SOME ENVIRONMENTAL FACTORS AFFECTING THE YIELD AND THE QUALITY OF SOFT WINTER WHEATS

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INTRODUCTION

There is probably no factor that has a more important bearing on the yield, quality, and kind of wheat which can be produced in a given locality, than the environment. The environment may be considered as being made up of two factors, the climate and the soil. The climate, as considered in this particular work, consist mainly of such measurable phenomena as the temperature; the amount, distribution, and nature of the precipitation; and the per cent sunshine or cloudiness. It is a general rule that the higher the rainfall and the cooler the summer, the softer the wheat that is produced. As great a variation in the quality of wheat may occur in different seasons on the same farm as occurs in different parts of Michigan in any one season.

Michigan normally grows about 900,000 acres of winter wheat, most of which is produced in the central and southern half of the lower pininsula. Practically this entire amount consists of either soft red winter or soft white winter wheat. Most of this wheat which reaches the commerical markets is used in a specific trade because many millers are not interested in a high protein wheat but want wheat suitable for pastry and cracker flours, or flours for other purposes for which wheat of moderate protein content is desired. They desire, generally, a plump wheat of good bushel weight, as is typified by the soft winter wheats produced in Michigan.

The purpose of this program of research was to accumulate data on the relation of the various factors of environment and cultural conditions to the milling and baking quality of both standard and newly developed varieties of soft winter wheat. The ultimate object of the program was to develop a basis upon which to establish a rational system of regional standardization of wheat varieties and wheat quality, having in mind the special requirements of the milling industry.

This study deals with the influences of various environmental and cultural factors on the composition of some of Michigan's soft winter wheats. Among the more important of these environmental and cultural factors reported upon are (1) effect of shading on the yield and quality of wheat, (2) effect of time of harvest on the yield and quality of wheat, (3) effect of varying amounts of water applied to the growing wheat plants on the yield and quality of the grain, and (4) some correlations between weather and the yield and quality of wheats. In this paper quality consists of such factors as per cent moisture, test weight per bushel, protein content, volume of loaf, weight per kernel, and expansion of dough. Yield per acre takes into consideration the amount of shattering of the grain, and the losses that might occur through natural agencies. All protein percentages are corrected to 13.5 per cent moisture unless otherwise indicated.

Some Effects of Shading on the Yield and Quality of Wheat

Plants which grow normally under full sunlight conditions are very different when produced with one-fourth or one-half of the normal amount of sunshine or under conditions of extreme cloudiness. Michigan climatic conditions vary from those of the hard wheat producing areas in that it has greater periods of cloudiness and higher atmospheric humidity, both of which have the general affect of reducing the sunlight intensity which reaches the plants, and lowering the mean temperature.

Three individual projects dealing with the effects of shading on small grains were conducted by Koch (13) in Germany, Thatcher (28) in Washington, and Welton and Morris (32) in Ohio. Their results point very definitely to the fact that shading produces grain with lower carbohydrate content, but increased nitrogenous and mineral matter. Each investigator noticed the increased vegetative growth and amount of lodging that took place with plants grown under shade.

In 1930, physiological studies were inaugurated by Wilsie (34) at this institution to obtain information regarding the qualitative and quantitative influences produced by these conditions, and because his work was the start of this phase of the four-year problem, his results are included in this paper. The purpose of these studies was to determine at just what time during the growing plant's activity could the greatest change be brought about in the composition of the grain produced by the plants by reducing the intensity of the sunlight reaching them.

Method of Procedure

The shading of the plants was accomplished with one thickness of cheesecloth stretched tightly over light wooden frames. These frames were about three feet square and about five feet high. A MacBeth Illuminometer recorded about 50 per cent as much sunlight intensity under the cages as outside. Thermograph records showed practically the same temperature outside the cage as they did inside. These upright cages were placed over the plants growing under field conditions. The area under each cage was harvested and was kept separate from the area under every other cage. Protein determinations were made upon the material from each cage separately using the standard Kjeldahl method, and the results for each set of cages were averaged. Areas extending entirely around the cages were taken as checks. There was a small amount of shading at different times of the day caused by the shadow from the cage, but by taking a composite sample from all sides of the cage it was thought that this factor might be compensated for.

The periods of shading varied slightly from one year to another. In 1930 three periods of shading were used, varying from May 8 until harvest, from May 3 until June 16, and from June 5 until harvest. In 1932 the cages were placed over the grain on April 25, May 7, 21, and June 4 and were left over until harvest. The 1933 experiments varied somewhat from those of the previous years in that additional data were gathered on plants shaded for two, four, and six week periods and the allowed to come to maturity under natural sunlight conditions. All cages were placed out in the field on April 28 while the plants were only a few inches tall and had not yet started active growth. At the end of two weeks four of the cages were moved over and the area that had been covered was staked off and the plants allowed to come to maturity without further treatment. At the end of another two weeks, four more cages were moved, and a third set was moved six weeks after April 28. These treatments were made to bring out any differences between plants shaded from April 28 until May 15, June 1, and June 15 respectively, and then allowed to ripen under natural sunlight. Each treatment consisted of at least four cages to allow for any variations that might be incountered.

Results and Discussion

Data are presented in Tables 1 to 4 giving the results obtained in the shading experiments from 1930 to 1933 inclusive. The exact periods of shading varied slightly in the different years, with additional information being gained in 1933 on the influence of shading for one, two, and three week periods in the early spring and then allowing the plants to mature under normal sunlight. The variations in protein content of the kernels were quite marked for each period of shading. In almost every case shading increased the protein content, being from 1.10 to 2.28 per cent if shading took place on or before the first week in May; from 1.10 to 1.55 if the shading began during the second week in May; from 0.66 to 1.27 per cent if shading began in the third week in May; and from 0.00 to 0.51 if the shading was delayed until after the first of June. Also, the results obtained in 1933 point out the fact that shading during May and the first part of June, and then allowing the plants to mature under full sunlight, increased the protein content from 1.44 to 2.04 per cent over the check. If there is to be any increase in the protein content the shading must, therefore, take place before the middle of June.

Plants shaded during this same period of growth produced kernels of lighter weight and lower germinating ability than did the checks. The differences in weight per 1,000 kernels ranged from 0.53 to 5.01 grams, with a difference in germinating ability from 0.00 to 7.00 per cent in the four years experiments. The plants inside those cages put out earliest in the growing season were from 10 to 12 inches taller before the middle of June than the plants immediately surrounding the cages. This difference was not quite so pronounced when the plants were harvested. There was considerable lodging of the shaded plants which was due mostly to their increased foliage and vegetative growth. In 1931 tests also showed that the grain grown under shade produced dough of greater expansion, which made larger loaves of bread, than the checks. This indicated a slightly stronger gluten for the shaded grain over grain produced under full sunlight.

Table 1 - Per cent protein of American Banner wheat kernels under varying lengths of shading in 1930 and 1931.

Duration of shading		1930*		1931	
		Percentage of protein			
From	Until	Shaded	Check	Shaded	Check
May 3	Harvest	11.4	10.3		
" 3	June 16	12.3	11.2		
" 13	Harvest			11.4	10.3
" 13	June 3			12.3	11.2
June 3 - 5	Harvest	10.1	10.5	10.3	10.5
" 9	"			11.5	11.4

* The 1930 results were obtained by Wilsie

Table 2 - Variations in the test weight, protein content, weight per 1,000 kernels, and per cent Germination of American Banner wheat produced by varying the length of shading in 1932.

Date cages put out		Test wt. in lbs.	% Protein	Wt. per 1,000 kernels grams	Germination percentage
April 25	Shaded	59.0	12.95	31.81	98.0
	Check	59.9	11.18	36.70	98.0
	Difference	.9	1.77	4.89	0.0
May 7	Shaded	59.0	12.89	31.35	96.5
	Check	60.7	11.64	36.38	98.0
	Difference	1.7	1.25	5.03	1.5
May 21	Shaded	60.3	11.77	36.82	98.5
	Check	60.0	11.11	36.29	99.5
	Difference	.3	.66	.53	1.0
June 4	Shaded	60.0	11.97	34.59	98.0
	Check	60.3	11.80	39.01	99.0
	Difference	.3	.17	4.42	1.0

Table 3 - Per cent of protein in kernels of wheat under light treatments of varying lengths of time in 1933.

