese Dwarf on Treatment III required twenty-four days for this growth period, while Thatcher required only fifteen days. Both varieties produced about the same amount of plant

Table XXX - Number of heads at end of second growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	4	41	0	45	5	5	5	15	60
Japanese Dwarf	5	5	5	15	5	5	5	15	30
Total	9	46	5	60	10	10	10	30	70

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	113	.85
Varieties	1	75	.56
Treatments	1	75	.56
Treatments x varieties	1	75	.56
Error	6	133	
Total	11		

Table XXXI – Gain in plant weight in grams during the third growth period (heading to soft dough).

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	20.84	32.15	18.33	71.32	.12	1.00	2.01	3.13	74.45
Japanese Dwarf	6.58	3.91	2.99	13.48	1.24	1.19	.59	3.02	16.50
Total	27.42	36.06	21.32	84.80	1.36	2.19	2.60	6.15	90.95

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	13.28	.09
Varieties	1	279.84	18.50**
Treatments	1	515.48	34.07***
Treatments x varieties	1	277.84	10.84**
Error	6	15.13	
Total	11		

**Significant at 2.5%
***Significant at 0.5% level

material on Treatment III. The analysis of variance indicates the interaction and varieties to differ at the 2.5% level of significance. Treatments varied at the 0.5% level of significance.

Water use for this period is presented in Table XXXII. The varietal difference in water use was different at the 10% level of significance. Thatcher on Treatment I required thirty-five times more water than on Treatment III.

Figure 8 demonstrates the comparable length of time for water use. Treatment III reduced the growth period by about a third for Thatcher as compared to Treatment I. Japanese Dwarf on Treatment I required eight times more water than on Treatment III. Figure 8 shows the growth period to be the same for these treatments. Thatcher required about five times more water for Treatment I than Japanese Dwarf for the similar treatment. Thatcher and Japanese Dwarf required about the same amounts of water on Treatment III.

The plant height difference is presented in Table XXXIII. The analysis of variance illustrates varieties and treatments to differ significantly at the 0.5% level and the interaction is significant at the 10% level. On Treatment I, Thatcher has slightly more height than on Treatment III. Japanese Dwarf on Treatment I has about a third more height than on Treatment III. Japanese Dwarf and Thatcher on Treatment I have about the same height, but on Treatment III, Japanese Dwarf is slightly shorter than on Treatment I.

Table XXXIV illustrates the number of tillers at the end of the third growth period. Thatcher has produced about seven times more

Table XXXII - Water use in milliliters for the third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	15,906	14,788	14,138	44,832	316	522	433	1271	46,103
Japanese Dwarf	2,285	2,189	3,748	8,222	337	540	164	1041	9,263
Total	18,191	16,977	17,886	53,054	653	1062	597	2312	55,366

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	40,635	.003
Varieties	1	113,098,800	6.70*
Treatments	1	214,562,547	12.72**
Treatments x varieties	1	12,182,033	.72
Error	6	16,874,504	
Total	11		

**Significant at 2.5%
*Significant at 10% level

Table XXXIII - Plant height in inches at end of third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	25	27	27	79	24	23	25	72	151
Japanese Dwarf	24	26	25	75	19	19	16	54	129
Total	49	53	52	154	43	42	41	126	280

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.5	.25
Varieties	1	41.0	20.50***
Treatments	1	66.0	33.00***
Treatments x varieties	1	15.0	7.50*
Error	6	2.0	
Total	11		

***Significant at 0.5%
*Significant at 10% level

Table XXXIV - Number of tillers at end of third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	57	85	54	196	9	10	9	28	224
Japanese Dwarf	17	19	10	46	5	7	5	17	63
Total	74	104	64	242	14	17	14	45	287

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	127	2.00+
Varieties	1	2160	34.28***
Treatments	1	3234	51.33***
Treatments x varieties	1	1610	25.56***
Error	6	63	
Total	11		

+Significant at 25%
***Significant at 0.5% level

tillers for Treatment I than for Treatment III. Japanese Dwarf produced two times more tillers for Treatment I than for Treatment III. Thatcher produced about four times the amount of tillers that Japanese Dwarf produced for Treatment I, but only slightly more on Treatment III. The analysis of variance shows the difference between varieties, treatments, and the interaction to be significant at the 0.5% level of significance. Replications for this data differed at the 25% level of significance.

The total number of heads at the end of the third growth period is presented in Table XXXV. Thatcher produced 110 heads on Treatment I but only 13 on Treatment III, while Japanese Dwarf produced 29 and 15 respectively. The analysis of variance indicates the varieties differed significantly at the 10% level and treatments were significantly different at the 2.5% level.

Fourth Growth Period (Soft dough to maturity)

Table XXXVI presents the data for plant gain for this period. Thatcher produced about two and one half times more plant material on Treatment I than on Treatment III. Japanese Dwarf produced twelve times more plant material on Treatment I than Treatment III. On Treatment I, Thatcher produced nearly twice as much plant material as Japanese Dwarf. On Treatment III, Thatcher produced nine times more plant material than Japanese Dwarf. The analysis of variance indicated treatments were significantly different for the period at the 10% level and varieties differed at the 25% level of significance.

Figure 7 indicates this stage of growth was shorter for Thatcher

Table XXXV - Number of heads at end of third growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	35	41	34	110	3	5	5	13	123
Japanese Dwarf	13	9	7	29	5	5	5	15	44
Total	48	50	41	139	8	10	10	28	167

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	5	.05
Varieties	1	520	5.47*
Treatments	1	1,027	10.81**
Treatments x varieties	1	54	.57
Error	6	95	
Total	11		

*Significant at 10%
**Significant at 2.5% level

Table XXXVI - Gain in plant weight in grams during the fourth growth period (soft dough to maturity)

	Treatment I Replications				Treatment III Replications				
Varieties	I	II	III	Total	I	II	III	Total	G. Total
Thatcher	26.8	5.8	12.7	45.3	5.5	8.2	3.6	17.3	62.6
Japanese Dwarf	8.1	1.8	14.0	23.9	1.1	.2	.6	1.9	25.8
Total	34.9	7.6	26.7	69.2	6.6	8.4	4.2	19.2	88.4

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	41.02	1.06
Varieties	1	112.84	2.90+
Treatments	1	211.33	5.45*
Treatments x varieties	1	3.01	---
Error	6	38.77	
	11		

+Significant at the 25% level
*Significant at the 10% level

than Japanese Dwarf. On Treatment I, this stage of growth for Thatcher occurred almost entirely after the similar stage for Japanese Dwarf. Japanese Dwarf on Treatment III matured twenty-six days earlier than Thatcher on the comparable treatment.

