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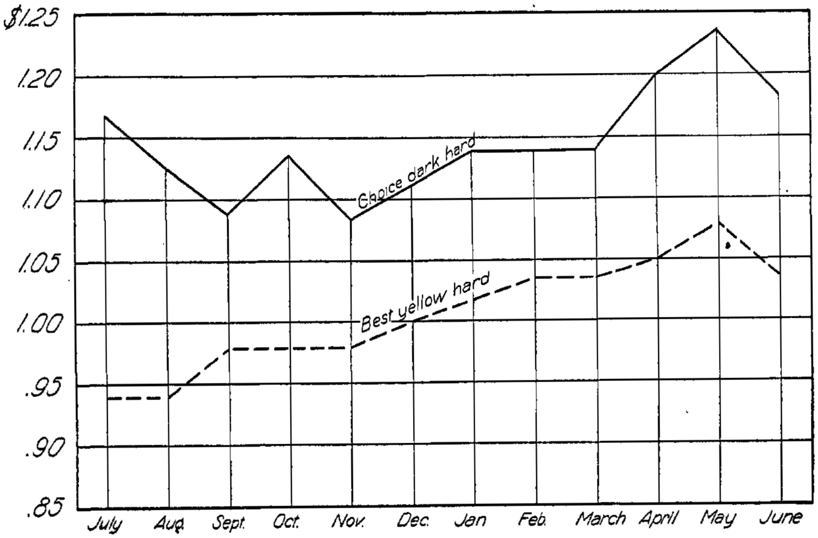

FIG. 1.—Average of monthly high and low prices of No. 2 hard wheat for 31 years on the Kansas City market, showing variation in price spread within the same numerical grade.

HOW TO GROW AND MARKET HIGH-PROTEIN WHEAT[1]

L. E. CALL, R. M. GREEN, AND C. O. SWANSON

There is an increased milling demand for hard wheat rich in protein. The millers want wheat of this character and are willing to pay a premium for it. This greater demand and the premiums offered for high protein are due in part to changing economic conditions. One of the most important recent changes has been the extensive transfer of bread making from the home to the commercial bakery. The commercial baker wants first of all, a flour that will make large, light loaves. Such a flour gives the largest number of

1. Contribution No. 158 from the Department of Agronomy, No. 19 from the Department of Agricultural Economics, and No. 26 from the Department of Milling Industry.

loaves from each barrel. He also wants flour that will make a dough strong enough to withstand the severe treatment of the mechanical mixing machines in his bakery. It is only wheat with a high protein content that will produce flour of this character.

The housewife on the other hand mixes bread by hand. It is handled gently as compared with the treatment received in mechanical mixers. The housewife, therefore, is less interested in a strong dough and wheat of lower protein content is satisfactory. Therefore the change that has taken place in the past 10 years by the transfer of bread making from the home to the commercial bakery has been one of the important reasons for the increased demand for high-protein wheat.

During this same period soil conditions have changed so as to make the production of high-protein wheat less common. Thus the increased demand on the one hand and the decreased supply on the other has led in some seasons to large premiums, and in all seasons to a good premium, for high-protein wheat.

There is no indication that the demand for high-protein wheat will decrease. Therefore, it is important that the Kansas farmer who is located under climatic and soil conditions suitable for the production of wheat high in protein, do everything practicable to produce wheat of this character and to market his wheat in such a way as to secure for himself the added price that such wheat should command on the market.

WHAT IS PROTEIN

Protein is a collective term applied to all the substances formed in the wheat kernel that contain nitrogen. The chemist determines the protein content of wheat by determining, first, the total nitrogen. He then multiplies this figure by 5.7 to get the per cent of protein in the grain.

The protein of the wheat kernel has certain qualities that make wheat flour better suited to bread making than the flour of any other grain. But not all the protein in wheat is alike. There are a number of different kinds and some are probably more valuable than others in bread making. The millers and bakers know, therefore, that wheat and flour may vary in the quality of the protein as well as in the quantity. The quality is probably determined by the quantity and makeup of the several different kinds of protein that, are present and the relation that these proteins have to the starch, moisture, fatty substances, and other material present in the grain.

It is not sufficient, therefore, to know simply how much protein wheat contains. It is equally important to know something about its quality.

QUALITY OF PROTEIN IN RELATION TO BREAD MAKING

A good milling wheat must be not only high in protein content but the protein must also be of good quality. A protein may be weak or strong, and thus it may happen that a wheat that is high in protein content is no better than another that is lower in protein content because of the difference in the quality of the protein in the two cases.