Duration of shading								
	April 28	May 15	June 1	June 15	Harvest	% Protein	Difference in favor of	Odds
Shaded	■	■	■	■	■	15.99	2.28 shaded	221:1
Check						13.31		
Shaded		■	■	■	■	12.71	1.55 shaded	3332:1
Check						11.16	0.09 Check	1.88:1
Shaded	■					11.07	1.64 shaded May 1 to harvest	221:1
Shaded			■	■	■	12.78	1.27 shaded	130:1
Check						11.51		
Shaded	■	■				12.95	1.44 shaded 0.17 April 28 to June 1	108:1 1.46:1
Shaded				■	■	11.04	0.51 shaded	4.33:1
Check						10.53		
Shaded	■	■	■			12.57	2.04 shaded 1.53 April 28 to June 15	322:1 37:1

Note:- The bars indicate period of shading.

Table 4 - Weight per 1,000 kernels and germination percentages for cages in 1933.

Date cages put out	Weight per 1,000 kernels*			Per cent germination		
	Shaded	Check	Uncovered**	Shaded	Check	Uncovered
April 28	25.36	30.37		90.00	94.50	
May 15	32.21	33.12	29.79	93.50	96.50	95.50
June 1	25.86	29.62	30.63	91.50	98.50	91.50
June 15	26.80	30.20	30.36	92.50	96.50	94.50

* Weight per 1,000 kernels is given in grams.

** Uncovered plats are those which were shaded from April 28 until date on which the data are given, and then were allowed to mature under normal sunlight.

Discussion Based on Four Year's Results

The production of grain under a 50 per cent reduction in sunlight intensity has a very material affect upon its quality. There is a slight decrease in weight per bushel but a significant increase in protein content of the kernels, with the difference being in proportion to the length of time shading is continued from early spring. The shading between the last of April and the first of May produced very little difference in the protein content of the kernels, but the shading from the last of April until after the first week in June does increase the protein content. This indicates that the protein content of wheat seems to be determined between May 1 and June 15 in Michigan under the conditions of these experiments.

A 50 per cent reduction in sunlight intensity tends to injure the ability of wheat plants to produce heavy well filled kernels, which causes a loss in weight per bushel with the kernels being smaller and more shrunken than normal. Shading also injured the germinating ability of the kernels to some extent. The gluten seemed to be stronger when produced in kernels under shade. The vegetative growth of plants under shade is much more profuse than would be under normal conditions. The plants were taller under the shaded and lodged considerably more than the checks. The plants were able to regain their strength of straw and were better resist lodging if they were not shaded after the middle of June.

It is generally conceded that plants under shade will absorb more nitrates than plants out in full sunlight even though the soil conditions are the same for both. The photosynthetic ability of the plants apparently was not affected, by their growing under shade, as shown by the increased vegetative growth, suggesting sufficient carbohydrates, which together with the presence of nitrates, would result in increased protein synthesis. These wheat plants having approached their limit of vegetative growth, were still able to absorb nitrates from the soil which they probably used for seed development rather than for further vegetative growth because there was not such a great difference in the vegetative growth of the plants under shade from those outside at harvest time.

Some Effects of Time of Harvest on the Yield and Quality of Wheat

When wheat is harvested with a combine it may be necessary for a part of the crop to remain standing for a considerable period of time after it is mature. Grain thus harvested must be ripe enough, at the beginning of harvest, to thresh well and to keep in storage without serious heating. The delay in harvest occasioned by wide use of the combine makes a study of the influence of this practice on the quality of different wheat varieties of great importance because combine users must know how the variety of wheat which they use responds to delayed harvest if they are to maintain profitable yields and produce wheat of an acceptable market quality.

Briggs (2) an early Michigan investigator cut wheat in "milky, dough, yellow ripe, and dead ripe" stages and found that the weight of grain increased with each successive cutting up to the yellow stage but there was a slight decrease in yield when cut at the "dead ripe" stage. He also reported that the kernels received additional weight from the straw while the grain was in the shock.

McDowell (19) in Nevada, Pierre (21) in France, and Davenport and Fraser (4) in Illinois all reported that wheat increased in yield up to maturity, but McDowell believed that the dangers incurred by leaving the grain standing until it was dead ripe were too great, the losses from shattering, wind, and hail being of greater importance than the increase in development of the grain obtained by leaving it standing until it was dead ripe.

Olson (20) working in Washington concluded that the increase in weight of grain was continuous under all conditions until the moisture content of the kernels had been reduced to about 40 per cent, with no further increase thereafter.

Stoa (25) found that, even under rust conditions in North Dakota, the translocation of plant food into the kernels continued up to maturity.

Burnett (3) in Iowa found that several varieties of wheat increased in yield up to 10 per cent if allowed to stand longer than the period when they were usually harvested. In some plats the time of harvest was extended 10 days beyond the normal period. He concluded that photosynthesis and translocation of food to the kernel continues much longer than was formerly thought to be the case. Losses from delaying the harvest of wheat were much less than with other grains.

It will be noted that most of the previous work on time of harvest of wheat emphasized results due to cutting before maturity while the experiments reported here, as was the case with Burnett's work in Iowa, deals with varietal response to delayed harvest.

Wilsie, who started these projects in 1930, reported (34) "In a dry season like last year, after the wheat had reached a moisture content of 14 per cent, long days of 10 to 12 hours could be put in, harvesting with a combine, without danger of high moisture wheat. There was no appreciable lowering in test weight or in milling quality in wheat harvested two weeks after it was ripe enough for binder harvest".

Method of Procedure

Nine replications were harvested on the same date with each replication being a block of grain five drill rows wide, with seven inches between rows, and one rod long. Each plat was cut by hand with great care being taken to avoid any loss from shattering during the harvesting operations. A composite sample was taken from grain immediately adjoining the harvested plants for moisture determinations. Protein determinations were made in the Experiment Station Chemical Laboratories and corrected to 13.5 per cent moisture. The dates upon which the cuttings were made varied from year to year with a longer time being allowed the last two years between the date of first and last cutting to bring out any differences -- which might not have been evident before. Bald Rock wheat was included in the tests with American Banner in 1932 and 1933.

Results and Discussion

The results are contained in the following tables with their discussions following immediately.

Table 5 - Time of harvest results on the 1931 crop of American Banner, showing yield per acre, moisture content, and protein content with the different stages of ripeness.

Date of cutting	Yield in bushels per acre	Per cent moisture in kernels	Per cent protein of kernels	Stage of ripeness
July 3	28.6	very high	11.2	Very soft dough
" 6	29.0	21.9	11.3	Soft dough
" 9	29.3	16.9	11.2	Hard dough
" 13	28.4	15.1	11.3	Ripe
" 18	28.8	12.4	11.2	Dead ripe
" 27	28.1	9.8	11.4	Over ripe

Table 6 - Time of harvest results on 1932 crop of American Banner and Bald Rock wheats, showing the yield in bushels per acre, moisture content at harvest, test weight, protein content of both grain and flour, loaf volume, and weight per 1,000 kernels on the different dates of cutting.

Date of cutting	Yield in bushels per acre	% Moisture at harvest	Test wt. in lbs.	Protein Grain %	Protein Flour %	Loaf volume cc.	Wt. per 1,000 kernels grams
			American Banner Results				
July 7	42.0	35.7	59.2	8.88	7.18	482.5	37.4
" 14	41.9	13.1	59.2	8.86	7.64	482.5	38.9
" 19	42.1	11.3	58.7	9.02	7.25	477.5	37.0
" 25	41.3	12.4	58.4	8.89	7.42	470.0	38.3
Aug. 3	41.7	13.0	56.5	9.05	7.47	481.7	37.7
" 11	41.5	13.0	56.2	8.97	7.26	495.0	37.3
			Bald Rock Results				
July 7	41.5	38.6	60.8	9.05	7.82	500.0	38.3
" 14	41.9	14.6	60.8	9.35	7.71	510.0	38.3
" 19	42.0	11.2	60.6	9.41	7.69	512.5	38.4
" 25	41.6	12.5	60.3	9.32	7.61	525.0	38.0
Aug. 3	42.1	12.8	58.5	9.13	7.83	527.5	37.9
" 11	42.0	12.8	58.1	9.30	7.78	522.5	37.9

Table 7 - Time of harvest results on the 1933 crop of American Banner and Bald Rock wheats, showing yield in bushels per acre, moisture content at harvest, test weight, protein content of both grain and flour, loaf volume, and weight per 1,000 kernels on the different dates of cutting.