Thatcher used almost twice the amount of water on Treatment I (Table XXXVII) as for Treatment III. Japanese Dwarf used about eighty-five times more water for Treatment I than for Treatment III. On Treatment I, Japanese Dwarf used slightly more water than Thatcher, although it produced only one-half as much growth. Thatcher used about thirty-two times more water than Japanese Dwarf on Treatment III. The analysis of variance indicates these differences to occur at the 25% level of significance for replications, 10% level for the interaction, and 0.5% level of significance for treatments.

Table XLVI indicates Thatcher on Treatment I required about one-third as much water to produce a unit of plant material as Japanese Dwarf. On Treatment III Thatcher required four times more water than Japanese Dwarf to produce a gram of dry matter.

The analysis of variance shows differences in plant height (Table XXXVIII) for varieties and treatments were significantly different at the 2.5% and 0.5% levels respectively. Thatcher on Treatment I had slightly more height than on Treatment III. Japanese Dwarf had about three-tenths more height on Treatment I than on Treatment III. Thatcher had about the same height as Japanese Dwarf for Treatment I and on Treatment III had a fifth more height than Japanese Dwarf.

The number of tillers occurring at maturity is presented in Table

Table XXXVII - Water use in milliliters during the fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	7,205	3,022	3,632	13,679	2,253	2,668	2,280	7,201	20,880
Japanese Dwarf	9,082	7,426	3,027	19,535	75	69	80	224	19,759
Total	16,107	10,448	6,659	33,214	2,328	2,737	2,360	7,425	40,639

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	5,565,677	1.87+
Varieties	1	104,480	.04
Treatments	1	55,412,470	18.61***
Treatments x varieties	1	13,734,064	4.61*
Error	6	2,976,986	
Total	11		

+Significant at 25%
*Significant at 10%
***Significant at 0.5% level

Table XXXVIII - Plant height in inches at end of the fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	26	25	26	77	21	23	24	68	145
Japanese Dwarf	24	23	23	70	20	18	16	54	124
Total	50	48	49	147	41	41	40	122	269

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.5	.20
Varieties	1	37.0	14.80**
Treatments	1	52.0	20.80***
Treatments x varieties	1	4.0	1.60
Error	6	2.5	
Total	11		

**Significant at 2.5%
***Significant at 0.5% level

XXXIX. Thatcher produced nearly four times more tillers on Treatment I than on Treatment III. On both treatments Thatcher produced about two and one-half times more tillers than Japanese Dwarf. The analysis of variance indicates varieties, treatments, and the interaction were significant at the 0.5% level of significance.

Table XL presents the total number of heads produced at the end of the fourth growth period. Thatcher produced more than three times more heads on Treatment I than on Treatment III. Japanese Dwarf produced about five times more heads on Treatment I than on Treatment III. On Treatment I, Thatcher produced two times more heads than Japanese Dwarf. The analysis of variance indicates varieties and treatments were significantly different at the 2.5% level and 0.5% level in that order. The interaction was significant also at the 10% level of significance.

Table XLI presents the data for number of heads without grain. On Treatment I approximately one-quarter of the total number of heads were sterile for both varieties. On Treatment III only a small proportion of heads were sterile, although Thatcher had more sterile heads than Japanese Dwarf. The analysis of variance indicates varieties and treatment varied significantly at the 10% and 0.5% levels of significance respectively.

Table XLII illustrates the number of heads that produced grain. Thatcher and Japanese Dwarf produced respectively three and four times more heads with grain on Treatment I than on Treatment III. However, Thatcher produced twice as many heads as Japanese Dwarf on Treatment I and three times more heads on Treatment III. The analysis of variance

Table XXXIX — Number of tillers at end of fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	57	54	59	170	11	20	15	46	216
Japanese Dwarf	26	21	23	70	5	7	4	16	86
Total	83	75	82	240	16	27	19	62	302

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.5	.007
Varieties	1	1,409.0	120.43***
Treatments	1	2,640.0	225.64***
Treatments x varieties	1	408.0	34.87***
Error	6	11.7	
Total	11		

***Significant at 0.5% level

Table XL - Total number of heads at end of fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	52	35	57	144	9	18	13	40	184
Japanese Dwarf	26	21	21	68	5	6	2	13	81
Total	78	56	78	212	14	24	15	53	265

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	13	.25
Varieties	1	884	17.33**
Treatments	1	2,107	41.31***
Treatments x varieties	1	200	3.12*
Error	6	51	
Total	11		

***Significant at 0.5%
**Significant at 2.5%
*Significant at 10% level

Table XLI - Number of heads without grain at end of fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	8	9	9	26	0	1	5	6	32
Japanese Dwarf	6	5	4	15	1	0	0	1	16
Total	14	14	13	41	1	1	5	7	48

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.75	.28
Varieties	1	21.00	7.98*
Treatments	1	96.00	36.50***
Treatments x varieties	1	3.70	1.04
Error	6	2.63	
Total	11		

*Significant at 10%
***Significant at 0.5% level

Table XLII - Number of heads without grain at end of fourth growth period.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	42	29	34	105	9	18	8	35	140
Japanese Dwarf	20	16	18	54	5	5	2	12	66
Total	62	45	52	159	14	23	10	47	206

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	12.5	2.90+
Varieties	1	457.0	106.27***
Treatments	1	1,046.0	243.25***
Treatments x varieties	1	64.0	14.88**
Error	6	4.3	
Total	11		

+Significant at 25%
**Significant at 2.5%
***Significant at 0.5% level

indicates varieties and treatments differed at the 0.5% level and the interaction was significant at the 2.5% level, while replications varied at the 25% level of significance with regard to fertile heads.

Table XLIII illustrates the average kernel per spikelet. Thatcher produced a fifth more kernels per spikelet on Treatment III than on Treatment I. Japanese Dwarf produced almost two times more kernels per spikelet on Treatment III than on Treatment I. On both treatments the dwarf variety produced more kernels per spikelet than Thatcher. The analysis of variance indicates the replications and the interaction were different at the 25% level; varieties and treatments were different at the 0.5% level.