The size of the cells in the bread is directly determined by the quality of the protein. These cells are formed by gas which is produced by yeast during fermentation. When the quality of the protein is good, the cell walls are thin and strong enough to retain the gas, and loaves of large volume containing numerous small cells and showing good texture are produced. When the quality of the protein is poor, the cell walls are weak and fail to retain the escaping gas, the loaf is small and the cells large, producing bread of coarse texture and poor quality. It will be seen, therefore, that a high protein content does not necessarily and always indicate a high-quality wheat. In hard winter wheats such as grown in Kansas, however, the wheat that is high in protein usually has protein of good quality and hence millers are usually justified in paying a premium for it.

GLUTEN AND PROTEIN

The term gluten is sometimes loosely used as a synonym for protein. Gluten is the yellow rubbery material obtained when wheat is chewed in the mouth or when dough made with flour and water is washed until all the starch is removed. If the gluten is dried, the quantity approaches that of total protein. High-protein flour gives a large quantity of gluten and low-protein flour, a small quantity. In the absence of a protein determination, the gluten test may be used as an approximation. Experimental workers are, therefore, able to obtain much information by washing out gluten and studying its qualities.

Gluten determinations, however, cannot take the place of protein tests—they are far less accurate. They vary with the manner of mixing the dough, the length of time the dough is allowed to stand before washing, the manner of washing, the temperature of the wash water, and the salts present in the dough and wash water. All these factors influence both the quantity of gluten and, to some extent, the quality. Gluten determinations, therefore, while useful are seldom used.

ESTIMATING THE PROTEIN CONTENT OF WHEAT

The only accurate way to determine the protein content of wheat is by a chemical analysis. It is possible, however, to make a fairly accurate estimate of the difference in protein content of two or more samples of the same variety of wheat in which differences are large. The factors which are the most valuable in estimating the protein content of wheat are (1) color, (2) texture, and (3) test weight.

COLOR AND PROTEIN CONTENT

The most important factor for estimating protein content of red wheat is the color of the grain. In hard red winter wheat, for example, a deep red color practically always indicates a fairly high protein content; whereas, distinctly yellow or light-colored wheat (yellow berry) indicates a low protein content. Ordinarily this is a reliable index when applied to varieties of wheat of the Turkey type. It is somewhat difficult to apply, however, when wheat is bleached, heat damaged, or damaged by rain after harvest.

TEXTURE AND PROTEIN CONTENT

A hard vitreous wheat is invariably high in protein, whereas, a soft starchy wheat is always low in protein. A combination of hard vitreous texture and deep red color is a more reliable indication of high-protein content than either factor taken alone.

TEST WEIGHT AND PROTEIN CONTENT

In Kansas, a low test weight is likely to be associated with a high protein content and *vice versa.* This fact is usually explained on the assumption that the protein is deposited in the grain earlier than the carbohydrates, and if the filling of the grain is cut short by hot winds, dry weather, or other climatic factors, the grain is left relatively high in protein. Grain that is not filled completely will be low in test weight per bushel, while well filled grain is high in test weight. Consequently low test weight is associated with the high protein content of prematurely ripened wheat, and high test weight with the low protein content of plump, completely filled grain. However, in Canada and in Montana and other northern states, a high protein wheat may also have a high test weight and this may also occur in Kansas. Hence, testweight cannot be regarded as a reliable guide, but may, in connection with color and texture, be helpful in arriving at a reasonable conclusion.

DETERMINING THE PROTEIN CONTENT OF WHEAT

An estimate of the protein content of wheat should be used only when it is impossible to secure an accurate determination by means of a chemical analysis. On the farm, at local elevators and other places where chemical laboratories are not available, fairly accurate estimates may be made. It is desirable, however, to check the estimate whenever possible by an exact determination. Kansas farmers are fortunate in having at their disposal state-operated chemical laboratories where samples of wheat may be sent and protein determinations obtained. Grain may be sent to the state laboratories at Wichita, Hutchinson, and Kansas City for analysis. In past years it has been the policy of the state grain inspection service to make protein determinations free of charge for Kansas farmers.

To have a protein determination made at any one of these laboratories, take a half-pound sample of wheat which is representative of the wheat in the bin or lot, address it to the Kansas State Grain Inspection Department at any one of the addresses given above. The sample should be marked on the outside, "For protein test." A slip of paper or card bearing in clear legible writing the name and address of the sender should be enclosed. Such a test will enable the farmer to know definitely the protein content of his wheat.