Date of cutting	Yield in bushels per acre	% Moisture at harvest	Test wt. in lbs	Protein Grain %	Protein Flour %	Loaf volume cc.	Wt. per 1,000 kernels grams
			American Banner Results				
July 8	35.5	18.5	57.0	13.30	10.61	505.0	31.6
" 19	36.7	13.6	56.0	11.52	10.16	500.0	31.5
" 31	33.0	13.2	54.9	12.79	10.02	502.5	33.0
Aug. 5	33.8	16.7	54.8	11.44	10.17	512.5	31.6
" 12	32.8	16.0	54.7	11.40	10.06	520.0	31.8
" 19	34.1	17.5	54.1	12.38	9.84	550.0	31.8
			Bald Rock Results				
July 8	36.3	25.1	59.7	14.08	11.84	495.0	32.7
" 19	35.8	13.3	58.5	13.62	11.79	507.5	32.1
" 31	35.3	13.1	57.4	13.72	11.64	532.5	33.3
Aug. 5	38.1	16.6	56.7	14.10	11.56	530.0	33.0
" 12	30.8	16.2	57.3	13.87	11.37	512.5	33.5
" 19	31.9	17.1	56.8	13.31	11.60	520.0	32.9

Discussion Based on Four Years Results

There was no significant decrease in yield in the American Banner variety in any of the three years, although the yield of Bald Rock decreased slightly the last two cuttings in 1933. This fact indicates quite clearly that either of these varieties may stand for at least a month after regular binder harvesting date with out any material loss in yield unless in case of very severe hail or wind storms.

The moisture content at harvest time decreased quite rapidly until it reached about 14 per cent where it fluoturated with atmospherical conditions. This shows there is little danger from high moisture wheat when harvested with a combine after the moisture has reached about 14 per cent.

There was a material decrease in test weight of both varieties after about the third week from binder harvest time. This one factor may be great enough in cases where a long delay is necessary between the time of cutting the first part of the crop and the last part to lower the market grade of the grain, but few farmers have this large an acreage in Micigan. The Bald Rock variety was heavier in test weight per bushel in every case than was the American Banner.

There was no significant differences in protein content during any one of the three years. There was a difference from one year to another but these might well be expected as seasonal variations in any variety. The Bald Rock was higher in its protein content than American Banner in every case which classes it as a slightly stronger wheat.

Loaves produced from grain cut later in the season were slightly larger than those baked from wheat cut earlier. These results, being consistent in both 1932 and 1933, indicate that leaving grain standing uncut in the field increased slightly the gluten strength of the kernels.

There was little variation in the weight per 1,000 kernels over the entire range of harvesting dates in either 1932 or 1933. There are some fluctuations which might be expected in picking out this many seeds from a sample.

It therefore, would be possible to harvest these varieties of grain with a combine under normal Michigan conditions. From 10 to 12 hours a day may safely be put in harvesting without serious damage from high moisture wheat, or loss of yield. The quality of the grain, as signified by slightly lower yields and lower test weight, which will depend somewhat on climatic conditions, will be slightly lower for grain harvested late in the season.

Some Effects of Applying Varying Amounts of Water on the Yield and Quality of Wheat

Water applied to wheat, either in the form of rain or as irrigation, can cause a considerable variation in the yield and quality of the crop. The time or stage of development of the plants, when rainfall or moisture is abundant or scarce, is also important in its affect upon the yield and quality that is produced. In general, it is quite well recognized that a high percentage of water in the soil lowers the protein content of the grain but increases the test weight per bushel. A definite relationship between the amount and the time of rainfall, and protein content of wheat and character of flour should make possible, (1) a better basis for recommendation of wheat varieties as related to rainfall of a given area and the moisture retentiveness of soils, and (2) advanced information on the probable protein content of the wheat crop of the State as soon as rainfall conditions are known.

Widtsoe (33) in Utah, reported that late irrigations were beneficial to wheat, and that the yield and protein content increased as the amount of water supplied to it was increased up until the first of July. He concluded that the first few inches of water possessed a much higher value than those applied later.

From a review of the literature on this subject, Lyon (16) at Cornell, came to the conclusion that the affect of an insufficient supply of soil moisture was to prevent maturation of the grain, and to thus produce a high per cent of nitrogen in the kernel. He found that under some conditions there was doubtless a greater absorption of nitrogen by the crop when the moisture supply was small.

Thatcher (28) found under conditions in Washington that with uniform conditions of soils, growing season, distribution of annual rainfall, elevation, etc., with the total annual rainfall the only variable, the average protein content of wheat varies inversely with the total rainfall received. He concluded that the "softness" of Pacific Coast wheats was because of the cool harvest weather, which induced a slow ripening in spite of the low moisture supply.

Welch (31) in Idaho, and Kezer (12) in Colorado, reported that applications of water at the tillering and jointing stages gave the highest protein content of the crop, with those at tillering being slightly higher than at jointing, and the lowest protein content was obtained when water was applied at the filling stage. Applications at heading and blossoming periods gave the best quality of protein in the wheat, and, if only one application was possible, one at this period would give the best results. In general, the earlier irrigations gave the higher protein contents, but the kernels were more shriveled with a lower test weight per bushel.

Harris (8) working with the irrigation of wheat at Greenville Farm, Utah, found that under those conditions the heaviest kernels were produced on plats receiving five inches of water each at the bloom stage, and when the plants were in the dough stage, while his lightest, but greatest number of kernels per head, came from plants which received a five-inch irrigation after the grain was planted and before it came up. The heaviest weight per bushel was produced by a five-inch application of water when the plants were in the dough stage.

Jones and Colver (10 & 11) reported from Idaho that the difference in quality of wheat produced under irrigation from that produced on dry land was much less than commonly thought, and that irrigation did not of necessity imply that the wheat crop would be soft, nor that all soft wheat was grown on irrigated fields. The protein of the kernels produced on the dry-farm was only one per cent greater, and the protein of their flour only 0.7 per cent greater, than the average irrigated sample. There was no significant difference between the average dry-farmed and irrigated sample in weight per bushel, in weight per 1,000 kernels, or in percentage of moisture, ash, or oil.

Olson (20) concluded from his irrigation tests in Washington that variation in the amount of water used, or the distance between the rows, had little to no affect on the protein content, or weight per kernel after the moisture content had been reduced below 40 per cent. He placed the roots of plants in water and found that the water moved nitrogen into the kernel as the plant approached maturity.

Bailey (1) draws the following conclusions based on work carried on by himself and others, "Cool summers with high rainfall, and a relatively long growth period results in the grain of wheat being high in percentage of starch and low in percentage of protein. Hot, dry summers, on the other hand, result in the production of wheat having a high percentage of protein. In general, the amount of rainfall during that period of growth which immediately preceeds ripening is responsible for the rate of starch deposition in the kernel, and, consequently, for the relative protein content. Climatic conditions are responsible for greater variations in the composition of wheat than are other factors, with the possible exception of irrigation. Since varying rainfall results in variations in the soil moisture available to the plant, and this in turn induces variations in the protein content of the wheat grown on the soil, it follows that applications of irrigation water are similarly responsible for variations in protein content of irrigated wheat. The addition of irrigation water to the soil will, within certain limits, increase the yield of grain per acre, but the kernels, while heavier and plumper, will contain a lower percentage of protein than when no water is applied. The protein content of the grain varies inversely with the quantity of irrigation water applied".

Kraybill (14) concluded from work carried on in Indiana that applications of water furing the translocation period may tend to reduce the available supply of nitrates to the plant because of leaching. In this way there was a greater production of carbohydrates and a lowering of the nitrogen content of the kernels.

Stark (24) in Illinois, concluded that cool weather with sufficient well distributed rainfall, from the period of heading to maturity, retards ripening and makes for the development of carbohydrates and their deposition in the form of starch in the kernels. Such wheat will contain plump full kernels but usually of low protein content. Hot, dry summers hasten maturity, which tends toward the formation of smaller kernels having a higher protein content. With the faster development from heading time until maturity less carbohydrates can be produced, and the kernels, therefore, will be higher in their crude protein content. Soil having good fertility and high moisture holding capacity affects the compositon of the grain by prolonging the vegetative growth and thus making a longer period of growth for the formation of starch. High amounts of available plant foods, especially nitrogen, usually makes for high protein wheat.

Method of Procedure

Two varieties of wheat were used in this experiment, American Banner and Red Rock. The experimental plants were laid out 23 drill rows wide by 20 feet long, and trimmed to 18 feet long and 19 drill rows wide at harvest time to allow for border affect. Dikes 6 inches high surrounded each plat to control the water, which was metered from the city mains the last two days of each week. Rainfall data for the last 60 years were obtained from the local weather bureau station and used as a basis for water applications. Three different amounts of water, termed surplus, average, and deficient were applied. The surplus amount equaled the greatest amount of rainfall for that month during the past 60 years; the average amount of rainfall for each month was calculated from the 60 years weather data; and the deficient amount corresponded to the least amount of water falling as rain for each of these months during the 60 year period. In this way the applications of water to the plats were similar to Michigan conditions during this long period of years.

