THE EFFECT OF HARVESTING AT DIFFERENT STAGES OF MATURITY UPON THE YIELD AND CHEMICAL COMPOSITION OF BARLEY

A THESIS

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Contents

Introduction:

Barley is fast becoming a cereal crop of major importance in Manitoba. During the past five years (1925-1930) Agricultural Statistics[7] reveal that the annual barley acreage in Manitoba has represented 81 per cent of the average annual wheat acreage for the same period. The average figure for the provinces of Saskatchewan and Alberta for the same period is 9 per cent. When these two figures are compared the importance of barley as a cereal crop in Manitoba, can be readily appreciated.

Yield and quality are the two most important considerations in crops harvested for either grain or hay. Harvesting operations should be planned to secure the best balance between these two factors. This is particularly true in the case of Barley.

An attempt will be made in this investigation to determine the effect of harvesting at different stages of maturity upon the yield of barley and also the nature and extent of variations in the mineral, carbohydrate and nitrogenous constituents of the component plant parts sampled daily from heading until past maturity.

Literature Review:

Studies on the stage of development of cereal plants in relation to variations in yield and chemical composition have been reported upon from time to time on this Continent and Abroad.

Most of these investigations have dealt with wheat, since it occupies throughout the world a position of prime economic importance.

One of the earliest trials in Canada was that conducted by Bedford[4]. He cut wheat at Early milk, Late milk, Dough and Ripe stages and reported the results of two years observations which indicated that there was no increase in yield for wheat harvested at maturity, over that harvested a week early in the dough stage. An increase in weight per bushel for grain harvested at maturity was shown.

Kiesselbach[13] after three years work on oats harvested at two day intervals beginning six days before maturity, found that harvesting four days early did not lower the yield but resulted in a decrease in the weight per bushel. Later the same investigator[14] gives results for Turkey wheat harvested at three stages of maturity, viz., (a) Early dough, (b) Late dough, and (c) Ripe, for a five year period. The data are from duplicate field plots with the grain cured in the shocks. He found little change in the portein percentage from early dough to maturity, but a decided increase in yield and weight per bushel from early to late dough and slight increases after. He concluded that four days before maturity when the grain contained 38.4 per cent moisture, wheat for all practical purposes could be considered mature.

Arny and Sun[2] reported on results obtained in the summer of 1925 from a series of wheat and oat plots. The samples were harvested each morning from several small areas in different parts of the plots. These samples which were divided into the different plant parts, were separated into two series, one series being dried rapidly in an oven and another series more slowly in the air. These investigators found that the weight per thousand kernels for both wheat and oats, for any date of sampling are as high for the grain dried rapidly in the oven with only the chaff or the chaff and rachis attached, as when curing proceeded more slowly with the same or more of the vegetative portions attached, indicating that translocation of food materials in leaves and stems after harvest did not occur in amounts large enough to be detected by the methods employed. However there was some indication of translocation in oats from the straw to the grain, sampled when the kernels were in the thick milk stage. They found a higher percent nitrogen both in the straw and grain of wheat and oats cut seven days early. An increase in 1000 kernel weight for wheat cut three days early and oats cut four days early was observed.

Brenchley[5] was the first investigator to study extensively the progressive development of the grain of barley. She reported her results on the basis of a unit of 1000 grains and presented them graphically by the use of curves.

In comparing the dry weight with green weight a gradual increase was noted almost to the end ,from flowering to maturity. The percent ash in the straw increased almost to maturity, while in the grain a definite decrease was observed. A definite relationship was found to exist between the maximum ash content and the maximum protein content in both the whole plant and grain. Comparing wheat and barley the above Author noted that in barley the percent dry matter and ash is considerably higher than in wheat.

From her investigations in wheat and barley Brenchley makes the statement: "That from the comparisons made it is clear that the progressive changes in wheat and barley run a very parallel course, though varying in detail". The differences seem to be chiefly due to the prolonged ripening period of barleys during which maturation, changes occur which are not evident in wheat owing to the earlier stage at which the latter is harvested".

Olson[17] in 1923 observed that wheat kernels ceased to fill when the moisture content fell below 40 per cent and that the percent nitrogen decreased as the grain became mature.

Keitt and Tarbox[12] in a study on the composition of the oat plant reported an increase in the percent nitrogen in the kernels of the oats up to the milk stage, and a rather rapid decrease in the percent from then to maturity.

Brenchley and Hall[6] after extensive studies on the development of a grain of wheat, concluded that the material which the plant moves into the kernel is uniform in composition throughout the period of endosperm filling.

Thatcher[18] some years later conducted a rather extensive investigation into the variations found in three different varieties of wheat. A regular decrease in percent ash, ether extract and crude fibre up to maturity, with a corresponding decrease in percent protein in earlier stages with marked increased in the later stages of development were found. The sugars were reported as dextrose and the results showed that the immature kernels contained larger proportions after which where was a rapid decrease to less than 20 per cent of the dry matter at the milk stage, and then a slight regular decrease to maturity.

Thatcher made an interesting observation on the amount of gain in dry matter per day. He found that the most rapid gain was made in the first three days by all varieties but at subsequent stages of development rapid and slow accumulation of dry matter appear to alternate. On the basis of weight per kernel there was found to be, as the kernels developed, a regular increase in the quantity of all the constituents except the sugars. This investigator reported facts which supported his contention that the material which the kernel gains from day to day is richer in carbohydrates than the original "mold" into which it enters and continues to be so until about the milk stage.

The ratio of carbohydrate to protein however soon begins to fall and continued to do so until maturity.

Harlan[10] harvested heads of Hannchen barley at twelve hour intervals from flowering to maturity. The increase in dry matter for two seasons was found to be essentially a straight line relationship from the sixth to the eighteenth day from flowering. The percent water in the kernels was found to be highest at flowering, but a constant decrease occurs up to maturity when only about 40 per cent moisture exists. The percent ash decreased uniformly from flowering to maturity. The maximum growth in length determined by measurements and cytological studies, occured at seven days after fertilization.

Harlan concluded that the period fifteen and sixteen days after flowering marks a period of important changes in development, since this date coincides with the shedding of the awns, the maximum water content, and the end of the period of most rapid increase in dry matter and ash. Harlan's protein determinations cannot be considered very reliable as they were based on microchemical methods, due to the size of his samples.

Three years later Harlan and Pope[11] reported on variations in the moisture content of the kernels of a number of barley varieties during growth and maturation. The percent moisture gradually decreased while the total water content was represented by a rapid increase after fertilization, then a stationery period and finally a rapid decline to maturity. The moisture content of the kernels declined steadily from 80 per cent at flowering to 42 per cent, and at this time the deposition of dry matter is interrupted and the kernels dry with great rapidity. Harlan and Pope conclude that the exact point where translocation becomes impossible, is at a moisture content somewhat lower than this.

More recently Woodman and Engledow[20] have reported on the development of wheat, using a pure line of Red Fife. Their results indicate a steady increase in percent dry matter right up to harvest with not much variation in percent total nitrogen in the dry matter during the whole period of development. A slight gain in percent nitrogen during the last week of ripening was explained as probably due to the loss of non-nitrogenous material from the grain by respiration rather than an actual gain of nitrogenous material by transport. The above investigators also concluded that the storage of carbohydrate was complete at the stage corresponding with the beginning of dessication. Starch was shown by chemical tests to be present in every one of the samples.

The first samplings were found to be richest in reducing sugars as indicated by the reducing power of aqueous extracts, subsequent samples gave a definite fall in reducing sugars during the dessication period.

The investigations of Le Clerc and Breazeole[15] led them to conclude that when both the grain and straw are to be fed on the farm, that cutting when the spikes or panicles have turned yellow but the leaves and stems are still green, is a good practice in order to minimize the leaching of valuable food materials from the vegetative parts by rain and dew.

Wilson and Raleigh[19] in 1929 in a continuation of the work of Arny and Sun found a decrease in the percent nitrogen of the grain, glumes and rachis with approaching maturity. While the percent in the leaves remained constant during ripening, an increase was noted in the internodes. An increase in 1000 kernel weight from an average of 9.93 grams for plants harvested in the milk stage and cured in the shock to 17.21 grams at maturity, representing an increment of more than seventy percent was observed. They concluded that the principle change in the vegetative portions of both wheat and oats was a loss of moisture with senescence and also that as the plant is nearing maturity food materials are moved from the leaf of the plant largely as formed or shortly afterw wards.

Recently Fagan and Watkin[8] working in Wales on four different oat varieties have reported on an extensive investigation into the chemical constituents of the oat plant.