PROTEIN CONTENT AND MARKET VALUE OF WHEAT

It is only in the last two or three years that protein determinations have been made on practically all samples of wheat at the Kansas City market. And only during the past year have definite price quotations on a protein basis been reported for this market. It is therefore impossible to present accurate statistics over any period of years showing the effect of protein content on wheat prices.

However, Kansas wheat has long been bought on a color basis. This was simply a less precise means of recognizing differences in protein content. As one Kansas grain man of 25 or 30 years' experience says, "I have bought grain in hard-wheat districts for more than 20 years, and during that time there has always been a premium paid for dark, hard, and vitreous wheat over the ordinary quality. The premium, however, ran from a few cents up to as high as 35 cents during a period of high-priced wheat."

It is possible to show by statistics the approximate price differential between wheats of different quality within the same numerical grade. Here again, however, available data, because of the method used in quoting prices, show more than just the quality differential.

The spread in price between top and low No. 2 hard wheat shown in figure 1, therefore, is a little too high. This is due to the method used in quoting prices. The top price is for No. 2 dark hard on the best day of the month, while the low quotation is for yellow hard on its lowest day in this period. Part of the spread between the high and low, therefore, is due to market differences on the different days. As an average for the 31 years, however, most of the difference shown is due to difference in quality, and protein content is an important factor in milling quality. It is probably safe to say that at least 75 per cent of the spread in prices shown in figure 1 is due to differences in quality.

The grain trade recognizes, however, that factors other than protein content also affect the quality of the wheat. Test weight per bushel, color, condition of bran coat, general appearance, freedom from bin or stack burning, and other factors affect the value and therefore the price that should be paid for wheat. In general, if all these factors are favorable, more will be paid for wheat of a given protein content than if some of these factors are unsatisfactory. The more careful buyers are finding that it is not economical to buy on a strictly protein basis.

The extent to which figure 1 reflects price differences paid for quality can be better understood by taking conditions in the market, at a certain time, say July, 1922. The best price quoted for top No. 2 hard, that is No. 2 choice dark hard: was $1.53 a bushel on July 13 and 14. The lowest price quoted during the month on yellow No. 2 hard, was $1.01 a bushel on July 31. This shows an extreme spread of 52 cents during the month, due to differences in quality of the wheat and to market differences on the two days.

On July 13, No. 2 yellow hard was quoted at $1.10, making an actual difference on that day of 43 cents, due to variation in quality within the numerical grade. The *Grain Market Review* on that day said: "High protein hard wheat was particularly wanted and competition between local and outside mills for this class of grain was rather keen." On the following day it was reported that local mills and shippers were particularly eager for good- to high-protein grain.

On July 31, No. 2 choice dark hard was quoted at $1.18, making the spread between the top and bottom of the grade that day 17 cents, or less than half of what it had been on July 13. The *Grain Market Review* for July 31 reported: "Heaviest declines were shown on intermediate and choice hard and on best quality dark hard which are selling at the lowest premiums in months. Mills were more careful in their selection of grain and reduced premiums had to be accepted generally to move the good character and protein stuff. Exporters and elevator concerns again bought freely of common qualities."

Thus it will be seen that the premium for protein or quality wheat fluctuates as much as 50 per cent within two or three weeks.

During the past two or three years, the premiums for protein wheat have usually been 8 to 10 cents for each per cent of protein above 11 to 11½ per cent, other quality factors being satisfactory.

HOW FARMERS MAY TAKE ADVANTAGE OF HIGH-PROTEIN WHEAT

Few elevators are equipped to keep separate small quantities of high-protein wheat. The elevator man cannot always, therefore, pay a premium on just a few wagon loads of high-protein wheat unless he has a chance to get at the same time more of such wheat in the community. He sells on the terminal market in carload lots, so that he must have 1,100 to 1,300 bushels or more of high-protein wheat to secure a premium. It is for this reason that a local mill is frequently in a better position than a local elevator to pay a premium for small quantities of good wheat.

The farmer who desires to market his wheat to the best advantage should separate his good wheat from his poor wheat at the time it is threshed. Fields of high-quality wheat should be placed in one bin, and fields of low-quality wheat in another. When fields are large, it may be advisable to separate the wheat from the same field into two lots based upon color and quality. After the wheat has been separated into different bins, protein tests should be made of a fair sample of the wheat taken from each bin. With this information at hand, the farmer is in a better position to market his high-protein wheat at a premium.

Where the farmer can convince local buyers that he has high-quality wheat, they will often at least split the premium with him.