Ten plats of American Banner were covered with a heavy water proof canvas to control the rainfall in the deficient plats in 1932, but because of heavy leaf rust infection these canvases were not used in 1933. Any rain falling during the week was determined by a rain gauge and this amount deducted from the water metered out to the plats the last two days of the week. Harvesting was done with a hand sickle, cutting the straw as close to the ground as possible to obtain a uniform yield. Weights were taken of the shocked straw and grain on each plat, and the yield of grain was obtained at threshing time. Protein content was determined for the grain and later for the flour from each plat. Flour yield, absorption percentage, test weight, weight per 1,000 kernels, and volume of loaf were also determined for each plat, and then averages for each treatment were found.

Results and Discussion

The results obtained in 1932 for both American Banner and Red Rock wheats are contained in Table 8. In the case of American Banner the yield of straw was less on those plats receiving the least amount of water and increased quite steadily and uniformly with each different treatment. The straw appeared a little more heavily covered with foliage and weaker, which could readily account for the more lodging which took place on plats receiving the greatest applications of water.

The yield of grain followed in the same general trend with the increase in straw yield. There is a much greater portional increase in yield for the first 3.5 than for any other 3.5 inches of water added. The plats which received the deficient amounts of water were materially lower in yield of grain.

Table 8 - Treatments with results in 1932 on American Banner and Red Rock wheats, data arranged in order of inches of water which the plats received after May 15, showing weight of straw and grain, weight of grain alone, test weight, protein content of both grain and flour, volume of loaf, and weigh per 1,000 kernels for each treatment.

Total inches of water added	Wt. of straw in lbs.	Wt. of grain in lbs.	Test wt. in lbs.	Protein Grain %	Protein Flour %	Loaf volume cc.	Wt. per 1,000 kernels Grams
			American Banner Results				
0 - 3.6	33.25	7.04	58.33	13.07	11.66	434	32.4
4.4 - 6.8	35.70	11.65	59.36	10.05	8.91	430	36.4
8 - 10.9	39.81	11.13	59.54	10.44	9.49	419	36.3
14.5 - 19.9	42.65	12.27	59.20	9.77	8.43	418	36.1
			Red Rock Results				
6.8	32.44	10.66	59.38	11.37	10.64	458	38.2
8.4 - 12.4	33.19	11.00	59.80	11.88	10.98	441	37.7
14.5 - 19.9	36.35	10.13	59.48	11.77	11.04	456	36.6

Test weight per bushel was lower on the grain grown with smaller amounts of water. The kernels appeared more shrunken and wrinkled. There was no significant differences noted in applications of water above seven inches. The weight per 1,000 kernels follows very closely with the test weight, indicating more distinctly the shrunkenness of the kernels.

The protein content was much higher in the grain grown with the least amount of moisture. After June 1 slight variations in protein were found with applications of water above seven inches. Greater variations were produced when the water was controlled in the early part of the growing season.

Volume of loaf was not so variable as might be expected from the corresponding protein percentages. The grain grown under conditions favorable to high protein did produce larger loaves and as these results are averages of a large number of loaves baked, the differences are the more significant. There was quite a marked decrease in size of loaves made from grain grown with more than seven inches of water applied after May 15.

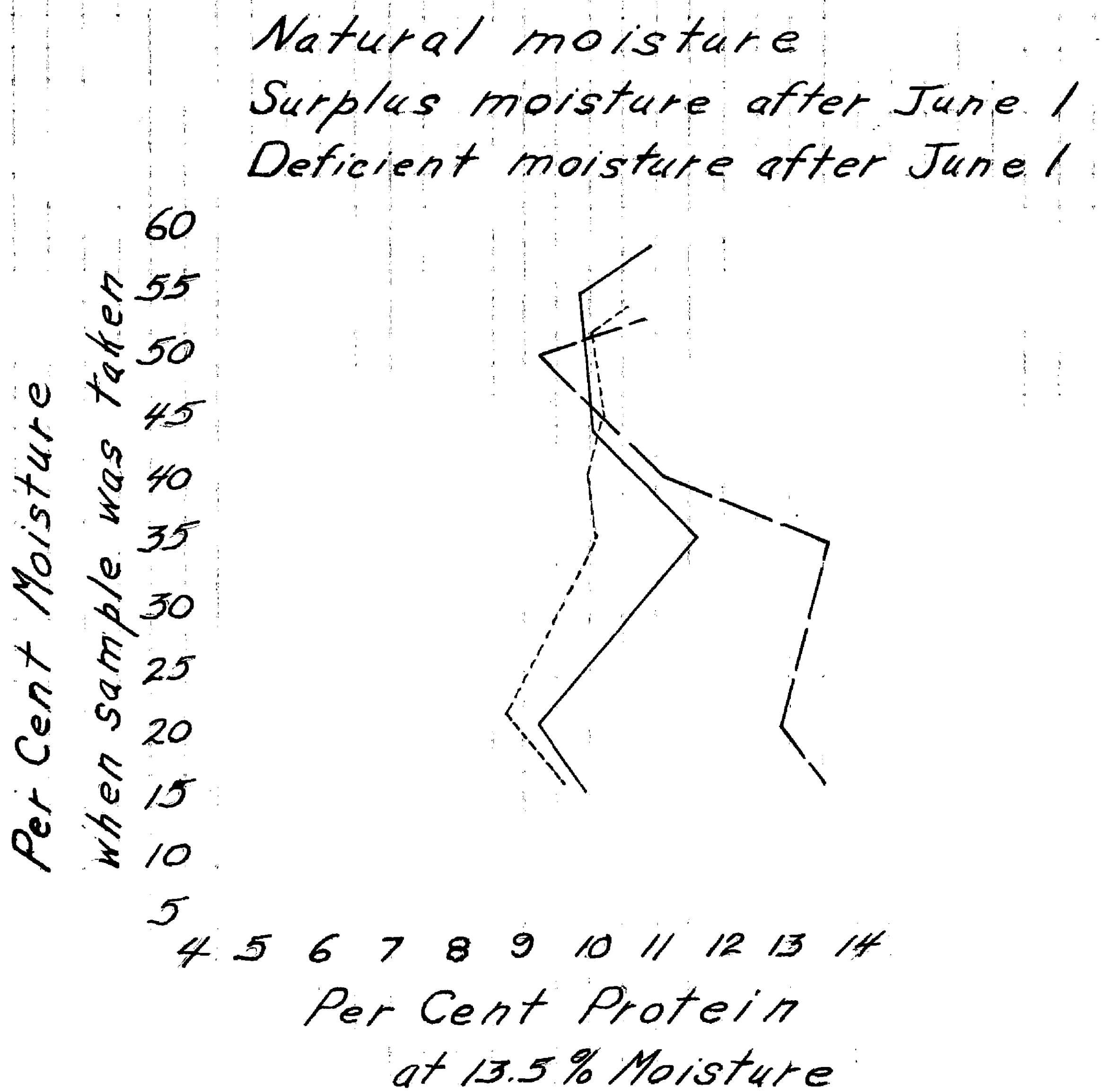
Little significance can be attached to the Red Rock results due probably to the wet season during May and June. There is however some indications of increased straw yield with increased water applications. The least amount of water received by any plat was almost seven inches, which seemed to produce as much grain having as high test weight, protein content, volume of loaf, and weight per 1,000 kernels as those plats receiving much greater amounts of water. Evidently seven inches of water applied after the middle of May created about as great a yield and as high a quality of grain as any amount up to 20 inches when coming at regular intervals.

Graph I shows the variation in the percentage of protein during the desiccation period. A small sample was taken from plats receiving the surplus, average, and deficient water applications, and protein and moisture content were determined for each. The first samples were taken June 27 when the moisture content of the grain was between 53 and 58 per cent. At this time the glumes were still so fast to the kernel that it was necessary to peel them off as the kernels were in the soft dough stage. Determinations were made every two or three days up until harvest time.