The total weight of grain harvested is shown in Table XLIV. Thatcher produced four times more grain on Treatment I than on Treatment III. Japanese Dwarf produced six times more grain on Treatment I than on Treatment III. On both treatments, Thatcher produced about twice as much grain as Japanese Dwarf. The analysis of variance indicates varieties were significantly different at the 25% level and treatments at the 2.5% level. The interaction was significant at the 25% level.

Table XLV presents the data for the average kernel weight. Japanese Dwarf and Thatcher produced kernels of the same weight for Treatment I. Treatment III reduced kernel weights below that of Treatment I by about one-third for Thatcher and one-half for Japanese Dwarf.

Table XLIII - Average kernels per spikelet on heads producing grain.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	1.1	.8	.9	2.8	1.4	1.2	.9	3.5	6.3
Japanese Dwarf	1.3	.6	1.3	3.2	2.1	1.8	1.7	5.6	8.8
Total	2.4	1.4	2.2	6.0	3.5	3.0	2.6	9.1	15.1

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F.
Replications	2	.15	7.14+
Varieties	1	.52	24.76***
Treatments	1	.80	38.09***
Treatments x varieties	1	.40	9.53+
Error	6	.021	
Total	11		

+Significant at 25%
***Significant at 0.5% level

Table. XLIV - Weights in grams of grain harvested.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	12.13	5.56	5.32	23.01	1.72	2.55	1.03	5.30	28.31
Japanese Dwarf	5.68	2.65	5.79	14.12	1.00	1.13	.30	2.43	16.55
Total	17.81	8.21	11.11	37.13	2.72	3.68	1.33	7.73	44.86

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	6.00	1.40
Varieties	1	11.54	2.69+
Treatments	1	62.03	14.49**
Treatments x varieties	1	13.01	3.03+
Error	6	4.29	
Total	11		

+Significant at 25%
**Significant at 2.5% level

Table XLV - Average weight in grams of kernels harvested.

Varieties	Treatment I Replications I	II	III	Total	Treatment III Replications I	II	III	Total	G. Total
Thatcher	.021	.023	.017	.061	.014	.013	.017	.044	.105
Japanese Dwarf	.022	.019	.021	.062	.009	.011	.010	.030	.092
Total	.043	.042	.038	.123	.023	.024	.027	.074	.197

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	.0000001	.32
Varieties	1	.0000014	4.52*
Treatments	1	.0001	322.58***
Treatments x varieties	1	.000119	38.39***
Error	6	.0000031	
Total	11		

*Significant at 10%
***Significant at 0.5% level

Table XLVI - Summary of water use per gram of dry matter produced during the different growth periods.

Growth period	Varieties	Treatments I	Treatments III
I			
	Thatcher	603	
	Japanese Dwarf	549	
II			
	Thatcher	623	925
	Japanese Dwarf	469	512
III			
	Thatcher	629	408
	Japanese Dwarf	610	345
IV			
	Thatcher	302	417
	Japanese Dwarf	817	119

Summary Figures and Tables

Figure 7 presents the growth curve for the second crop. After tillering, Thatcher produced more plant material than Japanese Dwarf for Treatment I. This figure illustrates that Thatcher required longer periods to reach heading and soft dough stages than did the Japanese Dwarf.

On Treatment III, Thatcher produced less plant growth than Japanese Dwarf up until shortly after soft dough stage. The time required for Thatcher to reach heading was longer than for Japanese Dwarf; however, the soft dough stage occurred at the same time for the two varieties. Following soft dough, Japanese Dwarf matured in about half the time required for Thatcher.

Figure 8 indicates that following tillering Thatcher used more water than Japanese Dwarf for both treatments. Figures 9 and 10 show that water uptake approximately parallels plant growth.

Figures 11 and 12 compare the water used and plant growth for both varieties on Treatment III. Figure 11 illustrates that the water use parallels the amount of growth very closely for Japanese Dwarf. A comparison of Figures 11 and 12 illustrates that Thatcher used more water than Japanese Dwarf for all periods except for the period preceding tillering.

Table XLVII illustrates the growth interactions for the second crop cycle. Data for the last three growth periods for both treatments is presented since comparisons apply from the time stress was initiated to maturity. Replications were not significantly different. Varieties