A progressive elevator manager may not pretend to be buying on a protein basis, but if he knows where he can get quality wheat, he will bid the price up a few cents although he may not say anything about protein.

If farmers have a carload of high-protein wheat, they can often ship to advantage if local buyers will not pay a premium for it.

In discussing figure 1 attention has been called to the fact that the premium for high-quality wheat is not the same at all seasons. The total supply of this kind of wheat available on the markets at different seasons, and the demand for it at different seasons, determine the amount of the premium.

In years of short total supply, premiums are likely to be lowest for a few weeks immediately after harvest when a large volume of wheat is going to market so that there is an abundance of good wheat. Likewise the spread in price is likely to be the greatest in the spring when there is a small quantity of this kind of wheat remaining to be marketed.

The tariff on wheat imports no doubt tends to strengthen premiums on Kansas wheat of high milling quality. By shutting out Canadian grain, mills in the spring wheat area are forced to turn to the southwest for supplies of high-protein wheat. These outside mills bidding against local mills in Kansas City are obliged to pay substantial premiums for good milling wheat. Kansas, as well as the spring wheat area, benefits by this tariff. On the other hand, the tariff has the effect of pushing the good Canadian wheat, that otherwise would come into this country, on to the Liverpool market. The result is that our lower quality export wheat meets even stiffer competition than before, and no doubt sells at a greater discount.

To take advantage of high-protein wheat, therefore, the Kansas farmer needs most of all:

1. Sufficient quantity of high-quality wheat to interest local buyers; that is, seven or eight hundred bushels or more,

2. To watch the quality at harvest time and where possible bin the better wheat separately.

3. To secure representative samples of wheat when he or the local elevator manager has protein tests made so that buyers can depend on his tests.

4. To watch the market for periods of highest premiums for high-protein wheat.

5. A mill demand in the United States dependent upon domestic supplies.

FACTORS AFFECTING THE PROTEIN CONTENT OF WHEAT

There are three important factors that affect the protein content of wheat. They are: (1) The variety of wheat that is planted; (2) the climate in which the wheat is grown; and (3) the kind of soil upon which the wheat is produced.

RELATION OF VARIETY TO PROTEIN CONTENT

One needs only to consider the soft white wheat of the Pacific coast states, the hard wheat of Kansas, and the durum wheats of the Northwest to realize that the variety, or the kind of wheat, has much to do with protein content and quality. It is well known also that the hard red winter wheats of Kansas average higher in protein content than the soft wheats grown under similar conditions.

As a rule, any variety of hard wheat grown on a commercial scale in Kansas, will produce wheat of a high protein content if the soil and the season are favorable. No variety of hard wheat has so far been discovered which is materially better in this respect than the varieties commonly grown. It is of interest to note, however, that Kanred wheat, which has been so widely distributed in Kansas the past few years, averages slightly higher in protein content than the other types of Turkey wheat, with which it has been compared. During this time on the College Farm it has produced an average yield of nearly three bushels more to the acre than Turkey as shown by Table I.

TABLE I.—A comparison of yield, protein content, and total protein per acre of Turkey wheat and Kanred wheat grown on the College Farm, Manhattan, 1914 to 1923, inclusive.

VARIETY.	Average yield per acre.	Average per cent protein.	Average yield of protein per acre.
	Bushels.		*Pounds.*
Kanred	29.1	13.8	241
Turkey	26.5	13.6	216
Average increase of Kanred over Turkey	2.6	0.2	25

Considering the fact that a high-protein content is often secured at a sacrifice in yield, it is rather remarkable that we have in Kanred wheat a variety which has the capacity to produce a high yield and at the same time a high-protein content.

CLIMATE IN RELATION TO PROTEIN CONTENT OF WHEAT

There is no factor that has a more important bearing upon the protein content of wheat than climate. Climate is so important that it is absolutely impossible under field conditions in certain climates to produce wheat of high quality, while on the other hand, under other climatic conditions there is a tendency for the wheat to analyze high in protein regardless of the variety sown or the soil upon which it is planted.

A long growing season with abundance of rain favors the development of a soft starchy kernel low in protein, while a short dry growing season, especially in the spring, in the case of winter wheat, favors the development of grains that are hard and vitreous and high in protein.

The wheat belt of Kansas is located under climatic conditions favorable for the production of wheat high in protein. It is for this reason that Kansas produces some of the best milling wheat raised anywhere in the world.