They found that in the whole plant the percent dry matter increases in a fairly steady manner up to the under ripe stage after which desiccation is rapid. The dry matter decreased progressively in percent total ash, potash, lime and chlorine. The percent nitrogen fell to a minimum value at the milky stage, followed by a rise at the under ripe stage, with a slight falling off at the ripe stage. A decrease in the percentage of total ash and nitrogen in the leaf and stem occurs with approaching maturity, while in the spikelet the percent nitrogen remains practically constant throughout the period. The relative proportions of the constituents is indicated by a progressive fall in the leaf, irregular fluctuations in the stem and regular increases in the spikelet with approaching maturity.

While there is considerable variance in the results of the work reviewed the indications are that, when the grain is harvested earlier than the stage when the majority of the kernels are in the hard dough, a reduction in both yield and weight per measured bushel is likely to occur. Under cool weather conditions grain crops may be harvested and shocked a week before complete maturity with practically no reduction in yield and quality.

Previous investigations also indicate that there is a decrease in percent ash, moisture and protein and an increase in percent dry matter. What little evidence has been presented regarding the carbohydrate distribution is contradictory.

Methods:

The investigations hereafter reported were conducted in both 1930 and 1931 with the O.A.C.21 variety. This variety was selected because it was generally recognized in Canada as the standard both from a malting and feeding standpoint.

In the spring of 1930 several 1/100th acre plots were sown, average seasonal conditions prevailed and cuttings were secured from four different plots beginning July 21st, and continuing at three day intervals, with one or two exceptions until the crop was considered mature. Four plots were also harvested four days after the crop was mature, to determine if there was any significant reduction in yield due to shattering. The harvested grain from these plots was shocked and capped with cotton sheets to prevent weathering. The plots were threshed individually in an experimental thresher and yield results secured.

Determinations were made on the threshed grain, of 1000 kernel weight, and weight per measured bushel. The 1000 kernel weights were determined from quadruplicate counts of 500 kernels and these averaged to give the result for each of the 36 plots. The results have been analyzed by taking the differences between paired values directly, and the significance of the variations from cut to cut determined. The weight per measured bushel was determined on the composite sample of threshed grain for any one cutting.

In the spring of 1931, O.A.C.21 barley was sown in drills one foot apart on May 28th, on well prepared summer-fallow. The soil is a dark, heavy lacustrine clay, high in mineral and organic matter.

The weather records during the growing period are given in Table I below, and indicate that for the first two months (May and June) the mean temperatures were somewhat higher than normal and that less than half of the normal precipitation occured.

The seedlings emerged on June 5th, and sampling was begun on July 13th, when the crop was completely headed and pollination had been complete for a number of days, as indicated by the shedding of the stamens.

The samples were extracted from the bulk grain as it stood in the field, thus representing farm conditions. This method of sampling has been used by previous investigators and found to be quite satisfactory[2]. Each days sampling was purely random and no attempt was made to cut plants of uniform maturity.

The samples were cut daily at mid-day, covered with a cotton sheet and taken to the laboratory as quickly as possible.

Table I

Meteorological Conditions During the Growing Season (1931)

TEMPERATURE DEGREES FAHRENHEIT					PRECIPITATION		HOURS OF SUNSHINE			
Month	Maxi-mum	Mini-mum	Mean	Normal	In Inches	Normal	Hours	Possible	% of Possible	Normal
April	77	10	40.3	37.9	.16	1.48	231.0	414.0	56	204
May	90	18	50.2	51.7	1.27	2.25	244.5	478.5	51	255
June	97	31	65.3	62.0	1.27	3.18	281.5	489.2	57	257
July	97	44	67.6	66.2	3.26	3.13	319.0	492.0	58	257
August	99	32	66.0	63.4	2.83	2.34	259.5	447.0	58	257

The plants were then separated into their component parts, namely, leaves, culms and heads. A definite weight of these along with whole plant samples were placed in cages and dried in an experimental drier which is a duplicate of the one described by McRostie[16] and illustrated in Figure 1. The work of separation of the fresh plants was carried out as quickly as possible to minimize the loss of moisture.

The samples were left in the drier for a period of from 2 to 3 hours and at this time the moisture content ranges from 3 to 5 per cent. The dried samples were then removed, ground in a Wiley mill until they would pass through a one millimetre sieve and placed in air tight containers. All the samples were passed through this mill twice as it was found, especially in the case of leaves and culms, that strips of the material had passed through intact. The final result was a very fine homogenous mixture. The samples were stored until such time as the chemical determinations could be made.

The chemical determinations such as moisture, ash, protein and total carbohydrate were carried out according to the Official Methods outlined in (1) and (3).

Some difficulty was experienced in ashing and the Modified Alcohol Glycerol Method with high temperatures finally had to be used.

In the determination of total carbohydrates a battery of four Gooch crucible holders were assembled together and suction was created by the use of a Cenco Hyvac pump. This arrangement illustrated in Figure 2 was very efficient and helped materially to speed up the process of determining sugars, since two samples in duplicate can be filtered at one time. The results of the chemical determinations have been reported in percent and on a uniform moisture basis.

In 1931 samples were again taken to obtain information on yield data. Cuttings were made of four rod rows beginning August 1st and continuing at two day intervals with one exception until 4 days after maturity. The weight per 1000 kernel determinations were also made on the threshed grain from each rod row.

General agronomic notes were taken from time to time since it is much easier to associate changes in yield and composition with some easily observed morphological condition, as indicated by the following records:

July 11 - 10% emergence of heads.

July 13 - Heading complete, shedding stamens.

July 24 - Kernels in the milk stage.

July 26 - Kernels in soft dough, lower leaves beginning to fade in color. First appearance of rust.

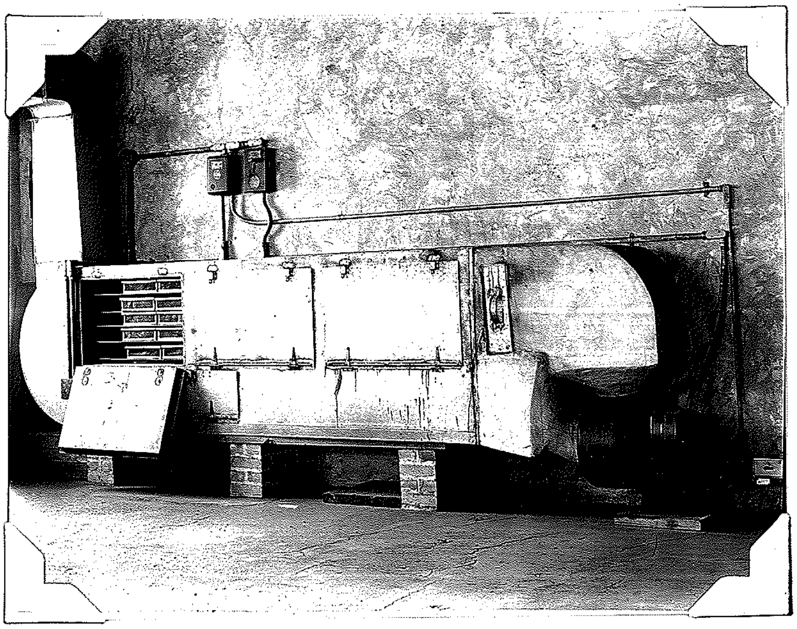
Aug. 2 - Rust appearing heavy (30%). Lower leaves dried up.

Aug. 4 - Awns turning yellow. Straw beginning to rattle and crack when bent. Leaves 45% dry; kernels in firm dough.

Aug. 11 - Culms mostly yellow at first internode. Leaves completely desiccated. Kernels in hard dough.

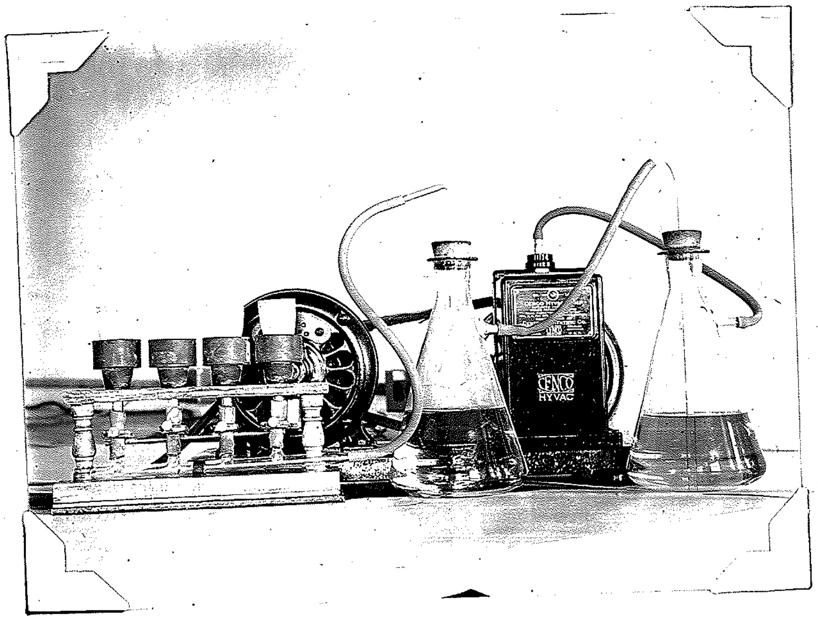
Aug. 13 - The crop was dead ripe and shedding of awns was observed to be general on 13th and 14th.