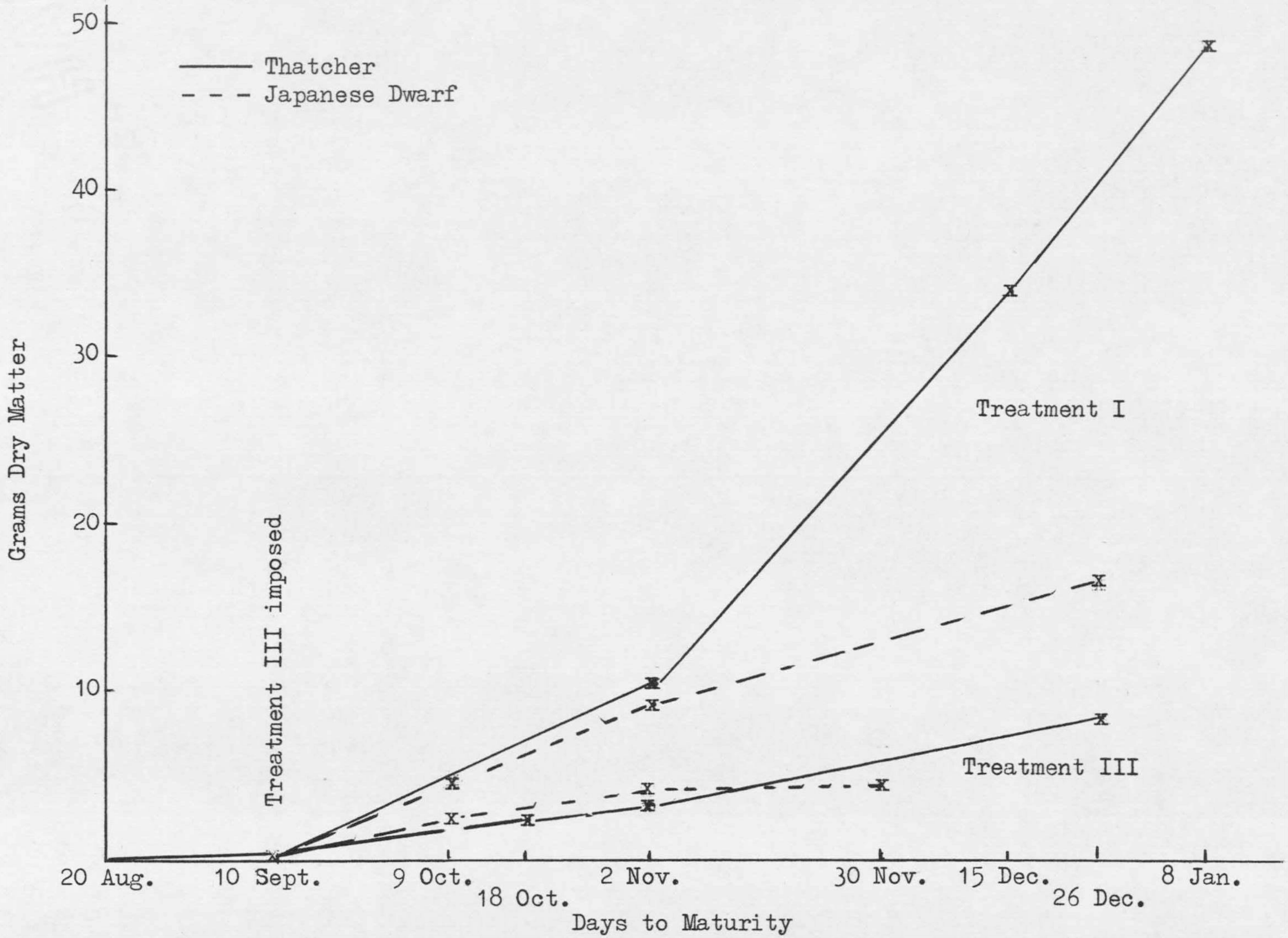


Figure 7. Summary of plant growth in relation to time.