The accompanying composite protein map of Kansas (fig. 2) shows the range in protein of the wheat produced in different counties of the state. The map shows the average protein content of the wheat from seven crop years, 1917-18 to 1923-24, inclusive, comprising 14,068 determinations from 103 counties. The data are from the laboratory records of Kansas mills. While the number of tests in some counties is too small to be representative, the data as a whole are comparable.

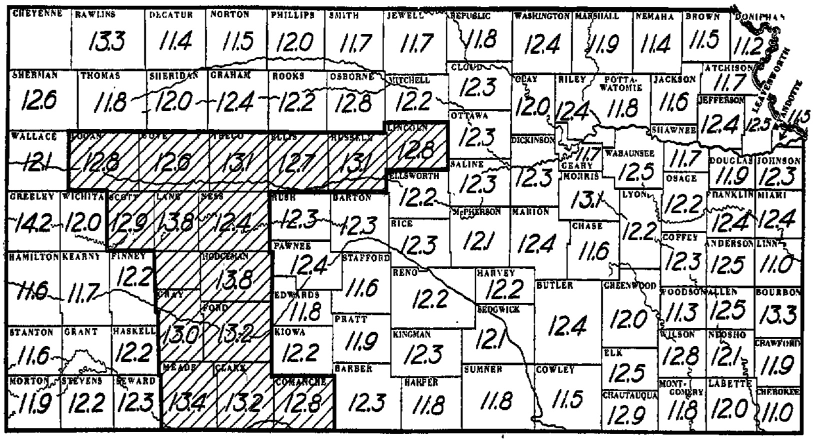

FIG. 2.—Composite protein map of Kansas for seven crop years, 1918 to 1924, showing average of protein tests by counties. The shaded area showed high protein tests most consistently.

The area producing high-quality wheat most consistently seems roughly to be the group of southwestern counties from Comanche westward to Seward and north to and including Hodgeman; and a west central group of counties from Russell west to Logan and south including Scott, Lane, and Ness.

Eastern and northern Kansas on the other hand constitutes an area characterized by low-protein wheat. The heavier spring and early summer rainfall of eastern Kansas and the cooler ripening period of northern Kansas are probably responsible for this difference. An area characterized by a somewhat lower protein content than would be expected occurs in Edward, Pratt, and Stafford counties and in southwestern Kansas south of the Arkansas river. The comparatively low protein content of wheat in these areas is probably due to the sandy soil upon which much of the wheat is grown. (The effect of the type of soil on the protein content of wheat is discussed on page 13.)

SEASONAL VARIATION IN PROTEIN CONTENT OF WHEAT

The variation in seasonal conditions may influence the protein content quite as much as the differences in climate in different parts of the state. For example, on the College Farm at Manhattan, the protein content of wheat produced on a plot that has been cropped continuously to the same kind of wheat and plowed each summer at the same time and at the same depth has varied from as little as 10.4 per cent in 1914 to as much as 16.8 per cent in 1918. These data are shown in Table II.

TABLE II.—Variation in protein content of wheat on the College Farm, Manhattan, 1912 to 1921, inclusive.

(Plot cropped continuously to Turkey wheat and plowed each season 6 to 7 inches deep in July.)

SEASON.	Per cent protein.
1912	16.2
1913	12.7
1914	10.4
1915	13.2
1916	12.4
1917	15.1
1918	16.8
1919	14.1
1920	15.8
1921	13.5
Average for 10 years	14.0

It is interesting to compare the data given in this table with that shown on the protein map of the state. (Fig. 2.) It will be seen that the variation in protein content of the wheat produced on this plot, which has been handled in the same manner each season, is greater than the variation in the protein content of wheat produced in an average season in any two counties of the state. This indicates that as great a variation in protein content of wheat may occur in different seasons on the same farm as occurs in different parts of the state in any one season. It is not safe, therefore, to assume that because high- or low-protein wheat was produced on a given farm one year that wheat of the same quality will be produced the next year.

Further evidence of the variation in the protein content of wheat from season to season is given in Table III, which records the protein content of the wheat of several counties for each of several years. These data show that there are no areas in the wheat belt of Kansas that are invariably low or high in protein content. In other words, there is no single county or group of counties that always ranks at the top or at the bottom in protein content.

TABLE III.—Average protein content of wheat in central Kansas by counties and crop years.