Figure 1



The Experimental Drier used in Drying the Samples Harvested Daily

Figure 2



The Battery of Gooch Crucible Holders and Suction Apparatus

Assembled for Use

Experimental Results:

As stated before the yield and quality of any crop are of primary importance. The yield results will therefore be presented and discussed first. The chemical phases of this problem will be presented in another section.

Field Plot Experiments in 1930:

The yield per plot in pounds was calculated to yield in bushels per acre. The significance of the plot yields was determined by the direct pairing method. This consists of finding the difference between the two items compared, and their mean difference. From this Mean, the Standard Deviation of the several differences is found by the usual formula. The ratio of the Mean difference to its Standard Deviation is designated as "t", the distribution of which has been calculated by Fisher[9]. Fisher's Tables were used here in order to determine the significance of "t".

The yield per plot and the statistical significance of the experimental data are presented in Table II. In determining the significance of the difference between barley cut 19 days early and that cut at maturity, a "t" value of 22.4 was obtained. Since a "t" value of 5.84 gives 100:1 odds, the difference observed is highly significant. Similar significant differences were obtained for the cuttings made on July 24th (16 days early) and July 28th (12 days early). The differences in yield when the cuttings were made nine, five and three days early and

and five days late were not significant.

Along with the significantly lower yield of early cut barley it might be expected that differences in weight of kernels would exist. This expectation is confirmed in the data summarized in Table III. Significant differences were obtained in weight per 1000 kernels for the barley harvested nineteen, sixteen and twelve days early. As in the case of the yield data, barley harvested nine, five and three days early and five days late gave no significant differences in 1000 kernel weight, when compared with barley harvested at full maturity.

The weight per measured bushel on the composite samples for each cutting (Table V) were found to increase regularly up to nine days before ripe, from this time on there was little change.

Table II

Yield in Bushels per Acre of Individual 1/100 Plots of
O.A.C.21 Barley Harvested at Different Stages of Maturity
At Winnipeg in 1930 and
The Statistical Estimation of the Difference

	DATE HARVESTED							
Plot No.	July 21	July 24	July 28	July 31	Aug.4	Aug.6	Aug.9	Aug.14
1	8.3	16.7	16.1	33.3	28.1	36.4	30.7	29.2
2	8.8	12.5	19.8	19.8	21.4	31.2	32.3	28.1
3	6.2	15.6	18.2	17.7	28.6	39.6	31.2	31.2
4	7.3	13.5	21.4	30.2	39.1	39.1	31.8	29.2
Mean Yield	7.6	14.6	18.9	25.2	29.3	36.6	31.5	29.4

Cuttings Compared	Mean Differences	"t"
July 21 - August 9.	23.8	22.4
July 24 - August 9.	16.9	12.0
July 28 - August 9.	12.6	12.8
July 31 - August 9.	6.2	1.6
Aug. 4 - August 9.	2.2	.60
Aug. 6 - August 9.	5.1	2.43
Aug. 14 - August 9.	2.1	2.41

5% Point = 3.18

Table III

Average Weight per 1000 Kernels in Grams, of Individual Plots Of O.A.C.21 Barley Harvested at Different Stages of Maturity And the Statistical Estimation of the Differences

	DATE HARVESTED							
Plot No.	July 21	July 24	July 28	July 31	Aug.4	Aug.6	Aug.9	Aug.14
1	13.62	17.76	22.21	25.86	27.94	27.59	32.06	25.94
2	15.22	17.02	22.52	25.71	25.54	29.16	31.00	25.19
3	12.31	18.10	21.97	26.07	27.96	28.24	26.82	25.97
4	13.78	18.87	22.68	26.74	29.84	26.48	29.16	28.17
Mean Wght.	13.73	17.94	22.34	26.09	27.82	27.87	29.76	26.32

Cuttings Compared	Mean Difference	"t"
July 21 - August 9	16.03	19.30
July 24 - August 9	11.82	8.50
July 28 - August 9	7.42	6.81
July 31 - August 9	3.66	2.88
Aug. 4 - August 9	1.94	1.16
Aug. 6 - August 9	1.89	1.52
Aug. 14 - August 9	3.44	2.36

5% Point = 3.18

Field Results 1931:

In 1931 four rod rows were cut at two day intervals ,beginning August 1st (12 days early), until the crop was mature and then one and four days after ripe. The samples were allowed to stand in the field until ready for threshing. The yield in bushels per acre was computed and the results analyzed as in 1930 to determine the significance of the differences between the various cuts as compared with the mature crop. These results are presented in Table IV. A significant difference in yield was obtained for the barley cut twelve, ten and eight days early as compared with that harvested normally. The cuttings made six, four and two days early, and one day late gave no significant differences. The rod rows harvested four days late gave a significant decrease. This decrease is no doubt due to shattering and losses from mechanical causes during harvest operations.

The weight per thousand kernels was determined on a number of samples taken daily from July 27th to August 17th and which had been dried immediately in the drier. The same uniform increase up to near maturity, with a slight decrease after as occurred in the 1930 results can be observed. A summary of the two years yield results is given in Table V. The results indicate that no significant decrease in yield or 1000 kernel weight will result from cutting barley one week before mature. Decreases in yield can be expected to result from late harvesting, due to shattering and mechanical loss of heads.

Table IV

Yield in Bushels per Acre of Individual Rod Rows Of O.A.C.21 Barley Harvested at Different Stages of Maturity at Winnipeg in 1931, and The Statistical Estimation of the Differences

	DATE HARVESTED								
	AUGUST								
Plot No.	1	3	5	7	9	11	13	14	17
1	27.8	33.9	23.0	43.0	47.2	55.2	54.4	50.8	37.5
2	34.5	42.4	47.2	63.5	63.3	63.5	66.6	53.8	53.8
3	32.7	37.5	38.7	61.1	48.4	53.8	63.5	62.3	49.0
4	14.5	31.5	17.5	36.9	42.4	48.4	35.1	47.2	29.6
Mean Yld.	27.4	36.3	31.6	51.1	50.1	55.2	54.9	53.5	42.5

Cuttings Compared	Mean Differences	"t"
August 1 - August 13	27.5	10.26
August 3 - August 13	18.6	3.62
August 5 - August 13	23.3	7.52
August 7 - August 13	3.8	1.37
August 9 - August 13	4.6	1.00
August 11 - August 13	.32	.07
August 14 - August 13	1.4	.27
August 17 - August 13	12.4	4.96

5% Point = 3.18

Table V

Summary of the Yield and 1000 Kernel Weight Results for the Years 1930 and 1931

1930 1/100 Plot Results								1931 Rod Row Results					
Date	Cut	Days Before Ripe	Average Yld. in Bus. per Acre	"t" Values	Wt. per Bushel	Average 1000 Kernel Weight Grams	"t" Values	Date	Cut	Days Before Ripe	Average Yld.per Acre in Bushels	"t" Value	Average 1000 Kernel Weight Grams
July	21	19	7.6	22.4	30	13.73	19.30	Aug.	1	12	27.4	10.26	21.96
	24	16	14.6	12.0	36.5	17.94	8.50		3	10	36.3	3.62	23.56
	28	12	18.9	12.8	42.5	22.34	6.81		5	8	31.6	7.52	25.46
	31	9	25.2	1.6	47.5	26.09	2.88		7	6	51.1	1.37	27.88
Aug.	4	5	29.3	.60	47.5	27.82	1.16		9	4	50.1	1.00	29.42
	6	3	36.6	2.43	48.0	27.87	1.52		11	2	55.2	.07	30.57
	9	-	31.5	-	49.0	29.76	-		13	-	54.9	-	29.74
		After								After			
	14	5	29.4	2.41	48.5	26.32	2.36		14	1	53.5	.27	30.39
									17	4	42.5	4.96	28.50

Results of Chemical Determinations:

After having observed the variations that occur in yield and quality with respect to harvesting at different stages, further observations lead up naturally to a consideration of the internal changes that may have occurred in the barley grown under the same conditions.

It is an established fact that early in their development, plants rapidly take up mineral nutrients from the soil. These materials are elaborated, stored in the stems and leaves, and later transferred to the heads and kernels. Accordingly a larger amount of stored material should be found in the leaves and stems before the kernel is well formed.