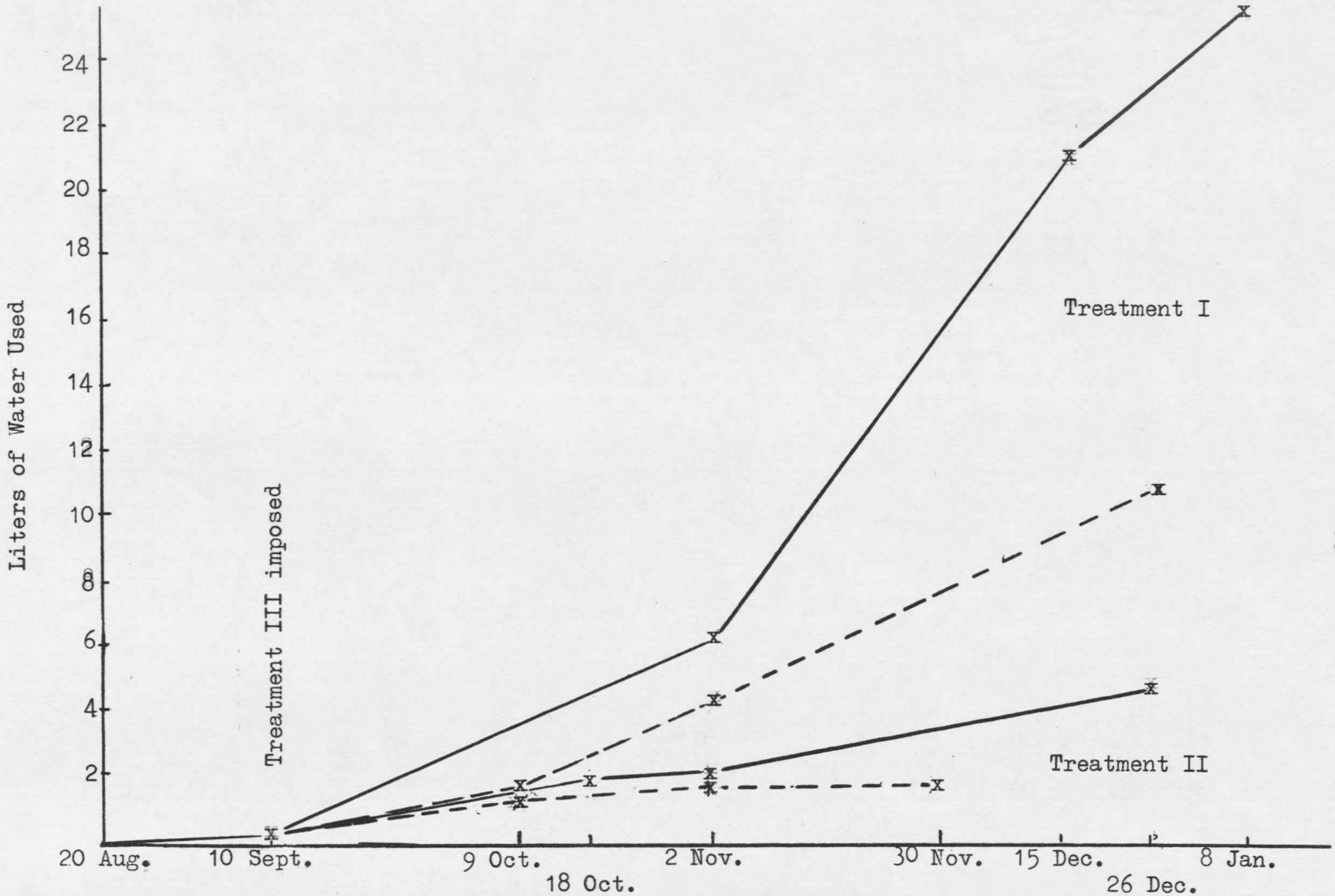


Figure 8. Summary of water use in relation to time. Days to Maturity

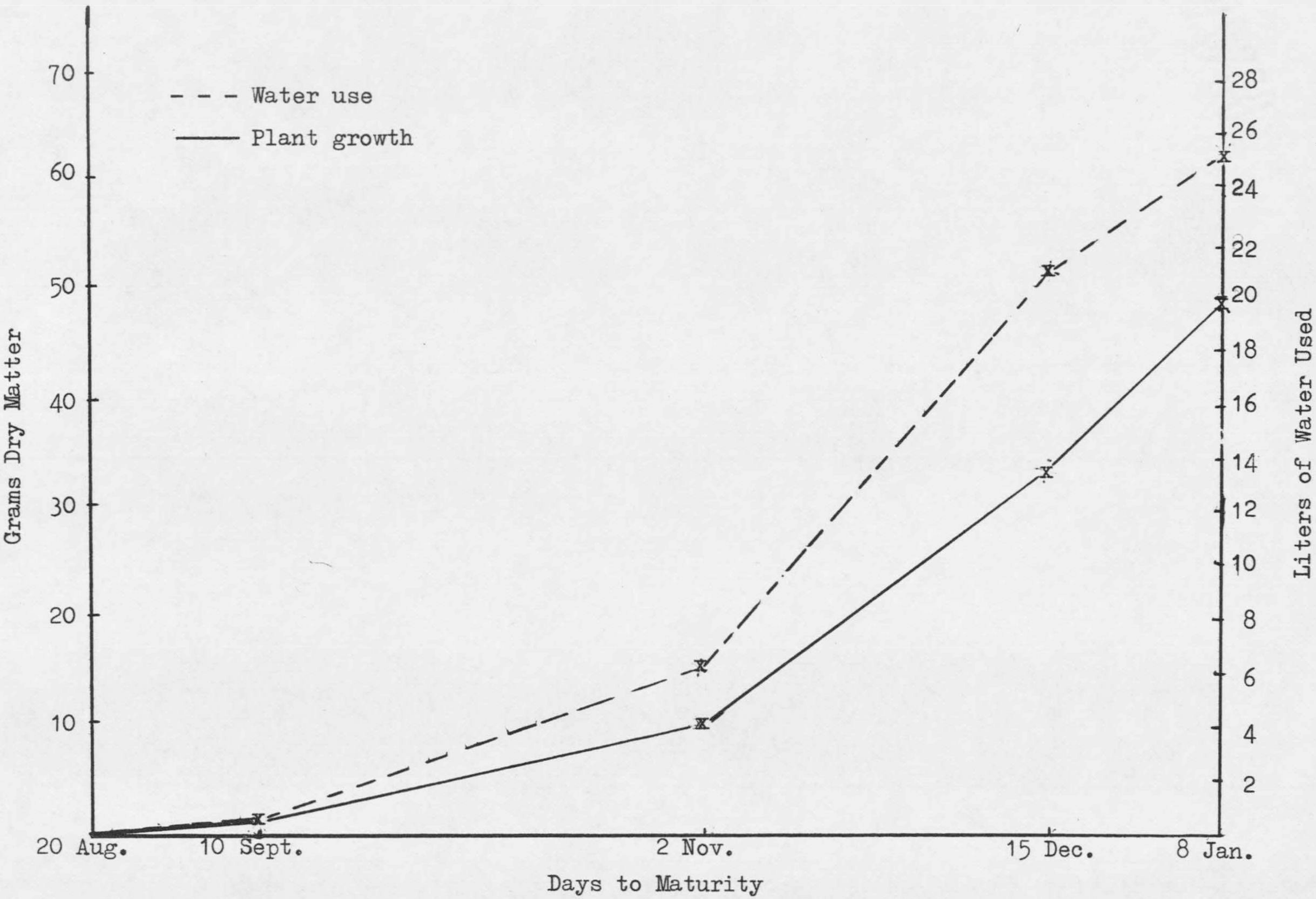


Figure 9. Comparison of water use and plant growth for the growth periods, Treatment I, Thatcher.

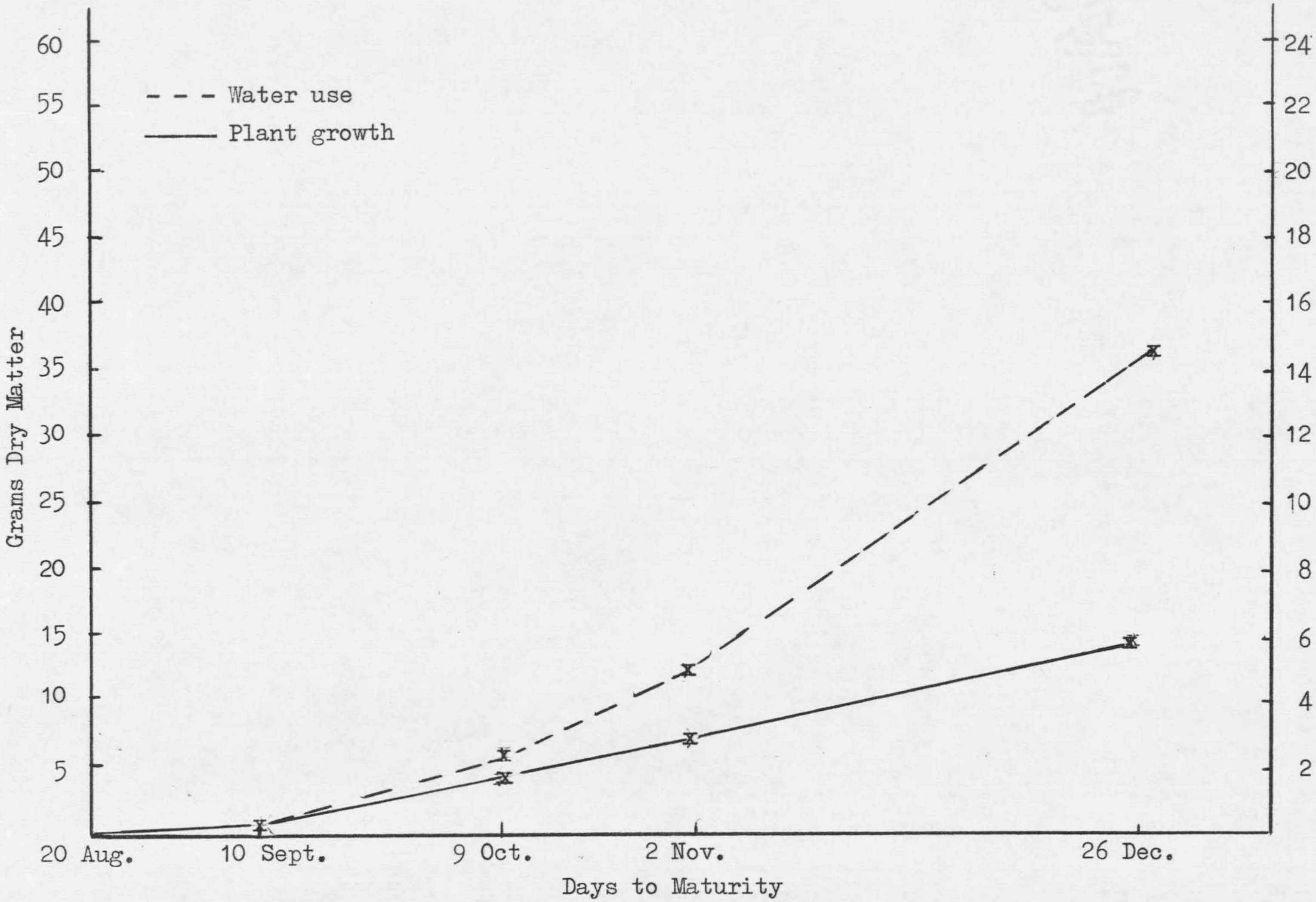


Figure 10. Comparison of water use and plant growth for the growth periods, Treatment I, Japanese Dwarf