COUNTY.	1917-18	1918-19	1919-20	1920-21	1921-22	1922-23	1923-24	Av.
Barber	12.6	14.7	12.9	13.1	12.7	11.0	12.3	12.8
Barton	12.2	14.2	12.5	11.8	13.4	11.8	12.1	12.6
Butler	11.7	14.1	12.9	12.9	12.1	12.5	12.9	12.7
Cloud	10.8	15.2	12.5	11.7	12.3	12.9	12.5	12.6
Cowley	10.4	12.8	12.8	13.2	12.2	13.0	12.3	12.4
Comanche	14.3	14.6	13.2	13.4	12.5	12.4	13.0	13.3
Harper	11.9	13.7	12.6	13.7	11.3	11.7	12.5	12.5
Harvey	11.0	14.2	12.8	14.1	11.6	12.1	12.2	12.6
Kingman	12.3	13.5	12.4	13.6	11.8	12.3	12.6	12.6
Marion	12.3	12.5	13.1	13.2	11.9	12.5	12.7	12.6
McPherson	11.4	13.5	12.6	13.5	11.7	11.5	12.3	12.4
Pratt	12.7	13.8	12.5	12.5	11.4	11.8	11.9	12.4
Reno	11.3	13.4	12.0	13.6	12.0	12.2	12.2	12.4
Rice	11.3	12.8	12.3	12.6	12.4	11.9	12.0	12.2
Sedgwick	11.6	12.7	12.1	13.4	11.7	11.8	12.2	12.2
Stafford	11.5	12.2	12.4	11.9	11.2	11.8	11.8	11.8
Sumner	11.2	12.5	12.0	12.5	11.5	11.6	12.5	12.0
Average	11.8	13.6	12.6	13.0	12.0	12.0	12.4	12.5

THE SOIL IN RELATION TO PROTEIN CONTENT OF WHEAT

The importance of the soil in relation to protein content has not until recently received the attention that the importance of the subject deserves. As has already been shown, nitrogen is one of the most important constituents of protein. Protein cannot be made by the plant without nitrogen. Cereal plants like wheat receive practically all of their nitrogen from the soil in the form of nitrates. It would appear, therefore, that the quantity of nitrates in the soil would influence the protein content of the wheat grown upon it.

That the nitrate content of the soil does affect the protein content of wheat has been shown by a number of investigators. Davidson and LeClerc[2] of the United States Department of Agriculture applied sodium nitrate to plots growing winter wheat in Nebraska at the rate of 320 pounds per acre. The nitrate was added at three stages of growth: (1) When the crop was 2 inches high; (2) at the time of heading; and (3) at the milk stage. The results were as follows: The application made when the plants were 2 inches high gave the highest yield. The application made at the time of heading gave grain of the best quality with reference to protein, but the vegetative growth was not affected. The application made at the milk stage had no effect on either yield or quality.

Neidig and Snyder[3] of the Idaho Agricultural Experiment Station investigated the problem further. They grew wheat, adding nitrogen both as soluble salts and as organic nitrogen. The conclusions of their work were as follows: If the soil lacks available nitrogen, both yield and per cent of protein will be low. If available nitrogen is abundant at the beginning of growth but somewhat lacking at the time of seed formation, the yield will be high but the protein per cent will be low. If the supply of available nitrogen is high continuously, both high yield and high-protein wheat will be obtained.

THE EFFECT OF SOIL TYPE ON PROTEIN

Farmers have been aware for a long time that the type of soil influenced greatly the quality of wheat. It has been known that "yellow berry" wheat, which is always low in protein, was more prevalent on sandy soils than on clay loam or silt loam soils in the same region. It has also been observed to be more prevalent on bottom land than on upland. There are probably two important reasons for this: (1) The ability of the soil to supply water to the plant; and (2) the nitrogen content of the soil.

Sandy loam soils have the ability to absorb water much more rapidly than clay or clay loam soils. They also have the ability to give up their water to plants more readily and more completely than soils of a heavier texture. Sandy soils, as a class, are also

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2. Davidson, Jehiel, and LeClerc, J. A. Effect of various inorganic nitrogen compounds, applied at different stages of growth, on the yield, composition, and quality of wheat. Jour. of Agr. Res. Vol. XXIII, No. 2, pages 55-68. 1923.

3. Neidig, Ray E., and Snyder, Robert S. The effect of available nitrogen on the protein content and yield of wheat. Agr. Expt. Sta., Univ. of Idaho. Res. Bul. 1:56. Plates 4. Charts 2. Tables 18. 1922.

more deficient in nitrogen than the heavier types of soil. Thus when wheat is seeded on a sandy or a sandy loam soil, it usually has a smaller supply of available nitrogen and may have a larger supply of available water than when seeded on a clay or a clay loam soil. Ample moisture with deficient nitrogen, as has already been explained, produces wheat low in protein. It is not surprising, therefore, that a sandy soil usually produces "yellow berry" wheat.