Results will be presented which will substantiate this fact.

Weather conditions during the period of sampling no doubt have an effect upon the daily variation in chemical composition. Meteorological records are also of interest when comparisons have to be made between the conditions under which this experiment was conducted and conditions elsewhere. The daily variations in the meteorological conditions during the period of sampling are given in Table VI.

Table VI

Daily Variations in Meteorological Conditions

During the Sampling Period

Date	Maximum Temp.	Minimum Temp.	Mean Temp.	Hours Sun-shine	Precipi-tation	
July					.53	
13	78	59	68.5	11.0	.16	1
14	82	57	69.5	7.0	--	2
15	86	64	75.0	9.5	.71	3
16	82	62	72.0	9.0	.40	4
17	83	57	70.0	8.5	--	5
18	76	53	64.5	14.5	--	6
19	77	55	66.0	9.0	.03	7
20	79	54	66.5	9.5	.11	8
21	80	51	65.5	15.0	--	9
22	76	49	62.5	15.0	--	10
23	79	47	63.0	14.5	--	11
24	84	58	71.0	14.0	--	12
25	93	62	77.5	14.0	--	13
26	97	73	85.0	14.0	tr	14
27	90	59	74.5	11.0	--	15
28	92	59	75.5	5.5	tr	16
29	75	48	61.5	12.0	tr	17
30	84	48	66.0	14.0	--	18
31	78	56	67.0	10.0	--	19
August						
1	75	55	65.0	.5	.40	20
2	58	53	55.5	0.0	.66	21
3	70	53	61.5	7.5	tr	22
4	86	61	73.5	11.5	--	23
5	97	60	78.5	11.0	--	24
6	70	50	60.0	6.5	--	25
7	69	54	61.5	4.0	--	26
8	76	61	68.5	3.0	tr	27
9	77	50	63.5	8.0	.10	28
10	68	47	57.5	5.0	.18	29
11	74	45	59.5	13.7	--	30
12	78	55	66.5	12.5	--	31
13	87	60	73.5	11.5	--	32
14	76	63	69.5	12.5	--	33
15	83	50	66.5	12.5	--	34
16	84	50	67.0	13.5	--	35
17	92	65	78.5	11.5	--	36
18	91	58	74.5	10.0	--	37

The Dry Matter and Moisture Results:

The daily fluctuations in percent dry matter in the different plant parts and whole plant samples, and the variations in percent moisture are given in Table VII.

The percent dry matter in heads and whole plant samples increases regularly from heading to maturity. The percent dry matter in the leaves fluctuates greatly but in general increases up to fourteen days after heading, followed by a stationery period of one week, and then a rapid increase up to maturity. During this period from fourteen days after heading until twenty days after, the kernels were in the soft milk to firm dough. This would indicate that during the period of rapid starch infiltration plant materials are translocated from the leaves almost as fast as they are manufactured. In the culms on the other hand, the percent dry matter increased up to the fourteenth day, followed by a fall for a period coincident with that of the leaves, and then a slight gradual increase to maturity. The percent dry matter in the heads is higher at all stages than that of the leaves and culms. The relative percentages for the last sampling for the leaves, culms and stems being 85, 40 and 96 respectively.

Table VII

Daily Variations in Percent Dry Matter and Percent Moisture in O.A.C.21 Barley

Date Sampled	Days from Heading	% Dry Matter				% Moisture (Green Wgt)				Daily Decrease or Increase in % Moisture			
		Leaf	Culm	Head	Plant	Leaf	Culm	Head	Plant	Leaf	Culm	Head	Plant
July													
13	1	18.0	14.8	20.7	18.4	82.0	85.2	79.3	81.6				
14	2	19.2	15.7	24.4	19.0	80.8	84.3	75.6	81.0	-1.2	- .9	-3.7	- .6
15	3	18.2	14.6	20.7	17.6	81.8	85.4	79.3	82.4	+1.0	+1.1	+3.7	-1.4
16	4	18.9	16.0	24.1	18.2	81.1	84.0	75.9	81.8	- .7	-1.4	-3.4	- .6
17	5	21.6	17.2	27.9	20.0	78.4	82.8	72.1	80.0	-2.7	-1.2	-3.8	-1.8
18	6	17.0	18.2	29.2	21.6	83.0	81.8	70.8	78.4	+4.6	-1.0	-1.3	-1.6
19	7	20.1	18.5	29.8	21.6	79.9	81.5	70.2	78.4	-3.1	- .3	- .6	0.0
20	8	24.2	22.2	35.1	26.2	75.8	77.8	64.9	73.8	-4.1	-3.7	-5.3	-4.6
21	9	22.7	21.1	34.9	25.3	77.3	78.9	65.1	74.7	+1.5	+1.1	+ .2	+ .9
22	10	24.2	22.7	34.8	27.1	75.8	77.3	65.2	72.9	-1.5	-1.5	+ .1	-1.8
23	11	26.0	23.6	36.4	28.0	74.0	76.4	63.6	72.0	-1.8	- .9	-1.5	- .9
24	12	26.8	25.4	35.8	27.6	73.2	74.6	64.2	72.4	- .8	-1.8	+ .6	+ .4
25	13	26.0	29.7	38.5	29.0	74.0	70.3	61.5	71.0	+ .8	-4.3	-2.6	-1.4
26	14	32.6	30.8	41.1	33.9	67.4	69.2	58.9	66.1	-6.6	-1.1	-2.6	-4.9
27	15	29.5	28.9	40.1	29.4	70.5	71.1	59.9	70.6	+3.1	+1.9	+1.0	+4.5
28	16	31.9	27.2	41.0	30.7	68.1	72.8	59.0	69.3	-2.4	+1.7	- .9	-1.3
29	17	33.9	28.9	43.6	35.5	66.1	71.1	56.4	64.5	-2.0	-1.7	-2.6	-4.8
30	18	32.8	27.3	43.8	33.1	67.2	72.6	56.2	66.9	+1.0	+1.5	- .2	+2.4
31	19	31.5	27.3	46.4	33.2	68.5	72.7	53.6	66.8	+1.4	+ .1	-2.6	- .1

Table VII (cont'd)

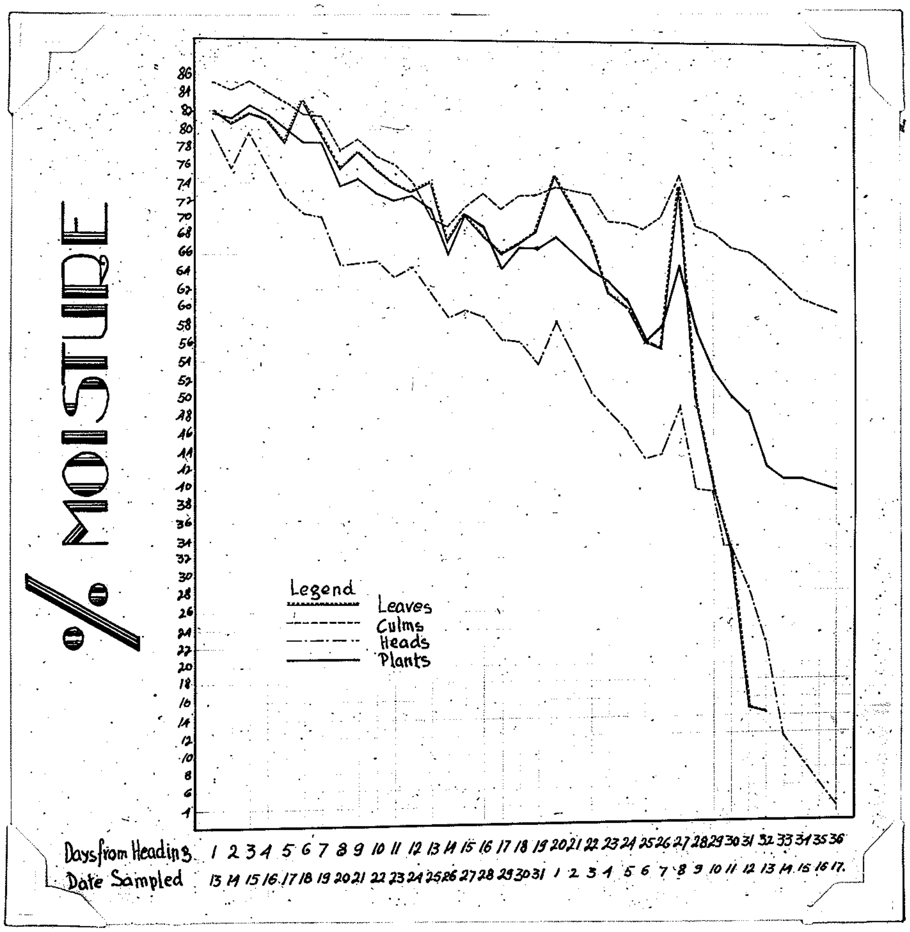
Daily Variations in Percent Dry Matter and Percent Moisture in O.A.C.21 Barley