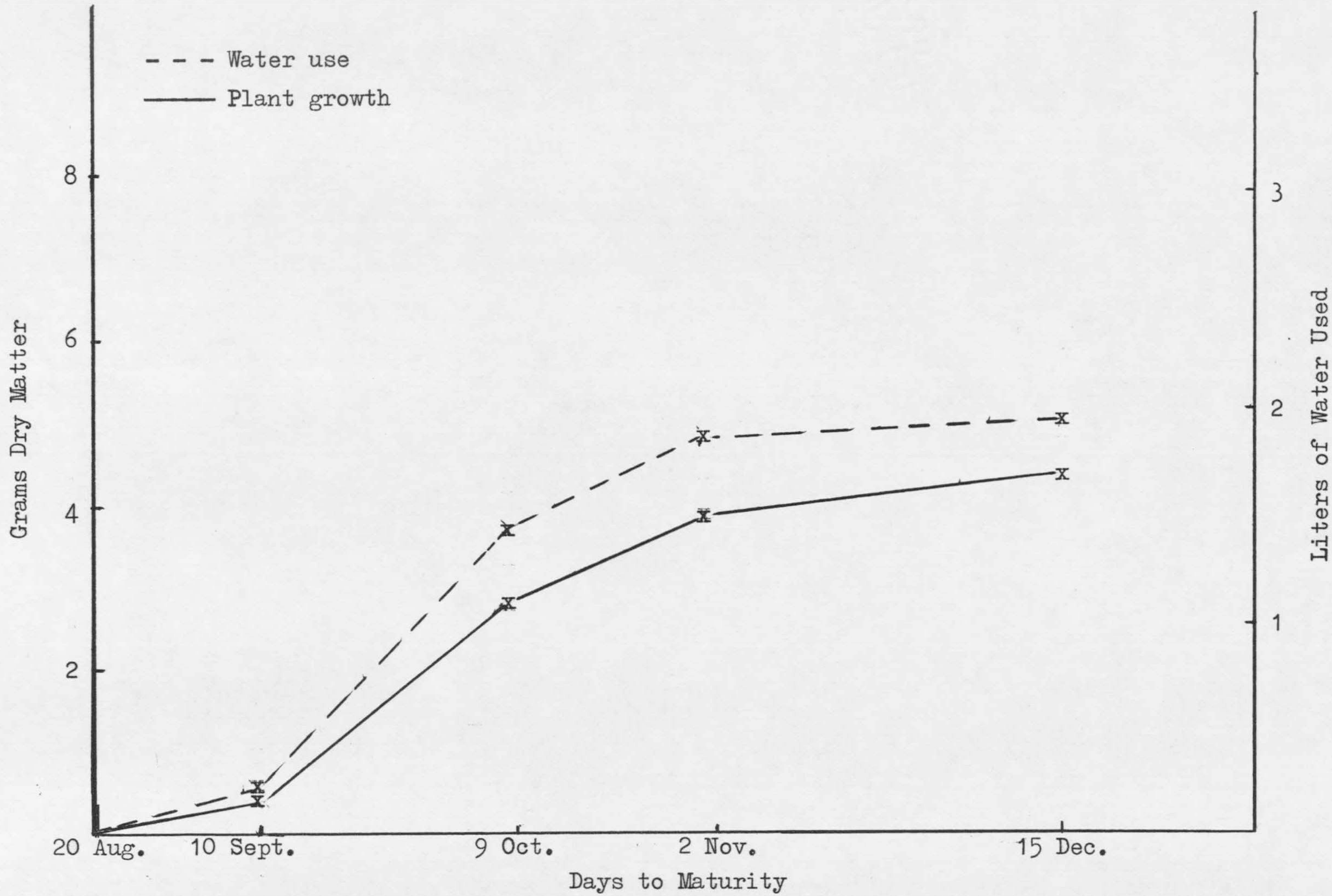


Figure 11. Comparison of water use and plant growth for the growth periods, Treatment III, Japanese Dwarf.