The percentage of protein shows a gradual increase as the moisture percentage decreases until on July 3 a heavy

Graph I

Variation in protein percentage of American Banner Wheat after heading date



rain of 1.8 inches fell in a few hours. At this time the moisture content of the grain was about 44 per cent. Three days later the protein percentage in all the plats shows a distinct drop. This might be explained by the plants starting new activity and growth which would call for an available supply of nitrogen. The heavy rain undoubtedly removed a great deal of the available nitrates from the soil necessitating the plants to draw on their own supply which was mostly stored in the seeds. This would cause a drop in the ratio of the percentage of protein in the seed to other materials and this affect would last until a balance between nitrates and the carbohydrates could be brought about. After the moisture content had decreased to about 22 to 23 per cent evidently normal activity had been resumed and the last few days just before harvest shows an increase in the protein percentage.

Those plats receiving the least amount of water show a greater percentage of protein than either those receiving an average or surplus amount. Those receiving an average amount show a slightly higher protein percentage than the surplus but due to the wet period during May and June the amount of water falling as rain was too great to produce the highest protein wheat.

The results obtained with American Banner and Red

Table 9 - Treatments with results on American Banner and Red Rock wheats in 1933. Results arranged in order of total inches of water applied after May 1, showing yields of straw and grain, grain alone, test weight, protein content of both grain and flour, and loaf volume for each treatment.

Total inches of water applied	Yield in lbs. Straw & Grain	Grain alone	Test wt. in lbs	Protein Grain %	Flour %	Loaf volume in cc.
			American Banner Results			
7.19 - 8.46	30.35	7.52	56.90	10.30	8.58	491.55
18.54 - 20.7	31.18	7.32	56.69	10.08	8.28	488.00
			Red Rock Results			
7.19 - 8.46	33.90	8.49	57.10	10.70	9.09	580.90
18.54 - 20.7	33.44	8.52	57.30	10.58	9.11	563.50

Rock in 1933 are contained in Table 9. Nitrate determinations were made at three different times during the growing season. Each plat was sampled in four different places and tests were run on the composite sample, using the method of determination developed by Dr. C. H. Spurway (23). The results of these tests showed the nitrate content of the soil to be low at all periods during the growing season. This indicated that the wheat plants were using the available nitrates as fast as they were formed.

The yields of straw and grain of either variety did not vary significantly between the lowest and highest applications of water, but the average test weight per bushel was slightly greater in those plats that received less than 8.5 inches of water than in those receiving over 8.5 inches. These differences are not very pronounced but the trend is in that direction.

There is also very little difference between the protein content of the different plats. There is a slightly higher protein content in those plats which received the least amount of moisture, but here again, the difference is not great enough to be significant. The protein content of the flour follows directly with that of the grain. There is no significant difference in the loaf volume between flours produced from grain which received 7 inches of water during May and June from those receiving over 20 inches. In all cases the loaves made from Red Rock flours were larger than those made from the American Banner flours. The protein contents in these two flours did not vary in the same proportion as their loaf volumes, which would tend to indicate a varietal difference in gluten strength.

Discussion Based on Two Year's Results

The results tend to indicate that 7 inches of water applied after the first of May seem to cause about as high a yield, percentage of protein, and to produce about as large a loaf as 20 inches applied regularly. Michigan average climatic conditions produce wheats of low protein content, and increasing the applications of water would not increase or even decrease materially the protein content. Any change that is to be brought about in these measures of quality must be done by lowering the applications of water below 7 inches during the months of May, June, and the first part of July.

Some Correlations Between Weather and the Yield and Quality of Wheat

The object of this phase of work was to determine the months of the year which had the most important affect upon wheat yield and quality. Michigan primarily is a soft winter wheat producing state with most of the wheat being planted from about the middle of September to the first part of October, and being harvested soon after the Fourth of July. The winters are usually not unduly severe on adapted varieties of winter wheat but it is necessary to plant the crop early enough in the fall so that the plants will be sufficiently developed to withstand the winter. It is also very necessary to wait until after the Hessian Fly free date, which varies slightly from year to year, before planting to avoid injury from this pest.

Lawes and Gilbert (15) did an immense amount of work correlating climatic conditions with crops, and in their publication gave the careful account of the meteorological characteristics of seasons favourable and unfavourable to wheat. Using principally Rothamsted data in respect to rainfall, they concluded that comparative dryness was desirable from seeding time in November to harvest, especially in the winter and early spring. Their table of averages showed no exceptional dryness of October for the favourable years, or exceptional wetness in the unfavourable years. They ascribed the affect of winter and spring rain partly to drainage causing loss of nitrates, and partly to hindering root development.

Shaw (22) pointed out as long ago as 1905, that, in the twenty years between 1885 and 1905, with but two exceptions, when the yield of wheat for Eastern England was above the average, the previous autumn rainfall was below the average and vice versa.

Hooker (9) found high negative correlations between the wheat yield and the rainfall for the periods centered in October and January, while between these two limits small positive correlations occurred. He also found that May rainfall was correlated positively with yield, being higher than the correlation in the fall and winter. From his work he concluded that a dry September-October ranked first among the wheat's requirements under the conditions with which he was working in England.

Fisher (6) found that, in general, rains are associated with lower temperatures in summer, in winter with higher temperatures and generally with diminished sunshine.

Under the conditions at Rothamsted he found that the average affect of additional rainfall above the normal is harmfull to the yield of wheat, with the exception of October, which gave a positive beneficial affect for rain. He also found that each additional inch of winter rain above the normal cost from one to two bushels in the crop's yield. This effect was found to be much greater on plats heavily supplied with manure, indicating that the damage done by winter rains was principally occasioned by the washing out of nitrates from the soil. He thought that a record of rainfall, in spite of the many points which it did not express, was of more value than the record of any other single element, in characterising the season from an environmental standpoint in relation to wheat.

Swanson (26) drew the conclusion based upon his work in Kansas that "Cool weather during the fruiting period and an ample supply of moisture usually means a soft yellowberry or starchy wheat." He found that cool weather was less stimulating to the production of available nitrogen, and an ample moisture supply meant a low concentration of nitrates. Thus, the varying of the season would vary the protein within a given locality.

Mangels (17) made a very complete survey of the protein content of North Dakota wheats as affected by climatic and other factors. He found that the variations in the protein content could not be explained by the variation in rainfall, but the higher percentages of protein were produced in years with the highest temperatures in June and July. The rainfall variations were so small that they could not explain the variations in protein content, so he concluded that temperature variations in June and July must be the explanation. High temperatures in June and July caused high protein and subnormal temperatures during these months caused a low protein. The subnormal temperatures increased the length of the growing season and thus aided in the carbohydrate formation.

Tippett (29) in England concluded that sunshine had a strong positive affect in the fall and winter. He suggested the winter sunshine affects the general soil temperatures and this in turn affects the root development of the plants. Soil temperature fluctuations in the spring had less affect because the average temperature of the earth was raised. The beneficial influence of summer seemed to be in the aiding of the ripening of the grain. He concluded that October and November were the most important fall months so far as sunshine influencing wheat yields were concerned. He found that for each hour of additional fall sunshine above the normal the yield of wheat ~~wheat~~ was increased 0.01

bushels.

Mangels (17) expressed the opinion that high temperatures in North Dakota increased the protein content of wheat but decreased the test weight. He found that the most critical climatic period was the two weeks just before harvest or just before the grain reached maturity.

Hallsted and Coles (7) working in Kansas with the winter wheats of that section, found a positive correlation between the moisture in the soil at seeding time and the yield of wheat the next summer at harvest time. From the results secured at Hays they concluded that a 20 per cent moisture content in the upper three feet of soil at seeding time practically precluded a failure of the crop. It was their opinion that the moisture content of the soil at seeding time may be of value in forecasting the yields or possible crop failures.

Methods Employed and Procedure

To obtain data for this type of study use was made of the college experiment station series plats from which yield data could be had over a 21 year period and protein data over a 12 year period. Weather data were obtained for the same corresponding periods from the United States Weather Bureau located in East Lansing about two to four miles from the various series plats.

All correlations were calculated by the machine method of calculation advocated by Wallace and Snedecor (34) of Iowa State College. Adjustments were made for the use small number of variates by the use of the formula advanced by Ezekiel (18). In the correlations on yield of both Red Rock from the series plats and the state yield of all wheat, the number of variates was over 20.

Correlations were calculated between protein content and April, May, and June rainfall individually; April and May totaled together; July, and August individually and totaled together; September, October, and November individually and totaled together. Single correlations were also run between per cent protein and the per cent possible sunshine for each of the months indicated above and each combination of months. Correlations were run between the protein content of Red Rock and the mean monthly temperatures of the same single and combinations of months as used in the rainfall and sunshine comparisons. Multiple correlations were then calculated between the rainfall and sunshine of spring, July, and fall with the protein content of Red Rock. To determine the difference made by the inclusion of the mean monthly temperatures, multiple correlations were also run between the rainfall, sunshine, and mean monthly temperatures, for spring, July, and fall, and the protein content of Red Rock. The same months and variates used in the protein content determinations of Red Rock were also used in the yield calculations with the exception that 21 years were used instead of the 12 for protein determinations.