Date Sampled	Days From Heading	% Dry Matter				% Moisture (Green Wgt)				Daily Decrease or Increase in % Moisture			
		Leaf	Culm	Head	Plant	Leaf	Culm	Head	Plant	Leaf	Culm	Head	Plant
August													
1	20	24.9	26.5	41.6	31.8	75.1	73.5	58.4	68.2	+6.6	+ .8	+1.4	+1.4
2	21	----	----	----	----	----	----	----	----	----	----	----	----
3	22	32.0	27.0	49.4	35.5	68.0	73.0	50.6	64.5	-7.2	- .5	-7.8	-3.7
4	23	38.2	30.1	51.8	36.8	61.8	69.9	48.2	63.2	-6.2	-3.1	-2.4	-1.3
5	24	39.9	30.2	54.0	38.9	60.1	69.8	46.0	61.1	-1.7	- .1	-2.2	-2.1
6	25	44.0	31.2	57.0	43.6	56.0	68.8	43.0	56.4	-4.1	-1.0	-3.0	-4.7
7	26	44.3	29.6	56.3	41.8	55.7	70.4	43.7	58.2	- .3	+1.6	+ .7	+1.8
8	27	26.9	25.1	51.1	35.1	73.5	74.9	48.9	64.9	+17.8	+4.5	+5.2	+6.7
9	28	49.9	30.8	60.6	42.7	50.1	69.2	39.4	57.3	-23.4	-5.7	-9.5	-7.6
10	29	61.0	31.4	60.7	47.0	39.0	68.6	39.3	53.0	-11.1	- .6	- .1	-4.3
11	30	67.5	33.1	67.0	49.7	32.5	66.9	33.0	50.3	-6.5	-1.7	-6.3	-2.7
12	31	85.2	33.4	71.5	51.6	14.8	66.6	28.5	48.4	-17.8	- .3	-4.5	-1.9
13	32	85.5	34.7	77.6	57.6	14.5	65.3	22.4	42.4	- .3	-1.3	-6.1	-6.1
14	33	----	37.0	88.4	59.3	----	63.0	11.6	40.7	----	-2.3	-10.8	-1.7
15	34	----	39.0	91.4	59.3	----	61.0	8.6	40.7	----	-2.0	-3.0	-0.0
16	35	----	----	----	----	----	----	----	----	----	----	----	----
17	36	----	40.2	96.2	60.4	----	59.8	3.8	39.6	----	-1.2	-4.8	-1.1

The moisture results indicate a uniform decline with approaching maturity for all the plant parts as well as the whole plant samples.

The percent moisture on the basis of green weight, are given in Table VII. These results are depicted graphically in Figure 33 The percent moisture in the heads decreased regularly from one to twenty nine days after heading, but from this time on, a rapid fall occurs. The marked fluctuations in the percent moisture in the leaves is to be expected since they are the active tissue, and respond quickly to fluctuations in meteorological conditions. In the culms the general trend is down for the first fifteen days, followed by a more or less stationery period for seven days, and finally a gradual decrease to maturity. It is interesting to note that no rapid fall occurs in the culms with approaching maturity, such as occurs in the other plant parts. This would seem to indicate that some translocation of food material must be taking place almost to the end or, that the cells contain large amounts of physically bound water. The marked increases in percent moisture on July 15th, August 1st, and August 8th, are due to the fact that the samples contained considerable surface moisture, due to rain. The results in general indicate that all the plant parts except the culms, decrease regularly in percent moisture up to the

Figure 3



The Daily Trend in Percent Moisture (green weight) in the Plant Parts and Whole Plant Samples from Heading To Past Maturity hard dough stage, and from then on, very rapidly due to desication. The culms however never reach a moisture content as low as the heads and leaves. The period of uniform moisture content in the culms coincides closely with the period of rapid storage of material in the kernel.

The daily increase or decrease in percent moisture indicated in Table VII shows periods of increase and decrease from day to day. This is quite in accord with the observation made by Thatcher[18] on wheat and oats. The average daily decrease for the leaves, culm, heads and whole plant samples was found to be: 2.2; 0.8; 2.3; and 1.4 percent respectively, giving an average for all the determinations of 1.7 percent. Investigations conducted on barley at Rothamstead[5] and Aberdeen (10 and 11) indicated a daily decrease in moisture of 1 percent and 2 percent respectively.

The Ash and Protein Results:

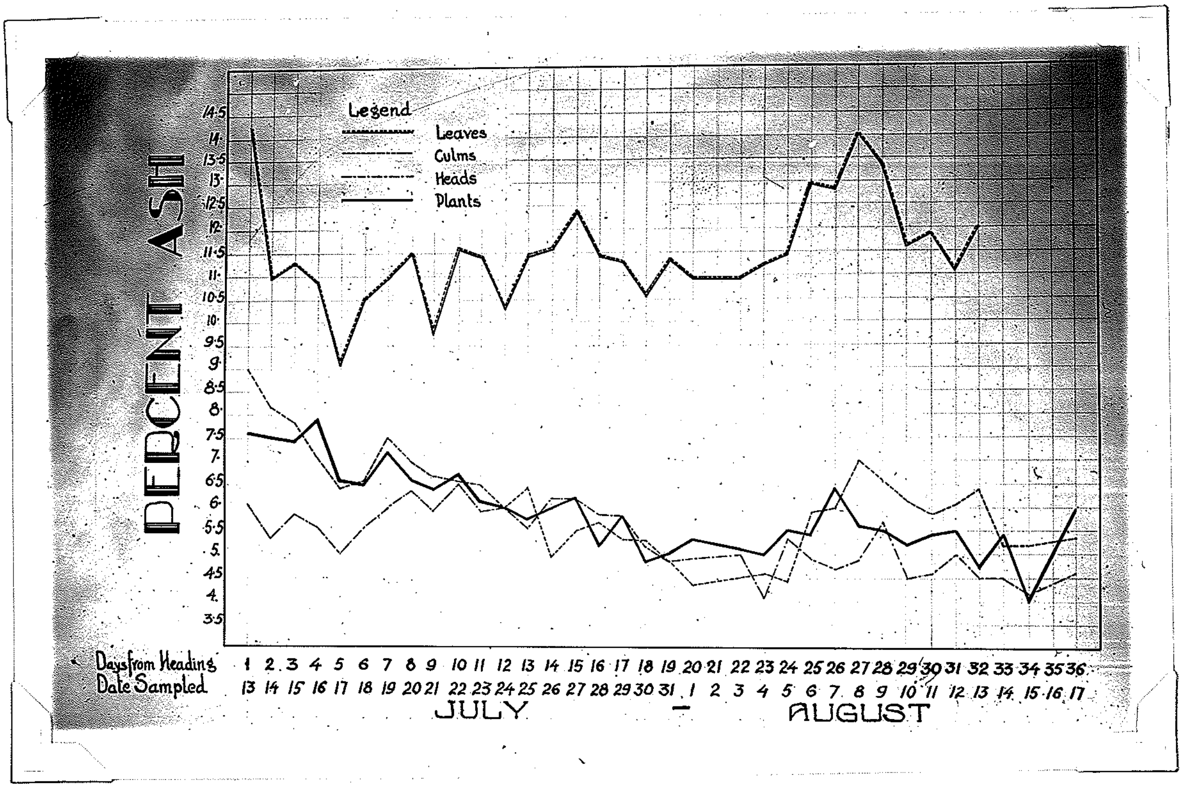
The percent ash was determined by the modified Alcohol Glycerol Method as outlined in (1). Great difficulty was experienced in ashing the head samples from the period July 23rd to 29th. This represents a period from the time the kernels were in the milk stage until about the firm dough stage. All modifications and combinations of temperatures, with and without the addition of alcohol and glycerol were used, but particles of carbon still persisted. The ashing problem at this particular stage would seem to bear further investigating.

The protein was determined by the Kjeldahl method outlined in (3), the percent nitrogen being multiplied by the factor 6.25, since this is the factor used in reporting percent crude protein in all barley malting tests.

The results reported to a 13.5% moisture basis are given in Table VIII. The results for the plant parts and whole plant samples are outlined in Figures 4 and 5.