Wheat grown on bottom land is usually lower in protein than wheat produced on the adjoining upland. This is due (1) to the fact that bottom-land soils are usually more abundantly supplied with moisture; and (2) to the tendency for bottom-land soils to contain more sand than upland soils. The low protein content of wheat so characteristic of sandy soils, and especially of sandy bottom-land soils, is in part compensated for by the larger yields that are usually produced on land of this character.

HIGH YIELDS AND HIGH PROTEIN

There is a tendency for high yields to be associated with low protein content, but this is not always the case. In fact it appears that it is only when the supply of available nitrogen in the soil is deficient that low-protein wheat is produced. Since high yields require much more available nitrogen than low yields, the plant is much more likely to run short of available nitrogen when large crops are grown. It would, for example, require 142 pounds of nitrate per acre to produce a crop of 20 bushels analyzing 16.7 per cent protein, but only 117 pounds to produce a yield of 20 bushels with a protein content of 13.8 per cent. Low-protein content is usually associated with high yields, therefore, because the soil seldom contains sufficient available nitrogen to produce both high yields and high protein. That it is possible in most cases to produce both high yields and high protein by means of a good system of crop rotation and soil management will be shown later in this discussion. (See page 17.)

DEPLETION OF SOIL FERTILITY AND PROTEIN CONTENT OF WHEAT

Since the principal constituent of protein is nitrogen, and since the wheat plant obtains its nitrogen from the soil, it is evident that soils deficient in nitrogen cannot produce wheat of high protein content. It is due to the great natural fertility and high nitrogen content of the soils of the Great Plains of the United States, including central and western Kansas, that this region has in the past produced wheat of such high quality and protein content. It is also due to this fact that the soils of the Prairie Provinces of Canada are able to produce such high-protein wheat. But as these lands become older and as the nitrogen supply of the soil is depleted, it becomes more difficult to produce wheat of high protein content. This is probably the reason why the older wheat soils of Kansas do not produce grain as high in protein content as the newer soils, The older soils, due to continuous cultivation and wheat growing, have lost a large part of their organic matter and nitrogen.

The extent to which the organic matter and nitrogen have been used in the older wheat soils of the state is well shown by soil analyses made on some of the soils of Russell county, which have been cropped continuously to wheat for more than 30 years, some of the results of which are shown in Table IV. When the analyses of these soils are compared with the analyses of virgin soils of the same type in the same community, it is found that the older wheat soils have lost in the past 30 years over one-third of their organic matter and nitrogen. (Table IV.)

TABLE IV.—A comparison of the nitrogen and organic matter content of two Russell county soils.

KIND OF SOIL.	Pounds per acre.	
	Nitrogen.	Organic matter.
Virgin prairie pasture	4,260	98,400
Old wheat soil	2,960	64,400
Loss	1,300	34,000

CLIMATE AFFECTS THE SOIL SOLUTION

The influence of climate in affecting the protein content of wheat, is very largely an indirect effect through its influence on the soil solution. When the rainfall is heavy and the supply of moisture is ample, and other conditions are favorable for growth, a large yield of wheat will result. If the soil is low in available nitrogen, the protein content of the wheat will be low. If on the other hand the supply of nitrates is ample, there may be produced a large yield of high-protein wheat. Since a heavy rainfall may wash out of the soil a part of the nitrates and at the same time usually causes a rank growth of wheat, it is very seldom that there is an ample supply of available nitrogen for high-protein wheat in a wet season. This is the reason why so much "yellow berry" or low-protein wheat is produced in a wet year.

In seasons of low rainfall very little nitrogen is removed from the soil by leaching, the temperatures are usually high which is favorable to the rapid formation of nitrates, and the yield of wheat is usually low which means that a small quantity of total nitrogen will be needed by the crop. The net result is a low yield of high-protein wheat.

The influence of rainfall and temperature on the yield and protein content of wheat is clearly shown by comparing the wheat crops of 1917-'18 and 1918-'19 at Manhattan as given in Table V. The season of 1917-'18 was a comparatively dry and warm one. A total of 20.14 inches of rain fell in twelve months preceding the harvest of the 1918 crop, and 7.8 inches in the three months immediately preceding harvest. The mean temperature for the four months preceding harvest averaged 62.1 degrees.