In the calculations made on the state yield, the yield was taken for all counties of the southern half of the lower peninsula south of a general line extending west from Bay City. About 90 per cent of the winter wheat produced in the state is grown is this area. The yield figures were obtained from the annual summary of the Crops Report for Michigan for the years on which the calculations were based. The per cent possible sunshine covering this area was obtained from the weather bureau stations located at Grand Rapids, Grand Haven, Lansing, Detroit, and Port Huron. The rainfall data ~~was~~ were taken from the climatological data sheet issued monthly by the weather bureau station located at East Lansing, which gives the averages in rainfall for the counties used in these correlations. This method of obtaining the data for the calculation of the correlations was at best rather unreliable because it was possible to obtain the sunshine percentage from only five locations, but it was thought that the results would give some indications and leads upon which it would be advisable to do further research.

Results and Discussion

The results of the correlations are given in the following tables.

Table 10 - Showing the simple correlations between the various factors used in the multiple on yield of Red Rock on the Experiment Station series plats. 1913-1933

	Spring* Rain	Spring Sun	Spring Temp.	July Rain	July Sun	July Temp.	Fall** Rain	Fall Sun	Fall Temp.
Yield	.5425	-.5688	.0467	-.3364	.2581	.0377	.2222	-.2613	-.0193
Fall Temp.	.0485	.0147	.0853	-.0621	.0047	-.0017	-.4170	.1074	
Fall Sun	-.4134	.1066	-.0265	.2244	-.2937	-.1160	-.5160		
Fall Rain	.5332	-.1250	-.0980	-.0538	.1811	.1058			
July Temp	.0858	.0082	.0138	-.1166	.2030				
July Sun	.2022	.2886	.1289	-.6999					
July Rain	-.0147	-.1309	.0172						
Spring Temp.	-.0117	-.3141							
Spring Sun	-.3890								

(R = .80 ± .05)

($\bar{R}$ = .57 ± .10)

** Fall was taken as the months of October and November

* Spring was taken as the months of April and May

Table 10 gives the correlations obtained between the various factors of weather and the yield of Red Rock wheat as taken from the series plats on the experiment station at East Lansing. The correlation between the mean temperature of the months used and the yield is small, but the interaction of temperature with the other factors seems to play an important part. These data and correlations are based upon 21 years, and the variations in yields during this period is very great.

Spring rainfall has a positive affect on yield while spring sunshine has about the same amount of negative affect. This indicates that the more sunshine in the spring the less rainfall there will be and the rainfall is more important in securing a large yield than is the sunshine. July rainfall has a negative affect on yield, while July sunshine has about an equal positive affect. Both rainfall and sunshine in the fall have the same influence on yield, but of lesser magnitude, than they have in the spring. This indicates that abundant moisture and sufficient sunshine in the fall are important to obtain a well developed root system and vegetative growth before freezing weather. July sunshine and rainfall have an opposite affect to that of either spring or fall, which might be explained by the fact that a dry summer would not allow the preparation of a good seed bed and the plants, therefore, would not get such a good start in the early ~~spring~~ fall.

Table 11 shows the actual yields of Red Rock as compared with the estimated based upon the rainfall, per cent possible sunshine, and mean monthly temperatures of the years 1913 to 1933 inclusive. Two year's estimated yields lie outside the limits set up by the standard error of estimate. The crop of 1917 was not included in the correlation because the data ~~was~~ were lost at harvest time of that year. The majority of the estimated values are quite close to the actual yields.

Graph II brings out more forcefully the variations in the yields from one year to another. There is a much greater fluctuation in the yield from one season to another than is found in the protein content of the wheat (Table 21). This fact might be accounted for by excessively hard winters that kill off a part of the stand and thus materially cut down the yield the following summer.

Table 11 - Showing actual and estimated yields in the series plats based upon the rainfall, per cent possible sunshine, and mean monthly temperatures for the spring months*, July, and the fall months**.

Year	Actual yield in bushels per acre	Estimated yield in bushels per acre	Difference in bushels per acre
1913	24.4	20.34	- 4.06
1914	43.1	39.50	- 3.60
1915	40.6	34.94	- 5.66
1916	23.7	28.39	4.69
1918	34.0	32.81	- 1.19
1919	51.1	47.50	-- 3.60
1920	10.1	33.83	23.73
1921	23.8	26.27	2.47
1922	22.5	28.06	5.56
1923	23.5	15.76	- 7.74
1924	34.0	31.05	- 2.95
1925	7.3	8. 78	1.48
1926	19.4	18.00	- 1.40
1927	44.8	39.53	- 5.27
1928	27.4	32.34	4.94
1929	39.8	38.71	- 1.09
1930	49.5	36.26	-13.24
1931	40.4	36.71	- 3.69
1932	37.6	42.00	4.40
1933	37.3	43.53	6.23

Standard Error of Estimate equals 10.35

* Spring months includes May and April

** Fall months includes October and November

Graph II
Actual yield per acre Compared with estimated

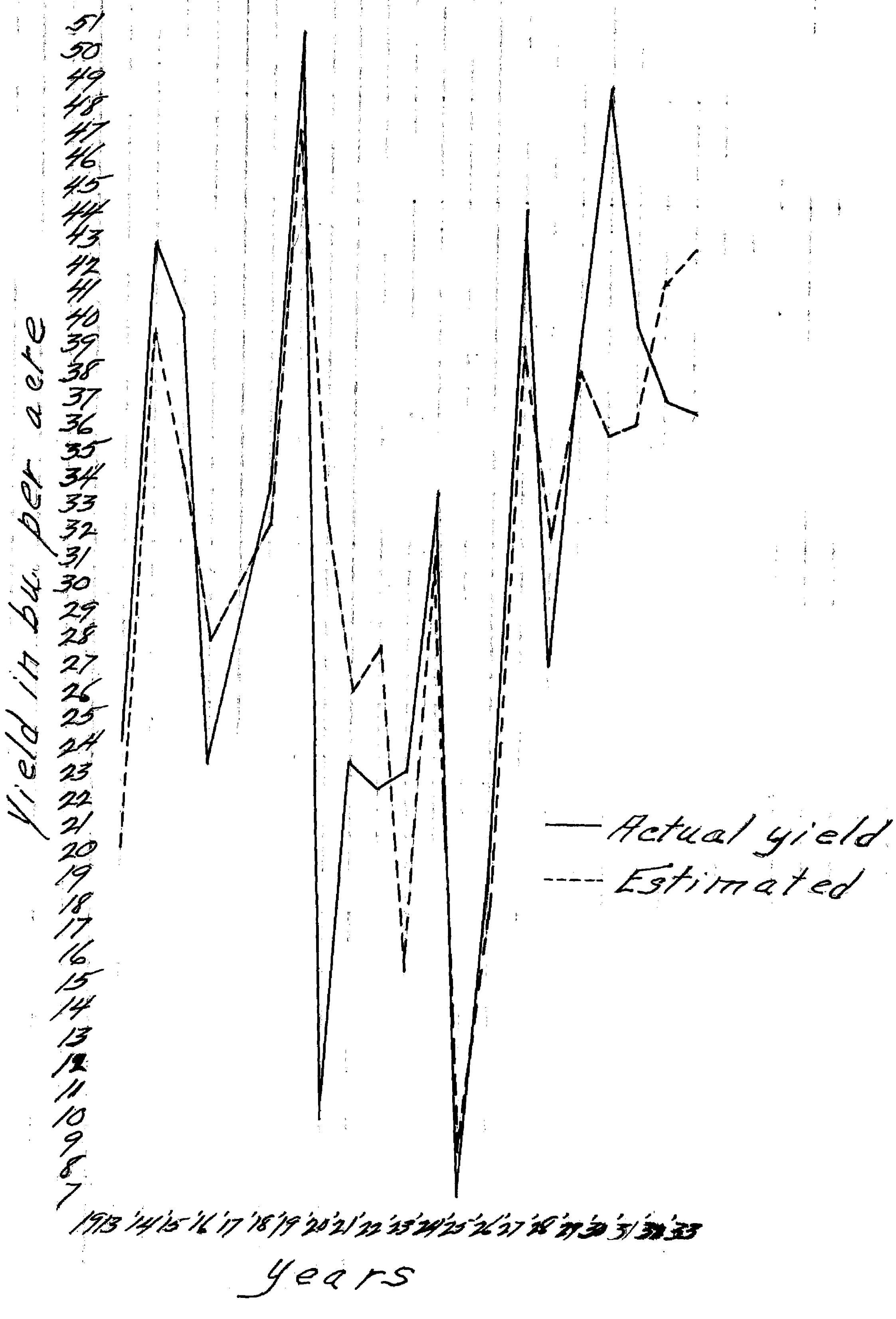


Table 12 - Single correlations between the various factors used in the multiple correlation between the rainfall, and per cent possible sunshine for Spring*, July, and Fall**, and the State yield of wheat from 1912 to 1933 inclusive.