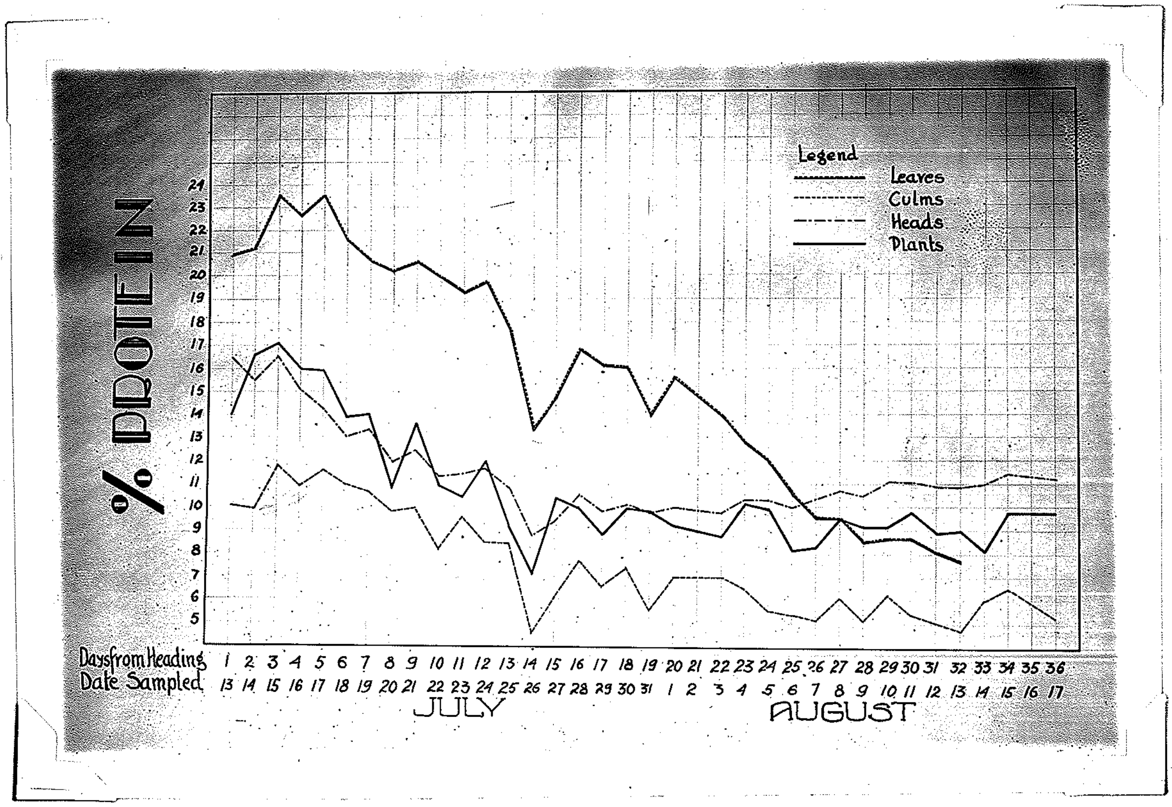
The ash content of the leaves shows a marked decrease to five days after heading, followed by a period of considerable fluctuation for two to three day periods and then a gradual rise to the high point five days before ripe, with a gradual falling to maturity. In general the trend is an increase to maturity. The percent ash in the leaves is considerably higher than in either the culms or heads. The distribution of the ash in the culms is indicated by a regular decrease to twenty four days after heading, when the kernels are in the firm dough, and then a marked increase to maturity.

Figure 4



Changes in Ash Content (13.5%) Moisture Basis) from Day to Day In the Component Parts and Whole Plant Samples from Heading To Past Maturity

Figure 5



Variation in Percent Protein (13.5% Moisture Basis) in the Plant Parts and Whole Plant Samples from Heading to Past Maturity

Table VIII

The Daily Percent Ash and Protein Content of Plant Parts and Whole Plant Samples from Heading to Four Days Past Maturity (13.5% Moisture Basis)

Date Cut	Days From Heading	% Ash				Percent Protein (N x 6.25)			
		Leaf	Culm	Head	Plant	Leaf	Culm	Head	Plant
July									
13	1	14.25	9.05	6.11	7.55	20.9	10.1	16.5	14.0
14	2	10.94	8.21	5.32	7.45	21.2	9.9	15.5	16.6
15	3	11.25	7.77	5.76	7.35	23.5	11.8	16.6	17.1
16	4	10.85	7.08	5.57	7.85	22.6	10.9	15.1	16.0
17	5	9.13	6.41	4.96	6.62	23.5	11.6	14.3	15.9
18	6	10.49	6.62	5.57	6.46	21.5	11.0	13.0	13.9
19	7	10.94	7.53	6.03	7.19	20.6	10.7	13.3	14.0
20	8	11.49	7.04	6.33	6.63	20.2	9.8	11.9	10.8
21	9	9.72	6.72	5.89	6.36	20.5	9.9	12.4	13.6
22	10	11.61	6.64	6.47	6.73	19.9	8.2	11.3	10.9
23	11	11.36	6.46	5.89	6.18	19.3	9.6	11.4	10.4
24	12	10.26	5.99	6.03	5.96	19.7	8.5	11.6	11.9
25	13	11.42	6.42	5.64	5.69	17.6	8.5	10.8	9.2
26	14	11.57	4.92	6.19	5.98	13.3	4.6	8.8	7.1
27	15	12.27	5.48	6.17	6.20	14.7	6.1	9.4	10.3
28	16	11.37	5.71	5.79	5.21	16.7	7.7	10.6	9.9
29	17	11.30	5.30	5.75	5.85	16.1	6.6	9.8	8.8
30	18	10.58	5.34	5.20	4.78	16.0	7.4	10.1	9.9
31	19	11.31	4.85	4.83	5.05	13.9	5.5	9.8	9.8
Aug.									
1	20	10.94	4.34	4.92	5.27	15.5	7.0	10.0	9.2
2	21	-----	----	----	----	----	---	----	---
3	22	10.88	4.48	4.96	5.14	13.9	7.0	9.8	8.7
4	23	11.21	4.60	4.10	4.98	12.7	6.5	10.3	10.1
5	24	11.36	4.36	5.29	5.52	12.0	5.6	10.3	9.9
6	25	12.89	5.94	4.90	5.39	10.5	5.4	10.0	8.2
7	26	12.81	6.01	4.67	6.44	9.5	5.2	10.4	8.3
8	27n	14.02	7.00	4.89	5.58	9.5	6.1	10.7	9.5
9	28	13.33	6.63	5.68	5.49	8.5	5.2	10.5	9.2
10	29	11.58	6.18	4.53	5.23	8.6	6.2	11.1	9.2
11	30	11.83	5.84	4.64	5.45	8.6	5.4	11.1	9.8
12	31	11.08	6.13	4.97	5.47	8.1	5.1	10.9	8.9
13	32	11.99	6.43	4.51	4.67	7.7	4.7	10.9	9.0
14	33	-----	5.21	4.53	5.36	---	6.0	11.0	8.2
15	34	-----	5.25	4.16	3.99	---	6.5	11.4	9.7
16	35	-----	----	----	----	---	---	----	---
17	36	-----	5.29	4.63	5.92	---	5.3	11.2	9.7

In the head samples the percent ash shows a tendency to increase up to eight days, after heading, then to remain more or less uniform for a period of ten days, with finally a period of decrease to maturity. The whole plant samples indicate a slight decrease with approaching maturity.

The results indicate conclusively that the ash content of the leaves is higher than either the culms, heads, or whole plant samples.

The trend of the percent protein is given in Figure 5. The protein content of the leaves decreases rapidly from heading to maturity, the same decrease to maturity takes place in the culms although not so great. The head samples decrease regularly to fourteen days after heading, or until the kernels are in the soft dough stage. From this time on however, a slight regular increase is noted up to four days past maturity. The steady decline in the percent protein in the leaves and culms during the grain forming period, indicates that the rate of migration into the grain exceeds that of the intake into either the culms or leaves.

The Carbohydrate Results:

Brenchley and Hall[6] were the first investigators to report upon the distribution of the carbohydrate content of a cereal crop. In their investigation on wheat they considered the carbohydrate as that part of the dry matter, less protein and ash, which must be admitted does not represent the true carbohydrate content. Later in her investigation on barley, Brenchley[5] apparently used the same method of determining the total carbohydrate content. Thatcher (18) reported sugars in wheat as dextrose but no outline was given of the method used.

In the carbohydrate results reported here, the reducing sugars were determined by the Quizumbing and Thomas[3] method as outlined. The sucrose was determined by inverting an aliquot of the sugar solution with hydrochloric acid as outlined in[3] under plant and plant products. The starch was determined by direct acid hydrolysis and this method includes as starch, the pentosans and other carbohydrate bodies that undergo hydrolysis and are converted to reducing sugars on boiling with hydrochloric acid. Carbohydrate determinations were conducted on every second sample from heading to past maturity. All the samples were treated with anhydrous alcohol free ether to remove the fats before any attempt was made to extract the sugars. The reducing sugar and sucrose results have been reported as invert sugar, and the starch results as dextrose.