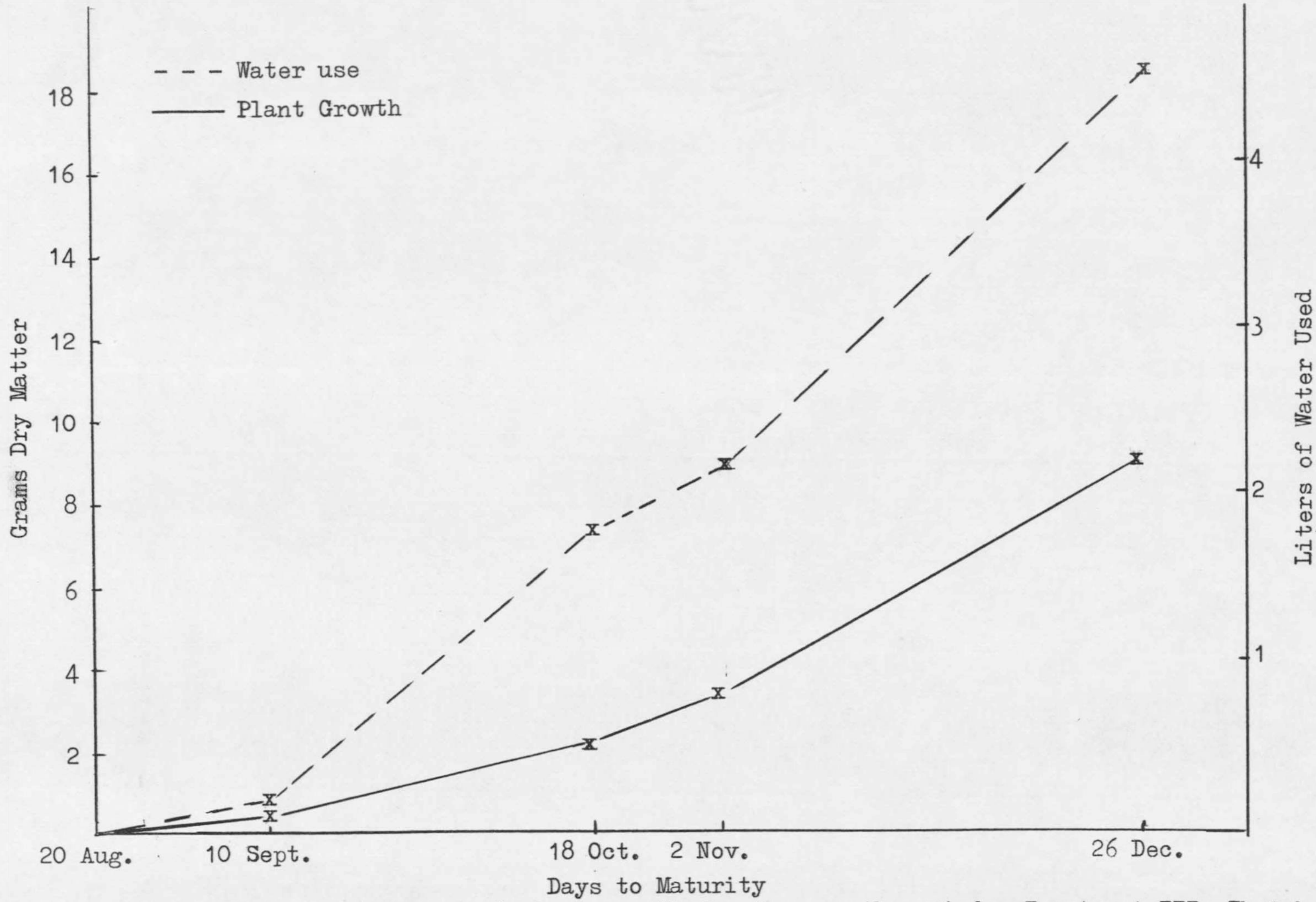


Figure 12. Comparison of water use and plant growth for the growth periods, Treatment III, Thatcher

were significantly different at the 0.5% level, because Thatcher produced more growth than Japanese Dwarf. Treatments differed at the 0.5% level with the most growth occurring on the low-stress treatments. The Treatment x Varieties interaction was significant at the 0.5% level with Thatcher producing more plant material for both treatments than Japanese Dwarf. Periods and other interactions were significant at a low level.

The water use of the second crop is presented by Summary Table XLVIII. All interactions and main effects except replications were significant at the 0.5% level. Thatcher used more water than Japanese Dwarf for all periods and treatments. On the low stress treatment, high periods of water use for Thatcher and Japanese Dwarf were the third and fourth growth periods respectively; however, on the high stress treatment, the periods of high water use for Thatcher and Japanese were the second and fourth periods of growth respectively.

Plant growth relationships for comparing the two crops grown on Treatment I is presented by Table XLIX. All interactions and main effects were significant at the 0.5% level with the exception of replications, which were not significantly different. More plant material was grown during the second crop than the first. There was no difference between varieties for plant growth for the first crop; however, during the second crop Thatcher produced more plant material than Japanese Dwarf.

For the first crop, the growth during the first three growth periods was not consistent between the two varieties with Japanese Dwarf making

Table XLVII - Plant growth interactions for treatments, varieties, and periods.

Stress and Variety

Periods	2	3	4	Avg.
	Grams	Grams	Grams	Grams
low				
Thatcher	29.1	71.3	45.3	48.6
Japanese Dwarf	9.7	13.5	23.9	15.7
Average	19.4	42.4	34.6	32.1
high				
Thatcher	5.3	3.1	17.3	8.6
Japanese Dwarf	7.2	3.0	1.9	4.0
Average	6.3	3.1	9.6	6.2

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	5.92	.31
Varieties	1	349.78	18.10***
Periods	2	40.92	2.11+
Treatments	1	667.72	345.61***
Treatments x varieties	1	200.47	103.78***
Varieties x periods	2	34.10	1.76+
Treatments x periods	2	57.00	2.97*
Treatments x varieties x periods	2	58.99	3.05*
Error	22	19.32	
Total	35		

***Significant at 0.5%
*Significant at 10%
+Significant at 25% level

Table XLVIII - Water use interaction for the second crop.

Stress and Variety

Periods	2 Liters	3 Liters	4 Liters	Avg. Liters
low				
Thatcher	18.1	44.8	13.9	25.6
Japanese Dwarf	4.6	8.2	19.6	10.8
Average	11.4	26.0	16.8	18.1
high				
Thatcher	4.9	1.2	7.2	4.4
Japanese Dwarf	3.7	1.0	.2	1.6
Average	4.3	1.1	3.6	3.0

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	1,815,349	1.29
Varieties	1	77,774,694	55.20***
Periods	2	114,614,569	81.34***
Treatments	1	24,388,290	17.31***
Treatments x varieties	1	46,152,779	32.76***
Varieties x periods	2	26,825,862	19.04***
Treatments x periods	2	29,086,459	21.20***
Treatments x varieties x periods	2	45,094,582	32.00***
Error	22	1,408,973	
Total	35		

***Significant at 0.5% level

Table XLIX - Plant growth relationships for Treatment I, first and second crops.

Crop and Variety

Period	1	2	3	4	Avg.
	Grams	Grams	Grams	Grams	Grams
Crop one					
Thatcher	4.1	2.6	16.2	27.7	12.6
Japanese Dwarf	3.5	6.4	5.5	28.4	11.0
Average	3.8	4.5	10.9	28.1	11.8
Crop two					
Thatcher	1.2	29.1	71.3	45.3	36.7
Japanese Dwarf	1.2	9.8	13.5	23.9	12.1
Average	1.2	19.5	42.4	34.6	24.4

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	1.850	.15
Varieties	1	231.034	19.06***
Periods	3	234.953	19.37***
Crop	1	211.312	19.00***
Crop x varieties	1	176.104	14.53***
Varieties x periods	3	72.006	5.93***
Crop x periods	3	70.388	5.81***
Crop x varieties x periods	3	64.844	5.35***
Error	30	12.124	
Total	47		

***Significant at 0.5% level

Table L - Water use relationships, first and second crops.