	Spring* Rain	Spring Sun	July Rain	July Sun	Fall** Rain	Fall Sun
Yield	-.3564	-.0560	-.3318	.1976	-.3123	.0488
Fall Sun	-.3324	-.0953	.1375	-.0584	-.5836	
Fall Rain	.5883	-.1391	-.0568	.2732		
July Sun	.0539	-.1572	-.7581		(R = .58 ± .10)	
July Rain	.1528	.0752			($\bar{R}$ = .28 ± .14)	
Spring Sun	-.5835					

* Spring includes the months of April and May

** Fall includes the months of October and November

Table 12 gives the climatic factors considered and their relation to the state yield. Temperature was not included in these correlations because no reliable information could be obtained, and as the variation in temperature from one part of the state to another was so great very little value could be placed upon it. Per cent possible sunshine was taken from five different locations scattered over the southern half of the state. It was thought that five positions from which sunshine data could be had was not enough to give accurate information, but it was the best that could be obtained and the knowledge gained might point out new possibilities. Spring sunshine does not seem to be so important in its reaction with the state yield as was found in the station series plats. July rain on the following year seems to play as important a part as does either the spring or the fall. Fall rain shows a high negative correlation with spring rain when considered from a state average. Sunshine and rainfall for any period seem to be highly correlated.

Table 13 gives the actual yields as compared with the state estimated yields based upon the rainfall and sunshine for the spring, July and fall months. Of the 22 year period on which information was available for correlations, only five years laid outside the limits set by the standard error of estimate. This fact indicates quite clearly the possibilities that might be had in the prediction of yield of wheat based on available weather information.

Graph III pictures the relationship between the estimated yield as compared with the actual. There is considerable variations in the actual yields which indicates the difficulty in estimating the probable yields within the limits of the standard error of estimate.

Table 13 - Actual state yield of wheat and estimated yield based upon the rainfall, per cent possible sunshine, and mean monthly temperatures for the spring months*, July, and the fall months** for the years 1912 to 1933 inclusive.

Year	Actual yield in bushels per acre	Estimated yield in bushels per acre	Difference in bushels per acre
1912	10.00	15.46	5.46
1913	15.30	12.72	- 2.58
1914	19.70	16.20	- 3.50
1915	21.30	23.55	2.25
1916	16.60	18.15	1.55
1917	18.00	21.50	3.50
1918	14.00	19.60	5.60
1919	20.30	17.46	- 2.84
1920	15.60	21.67	6.07
1921	16.00	17.25	1.25
1922	14.00	16.07	2.07
1923	17.00	15.96	- 1.04
1924	24.00	20.51	- 3.49
1925	17.00	19.18	2.18
1926	18.30	18.10	- 0.20
1927	21.50	20.14	- 1.36
1928	16.00	17.38	1.38
1929	18.60	11.61	- 6.99
1930	23.50	20.52	- 2.98
1931	26.00	21.76	- 4.24
1932	24.00	20.47	- 3.53
1933	16.50	17.93	1.43

Standard Error of Estimate equals 4.18 bushels

* Spring months includes April and May

** Fall months includes October and November

Graph III

Actual State yield of wheat compared with estimated

The amount of rain falling during the spring months of April and May have a negative correlation with the protein content of that year's wheat crop. The percentage of sunshine for this same period indicates a positive correlation. The rainfall and sunshine during the month of July seem to have an opposite affect on the following year's crop to that shown by the spring months and also the fall months. The rainfall and sunshine of the fall months agree in their affect upon the protein with the following spring months although the correlations are not so strong. Fall rainfall and sunshine are correlated rather closely with that of the following spring.

These data seem to indicate that the greater the percentage of sunshine in the fall the lower the percentage of rainfall the following spring, but the higher the percentage of sun in the fall the higher the percentage the following spring. A wet fall seems to indicate that the following spring will also show a high amount of rainfall. The sunshine and rainfall are correlated strongly during any one season of the year. They also tend to indicate that the more sunshine during any one period of the year the less rainfall there will be.

Table 14 - Simple correlations between the various factors used in the multiple correlation for the protein content of Red Rock of the series plats from 1922 to 1933 inclusive.

	Spring* Rain	Spring Sun	July Rain	July Sun	Fall** Rain	Fall Sun
Protein	-.6980	.5055	.1987	-.5804	-.5464	.4171
Fall Sun	-.5253	.5921	.0100	.0568	-.6690	
Fall Rain	.6235	-.4542	-.0456	-.0353		
July Sun	.5127	-.3934	-.6148		(R - .90 ± .03)	
July Rain	-.1058	-.0117			($\bar{R}$ = .76 ± .09)	
Spring Sun	-.6121					

* Spring includes the months of April and May

** Fall includes the months of October and November

Table 14 gives the simple correlations between rainfall and sunshine and protein content of Red Rock. Spring rainfall has the highest negative correlation of any factors used, and spring sunshine has the highest positive correlation with the protein content. July sunshine seems to have a negative affect upon the protein content of the wheat the following spring. Fall sunshine is correlated negatively with the rain coming the following spring, and positively with the sunshine the following spring. Sunshine and rainfall of the same season are correlated negatively. July sun shows a positive correlation with spring rain, and a negative correlation with spring sun. July rain shows a low negative correlation with that of the preceeding spring.

Table 15 gives the actural protein contents of Red Rock as compared with the estimated percentages. The estimated protein contents are based only upon the affect of sunshine and rainfall, and shows only one estimated value that lies outside the limits of the standard error of estimate. In the fall of 1923 the per cent possible sunshine was higher than any other season and the rainfall was rather low, which might account for the per cent of protein in the grain the follwing year.

Graph IV pictures the trend of the estimated protein content as compared with the actual amount.

Table 16 gives the correlations between the climatic factors, including the mean monthly temperatures, affecting the protein content of Red Rock. Spring and fall temperatures, as well as July temperatures, have a negative affect upon the protein content. July temperatures show a very strong negative correlation with the following year's protein content. Spring temperatures show a rather strong positive correlation with July temperatures.

Table 15 - Actual and estimated per cent protein of Red Rock wheat based upon the rainfall and sunshine of spring* July, and fall**1922-'33.

Year	Actual percentage	Estimated percentage	Difference in percentage
1922	10.70	8.84	- 1.86
1923	15.27	14.92	- .35
1924	12.42	14.82	2.40
1925	17.70	16.42	- 1.28
1926	13.90	14.48	.58
1927	12.90	14.68	1.78
1928	13.30	12.98	- .32
1929	11.50	10.39	- 1.11
1930	11.20	11.47	.27
1931	14.80	15.18	.38
1932	9.50	11.16	1.66
1933	14.48	12.33	- 2.15

Standard Errof of Estimate equals 2.16 per cent

* Spring includes the months of April and May

** Fall includes the months of October and November

Graph IV

Actual protein percentage of Red Rock compared with estimated

——Actual percentage
-----Estimated

Table 16 - Simple correlations between the various factors used in the multiple on protein content of Red Rock wheat 1922-'33.

	Spring* Rain	Spring Sun	Spring Temp.	July Rain	July Sun	July Temp.	Fall** Rain	Fall Sun	Fall Temp.
Protein	-.6980	.5055	-.1205	.1987	-.5804	-.7187	-.5464	.4171	-.0458
Fall Temp.	.1070	.2873	-.0350	-.3555	.4122	.2244	-.2467	.3816	
Fall Sun	-.5253	.5921	-.0305	.0100	.0568	-.3880	-.6690		
Fall Rain	.6235	-.4542	.0866	.0456	.0353	.2966			
July Temp.	.4926	-.3031	.5126	-.2227	.5629				
July Sun	.5127	-.3934	.5515	-.6148			(R = .98 ± .01)		
July Rain	-.1058	.0117	-.3184				($\bar{R}$ = .88 ± .05)		
Spring Temp.	.1175	-.2005							
Spring Sun	-.6121								

* Spring includes the months of April and May

** Fall includes the months of October and November

The results from these data tend to indicate that if the spring is hot, July too is liable to be above the normal. Also that temperature does not seem to be as strongly correlated with rain as might be expected, but July temperature is quite strongly correlated with July sun.