The results of the reducing sucrose and starch determinations on the leaves, culms and head samples are given in Table IX. It must be noted here that the starch results for the head samples are low and this is due to the fact that the head samples did not consist of the grain only, but the glumes, rachis and awns were included. The head samples would therefore have a much higher crude fibre content than the threshed grain only, resulting in a material reduction in percent carbohydrate.

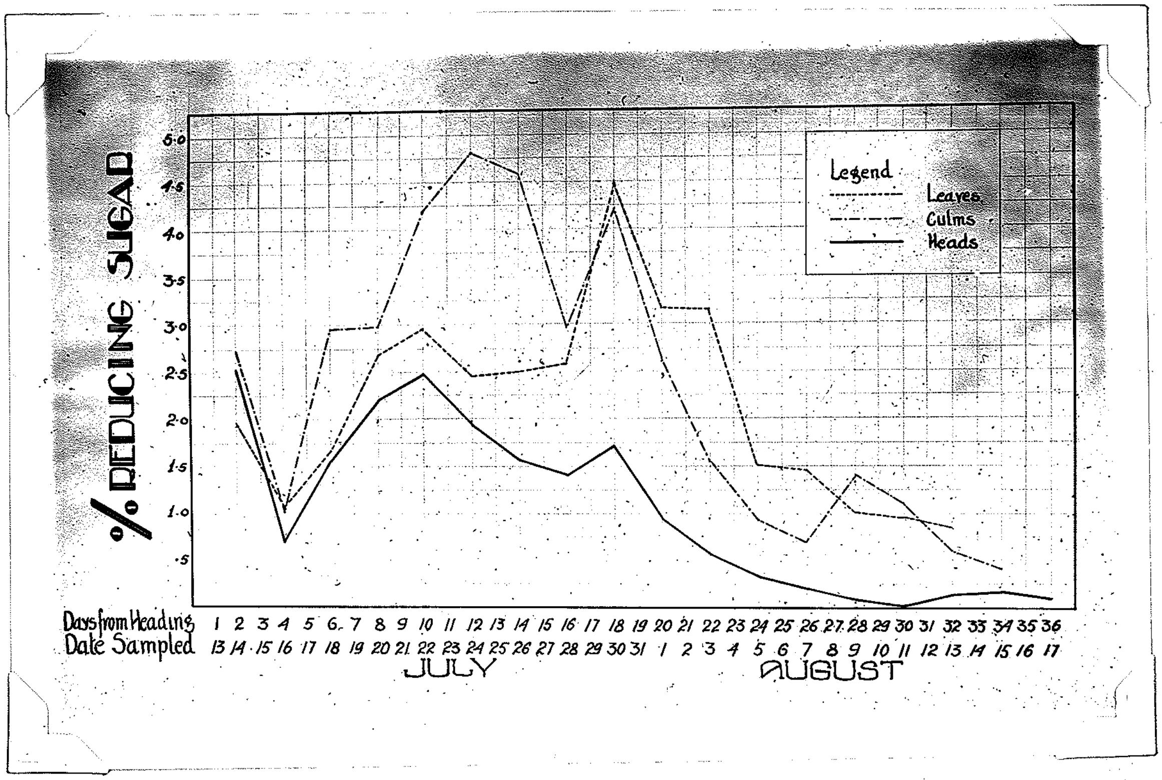
The distribution of the percent reducing sugar in the culms, leaves and heads is given in Figure 6. There is a marked decrease in reducing sugars in all the plant parts four days after heading. This may be due to a three day rain which took place at this time and a period of relatively little sunshine, which would indicate that photosynthetic processes in the plant were not active or not as active, as translocation processes. The reducing sugars in the leaves increased from this time until eighteen days after heading, when the kernels were almost in the firm dough stage. From this stage on the percent reducing sugars in the leaves decreases rapidly. The maximum content of reducing sugars in the culms is found twelve days after heading. From this period which coincides with the milk stage, a rapid decline is observed. In the head samples the increase and decrease in percent reducing sugar practically coincides with that of the culms, although the actual percentage is less.

Table IX

The Distribution of Reducing Sugars, Sucrose and Starch at Two Day Intervals From Heading to Past Maturity in the Component Parts of O.A.C.21 Barley

Date Sampled	Days from Heading	LEAF			CULM			HEAD		
		Per-cent Reducing Sugars	Per-cent Sucrose	Per-cent Starch	Per-cent Reducing Sugars	Per-cent Sucrose	Per-cent Starch	Per-cent Reducing Sugars	Per-cent Sucrose	Per-cent Starch
July										
14	2	1.90	2.33	.18	2.74	.97	.54	2.56	3.64	4.79
16	4	1.18	4.22	.29	1.08	.65	2.88	.72	2.72	8.46
18	6	1.64	7.36	.11	2.84	2.01	5.60	1.54	5.01	9.61
20	8	2.72	1.26	.44	2.98	2.96	.54	2.23	10.49	8.12
22	10	2.94	1.18	.16	4.37	3.85	1.37	2.44	12.30	5.15
24	12	2.45	2.36	4.59	4.78	3.69	1.64	1.98	9.46	1.94
26	14	2.53	2.10	.11	4.68	8.50	2.21	1.54	15.85	11.74
28	16	2.71	.60	.54	2.90	2.96	.54	1.37	6.59	8.91
30	18	4.44	.87	.20	4.23	3.22	1.10	1.73	6.28	5.81
August										
1	20	3.35	.31	.41	2.63	3.84	.61	.94	4.01	5.58
3	22	3.32	.21	.13	1.61	3.12	.58	.54	3.56	13.05
5	24	1.54	.77	4.27	.90	1.35	.32	.31	2.18	15.86
7	26	1.44	.40	2.03	.71	.49	2.61	.22	2.55	24.37
9	28	1.06	.00	2.52	1.39	2.19	3.28	.14	1.93	18.14
11	30	.88	.05	6.50	1.18	1.62	7.15	.04	1.62	20.72
13	32	.78	.00	.34	.65	.12	2.47	.17	1.47	22.91
15	34	----	---	----	.38	.00	.68	.18	1.36	21.76
17	36	----	---	----	----	----	----	.15	1.48	29.66

Figure 6

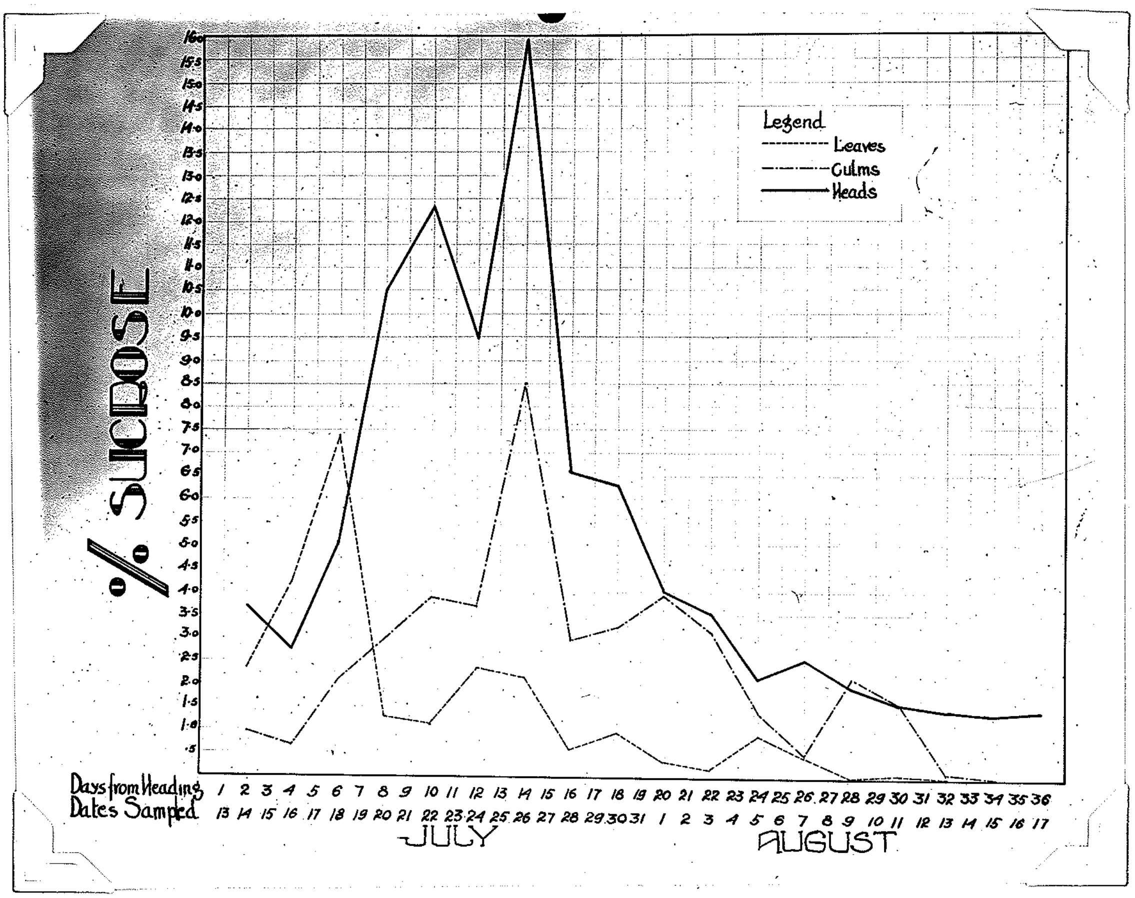


The Trend in Percent Reducing Sugar (as Invert) in Leaves, Culms, and Heads of O.A.C.21 Barley at Two Day Intervals From Heading to Past Maturity