Crop and Variety

Period	1	2	3	4	Avg.
	Liters	Liters	Liters	Liters	Liters
Crop one					
Thatcher	1.9	1.2	4.8	7.8	3.7
Japanese Dwarf	1.6	1.9	4.7	3.7	3.0
Average	1.8	1.6	4.8	5.8	3.4
Crop two					
Thatcher	.7	18.1	44.8	13.9	21.1
Japanese Dwarf	.6	4.6	8.2	19.5	8.2
Average	.7	11.4	26.5	16.7	13.8

Analysis of variance

Variation due to	d.f.	Mean Square	Cal. F
Replications	2	644,166	.54
Varieties	1	48,823,897	40.60***
Periods	3	51,451,104	42.78***
Crop	1	143,562,257	119.37***
Crop x varieties	1	34,165,813	28.41***
Varieties x periods	3	25,831,704	21.48***
Crop x periods	3	29,005,369	24.11***
Crop x varieties x periods	3	33,595,726	27.94***
Error	30	1,202,632	
Total	47		

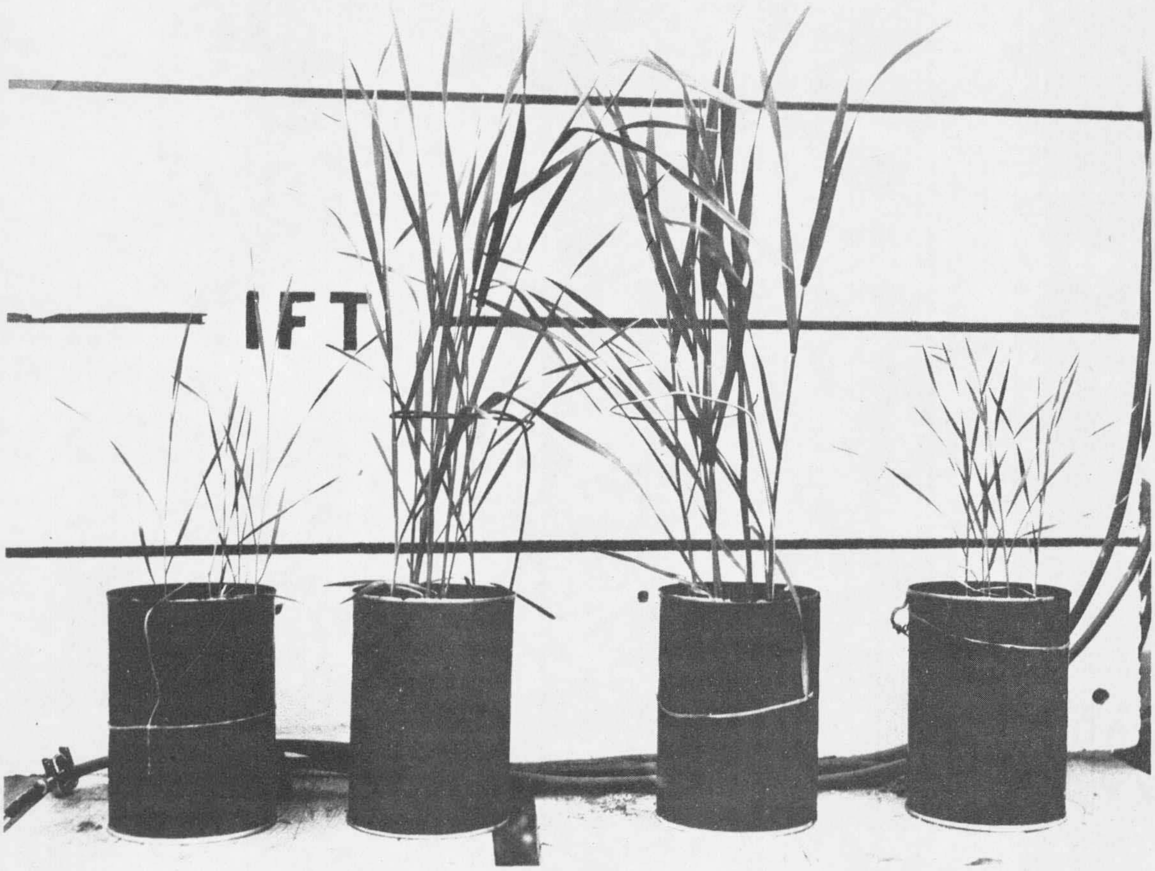
***Significant at 0.5% level

active growth between tillering and heading, while Thatcher made most active growth between heading and soft dough. The growth between soft dough and maturity was similar for the two varieties. For the second crop growth increased for both varieties from period to period, excepting that Thatcher made its maximum growth in the third growth period. Thus the character of growth of the two varieties in the different growth periods differed between crops and this is brought out by the Crop x Variety x Period interactions.

The water use for Treatment I, when comparing the two crops, is presented by Table L. All comparisons made, except replications, were significant at the 0.5% level. Water use usually paralleled plant growth for the varieties during the growth periods for both crops. The same relationships were found between plant growth and water use for the two crops, i.e., as plant growth increased or decreased water use followed a similar pattern.

Conclusions

1. Two varieties of spring wheat grown at an osmotic stress of seven atmospheres produced less than one-tenth the dry matter and grain than when grown on a nutrient solution of three-fourths atmosphere tension.
2. When the high tension was not imposed until tillering, the reduction in dry matter production and grain yield was reduced to about one-fifth of the production at low tension.
3. Total water use and water use efficiency differed between varieties and treatments with periods of growth and with the climate which prevailed during the growing period.
4. Drastically different day lengths and climate conditions which prevailed during the growth cycle of the two crops altered the length of time the two varieties remained in a growth period and altered the comparative growth during the periods.
5. In all treatments Thatcher produced more tillers and heads than Japanese Dwarf, but grain yields were not correspondingly increased. Japanese Dwarf on the low stress treatment produced more kernels per spikelet than Thatcher, but Thatcher produced the heaviest kernels. High stress from tillering to heading induced Thatcher to produce heavier kernels but fewer kernels per spikelet than Japanese Dwarf.
6. Plant growth usually varied within treatments and between periods for the two varieties but results were not conclusive due to the different plant growing conditions between cropping cycles.



Thatcher Japanese Dwarf

High Stress Low Stress Low Stress High Stress

Figure 13. Typical growth for first crop at tillering stage of two varieties at two osmotic stresses.

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