Table 17 gives the actual protein content when compared with the estimated content based on all nine weather factors. With the inclusion of temperature in the correlation there is no estimated protein content that lies outside the limits set by the standard error of estimate. This tends to indicate that temperature does play some part in the determination of the quality of wheat as judged by its protein content.

Graph V shows how much closer to the actual protein content the estimated lies when temperature is included into the correlation. The difference between the actual and the estimated that was so evident in 1924 (Table 15) is almost completely obliterated when the high temperature in the fall of 1923 is taken into consideration. The difference brought out in 1927 is much smaller when the effect played by temperature is brought into the correlation.

Table 17 - Actual and estimated protein content of Red Rock wheat based upon the rainfall, sunshine, and mean temperature of spring* July, and fall** 1922-'33.

Year	Actual percentage	Estimated percentage	Difference in percentage
1922	10.70	10.36	- .34
1923	15.27	15.75	.48
1924	12.42	12.35	- .07
1925	17.70	18.27	.57
1926	13.90	12.81	1.09
1927	12.90	13.86	.96
1928	13.30	13.67	.37
1929	11.50	11.46	- .04
1930	11.20	11.64	.44
1931	14.80	13.15	-1 .65
1932	9.50	10.00	.50
1933	14.48	14.33	- .15

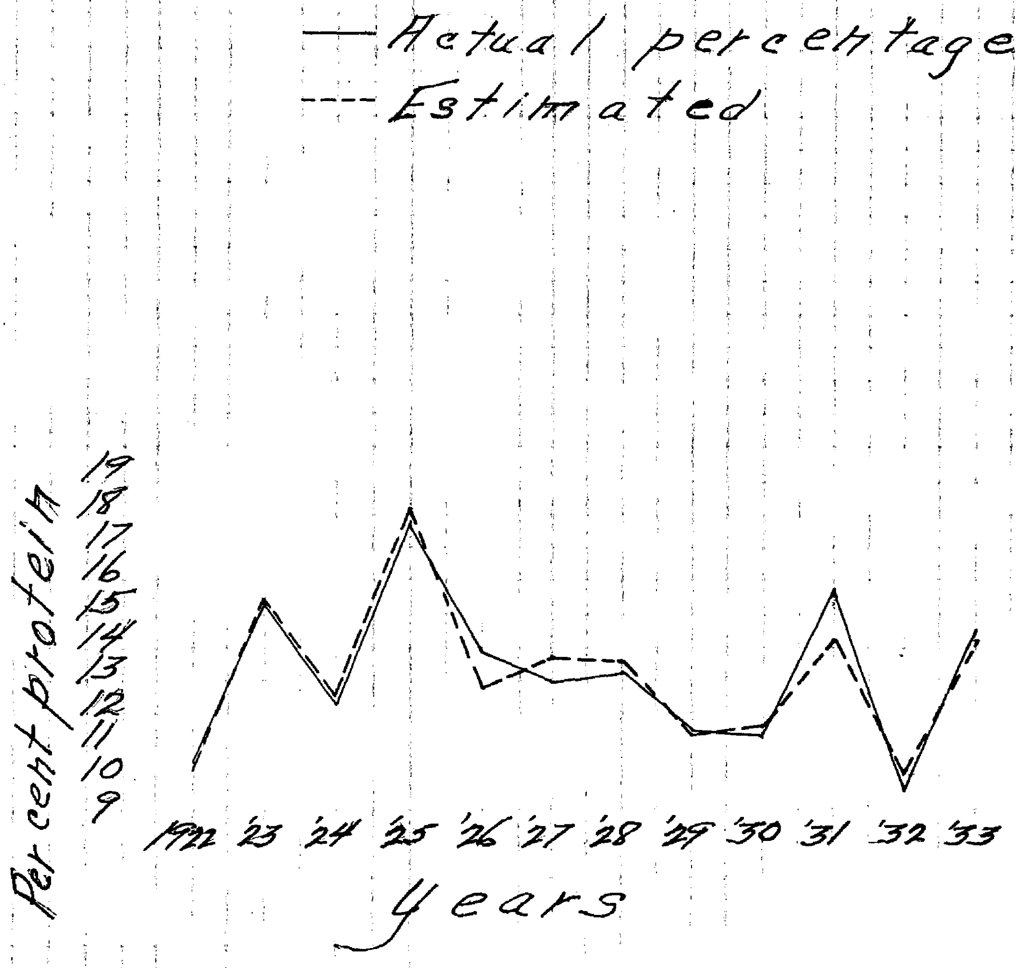
Standard Error of Estimate equals 1.89 per cent

* Spring includes the months of April and May

** Fall includes the months of October and November

Graph V

Actual protein content of Red Rock compared with estimated



SUMMARY

This thesis reports some efforts made to better understand the environmental factors affecting the yield and quality of soft winter wheats produced in Michigan. Some of these environmental factors considered are (1) effect of shading on the quality of wheat, (2) effect of time of harvest on the yield and quality of wheat, (3) effect of applying varying amounts of water on the yield and quality of wheat, and (4) some correlations between weather and the yield and quality of wheat.

Some of the effects brought out by shading are discussed. The protein content of wheat can be affected by growing the plants from the first of May to about the middle of June under shade. The increase in protein of grain grown under shade for this period was as much as 2.28 per cent over the checks, but there was no significant difference in the protein content unless the shading took place before the middle of June. The plants grown under shade had a more profuse vegetative growth, and gave indications of weaker straws with considerable lodging, but if the shading was discontinued after June 15 the plants were able to regain much of their stiffness of straw and to

better resist later lodging. The germination of wheat that was shaded for at least a month in the early spring was slightly lower than that not shaded at all. Grain shaded during this period was also lower in test weight per bushel, weight per kernel, and the kernels were more shrunken than those not shaded at all.

Some effects shown by delaying the time of harvest after the regular binder date are brought out. There was no significant decrease in yield in the American Banner variety in any of the three years, although the yield of Bald Rock decreased slightly the last two cuttings in 1933. It is shown that there was a rapid decrease in percentage of moisture from 40 per cent down to about 16 per cent, and after that the percentage merely fluctuated with climatic condtions. There was a consistent decrease in test weight per bushel in each variety after the grain reached the dead ripe stage. There was not a significant lowering of the protein percentage even up to five weeks after the regular binder harvest date. There were some indications of increased gluten strength of the wheat cut later in the season as reflected in the increased volume of loaf. These results tend to indicate the possibility of harvesting with a combine in the state of Michigan.

Results from varying the amounts of water applied to wheat on its yield and quality indicate that there is very little variations in the yield, protein content, or volume of loaf, between wheat produced with 7 inches of water, and that produced with 20 inches after the first of May. The normal amount of rainfall during this period is over 7 inches, so any material changes in yield or quality must be accomplished by reducing the moisture below the normal rainfall. Wheat produced with less than 7 inches does contain a higher protein percentage and lower yield than that produced with the normal amount of rainfall.

As a result of some correlations determined between weather conditions and the yield and quality of wheat, the indications are that climatic variations play a very important part in the determinations of yield and quality of wheat. Spring rain has a positive correlation with yield, but the per cent of possible sunshine for the same period has about an equal negative correlation. July rainfall showed a negative correlation with the yield of wheat the following year, but the sunshine during July showed a positive correlation. Fall rain and sunshine agree in their affect upon the yield with that of the spring months, although the correlation is not as strong. Rainfall in April and May show a negative correlation with the protein content of wheat, but the percentage of sunshine for this same period shows a positive correlation with the protein content. The rainfall and sunshine during the month of July seem to have an opposite affect on the following year's crop to that shown by the spring and fall months. The rainfall and sunshine of the fall months agree in their affect upon the protein with the following spring months. Fall rainfall and sunshine are correlated rather closely with that of the following spring. The sunshine and rainfall are correlated strongly during any one season, and the correlations also tend to indicate that the more sunshine during any one period of the year the less rainfall there will be.

In years of normal rainfall and climatic conditions correlations between weather and the yield and quality of crops are of much value in estimating the final results, but one or two weeks of very severe weather during the critical period may serve to offset an entire year of favorable weathdr, and therefore, the advanced estimation of yield or quality based on past conditions is not always accurate.

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