The variations in the sucrose content of the component plant parts are given in Figure 7. The sucrose content in the leaves reaches a maximum six days after heading, and then decreases more or less uniformly up to maturity. The maximum in the culms occurs eight days later or fourteen days after heading, and from then on to maturity a definite loss occurs. It is of interest to note that almost in every case the high and low sucrose contents of the leaves and culms respectively are eight days apart. If this is a metter of translocation, it would indicate that eight days elapsed between the time of maximum content in the leaves and the building up of a maximum content in the culm. The sucrose content of the heads increases up to fourteen days after heading when the kernels are in the milk stage, and then rapidly declines to four days before maturity, assuming equilibrium from then on. The percent sucrose in the heads greatly exceeds the amount contained in either the leaves or culms throughout the growing period, with the exception of the first six days after heading.

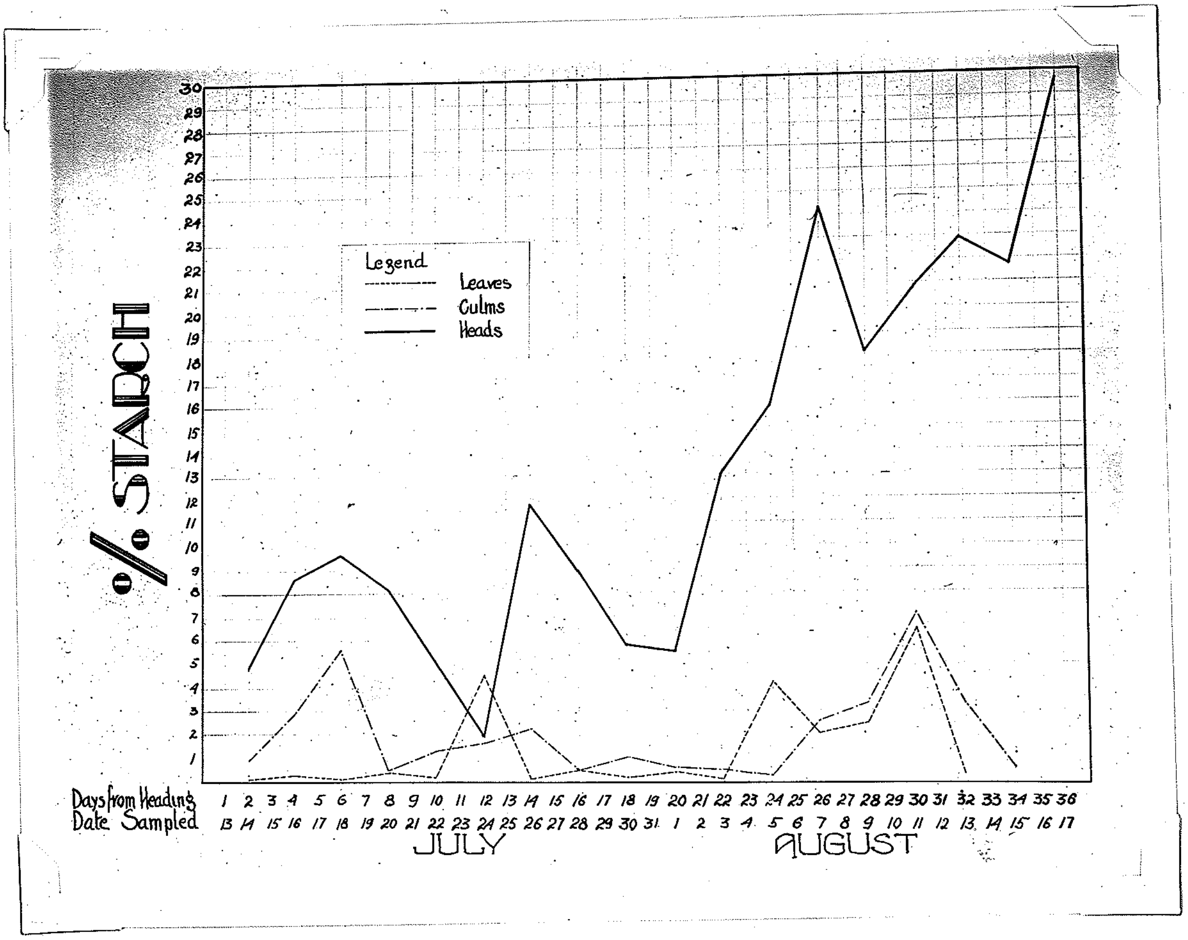
The distribution of the starch, Figure 8, indicates wide fluctuations in all the plant parts. The general trend however indicates a rapid increase in the starch content of the head samples with approaching maturity, and an increase in the percent starch of the leaves and culms during the last stages of ripening and desiccation.

Figure 7



The Distribution of the Percent Sucrose (as Invert) in the Leaves, Culms and Heads at Two Day Intervals

Figure 8



The Distribution of the Percent Starch (as Dextrose) in The Component Plant Parts; Leaves, Culms and Heads at Two Day Intervals from Heading to Past Maturity

An attempt was made to correlate the fluctuations in carbohydrate content from day to day, with the meteorological conditions for corresponding days. No significant correlations were obtained, possibly due to the fact that climate is a complex of many factors, and that the effect of particular climate conditions on plants is accumulative, thus tending to obscure the immediate effect.

From the data on reducing sugars and sucrose, it is evident that the vegetative portions of the plant in the earlier periods of development actually manufacture sugars and translocate them to the kernel faster than the endosperm cells are able to synthetize them into starch, but in the later stages starch formation proceeds at a relatively more rapid rate and the percentage of sucrose and reducing sugars decrease rapidly in all the parts.

Conclusions:

Subject to the environmental conditions under which this investigation was conducted, the following conclusions can be made.

(1) No significant reduction in either yield per acre or weight per thousand kernels results from harvesting O.A.C.21 barley one week before mature.

(2) The weight per measured bushel increases up to nine days before ripe, from this time on there is little change.

(3) The percent dry matter in the heads and whole plant samples increases regularly from heading to maturity.

(4) The percent dry matter in the leaves fluctuates greatly, but in general, increases up to fourteen days after heading, followed by a period of uniformity for one week, and finally a rapid increase up to maturity. In the culms the dry matter increased, followed by a decrease coincident with the periods in the leaf and then an increase to maturity.

(5) A uniform decline in moisture content occurs with approaching maturity in the plant parts and whole plant samples.

(6) The percent ash in the leaves and whole plant samples tends to decrease with approaching maturity while in the heads a rise followed by a period of uniform content up to the eighteenth day, and then a decrease to maturity was observed. The decrease in the culms continues to the twenty-fourth day after heading, followed by an increase to maturity.

(7) The ash content of the leaves is higher than any other plant part.

(8) A steady decrease in percent protein of the leaves and culms takes place up to maturity. The heads decrease in percent protein until the kernels are in the soft dough stage, but from this time on a slight increase takes place.

(9) The percent reducing sugars in the leaves increases

during the period from four days to eighteen days after heading, at which time the kernels are in the firm dough stage, from then on however, a rapid decrease takes place.

(10) The reducing sugars in the culm increases to a maximum at the milk stage, and then rapidly declines to maturity.

(11) The increase and decrease in percent reducing sugars in the heads coincides with that of the culms, but the actual percentage is less.

(12) The maximum percent sucrose occurs in the culms and heads fourteen days after heading, or when the kernels are in the milk stage. From the time the kernels are in the milk stage, to four days before maturity a rapid decline takes place.

(13) The sucrose content of the leaves reaches a maximum about one week after heading, and about one week previous to the high point in the culms and heads.

(14) The general trend of the percent starch in the head samples indicates a rapid increase with approaching maturity.

(15) An increase in the starch content of leaves and culms sampled during the last stages of ripening and desiccation is indicated.

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