TABLE V.—The influence of rainfall and temperature on yield and protein content of wheat.

(Ground cropped continuously to wheat and plowed each season 6 to 7 inches deep in August.)

SEASON.	Yield per acre.	Per cent protein.	Total rainfall preceding 12 mos.	Rainfall preceding April, May and June	Mean temperature, March and April.
	Bushels.		*Inches.*	*Inches.*	*Degrees F.*
1917–18 (Dry, warm season)....	12.1	16.7	20.14	7.8	62.1
1918–19 (Wet, cool season).....	20.0	13.8	34.63	11.2	58.7

The season of 1918-'19 on the other hand was comparatively cool and wet. The total annual rainfall was 34.63 inches and the rainfall in the three months immediately preceding harvest was 11.2 inches. The mean temperature for the four months preceding harvest averaged 58.7 degrees.

Ground that had been in wheat continuously for the preceding nine years and plowed each year in August to a depth of 6 to 7 inches, produced in the dry warm season of 1918 a yield of 12.1. bushels of wheat to the acre, which had a protein content of 16.7 per cent. The same field handled in the same way during the cool wet season of 1919 produced a yield of 20 bushels of wheat to the acre, which analyzed but 13.8 per cent protein.

The warm spring of 1918 favored the formation of nitrates in the soil and the rainfall was too light to cause much leaching. The wheat did not make a rank growth and sufficient nitrogen was available during the entire growing period to produce wheat of high protein content. In 1919, nitrate formation in the soil took place more slowly. The wheat made a rank vegetative growth and, while the total protein produced per acre this season amounted to 165 pounds as compared with 121 pounds in 1918, the amount available during the late spring months in proportion to the crop that was produced was probably not as great as in the preceding season.

HOW A FARMER MAY INCREASE THE PROTEIN CONTENT OF HIS WHEAT

There are two general methods of soil treatment by which a farmer may increase the protein content of his wheat: (1) By increasing the fertility of his soil so that more nitrogen will be available for the use of the crop; and (2) by early plowing and a thorough preparation of the seed bed so that more of the nitrogen in the organic matter of the soil may be changed into nitrates and thus made available for the wheat plants.

HOW TO ADD NITROGEN TO THE SOIL

The best and cheapest way to add nitrogen to the soil is to grow a leguminous crop. The best legumes for Kansas are alfalfa, sweet clover, cowpeas, soybeans, and red and alsike clover. These crops, when inoculated, have the ability to secure nitrogen from the air. When they are grown in rotation with wheat, they leave in the soil a supply of nitrogen that can be quickly changed into nitrates and used by the wheat plant. The protein content of wheat, therefore, can be increased greatly by planting wheat on ground that has previously grown alfalfa or some other legume.

The following incident illustrates how rapidly available nitrogen may be added to the soil by alfalfa: In the fall of 1922 a plot of ground on the College Farm at Manhattan was divided into two parts; one part was planted to alfalfa and the other to wheat. In July, 1923, after harvesting the second cutting of alfalfa, the ground was plowed and prepared for wheat. The adjoining wheat ground was plowed at the same time and prepared for wheat in the same way. It was found at seeding time that the plot that grew alfalfa the preceding season contained 143 pounds of nitrates per acre, while the ground that had not been in alfalfa contained but 74 pounds. In 1924, when the wheat on these plots was harvested and threshed, it was found that the crop on the alfalfa ground produced 49.7 bushels of grain per acre that analyzed 12.4 per cent protein, while the yield on the old wheat ground was 43.2 bushels which tested 10.7 per cent protein. This is a difference of 6½ bushels per acre in yield and of 1.7 per cent in protein in favor of ground that had previously grown alfalfa but one season.

Another illustration of the value of legumes, when grown in rotation with wheat, upon the protein content of the grain is found in the rotation experiments on the College Farm. In these experiments wheat that is grown in a 16-year rotation with alfalfa may be compared with a similar rotation with Brome grass. Alfalfa, since it is a legume, has the ability to secure nitrogen from the air, while Brome grass does not; but Brome grass improves the soil in other ways. Both alfalfa and Brome grass were grown for four years. Then they were plowed up and the ground planted to corn for one season and wheat for two seasons. The corn and wheat were alternated in this way for 12 years. The ground was then seeded again in one case to alfalfa and in the other case to Brorne grass. It is possible, therefore, to compare in this rotation the yield and composition of wheat grown on land which, in one case, previously grew alfalfa for four seasons and, in the other case, grew Brome grass for the same period of time. It is possible, also, to compare the wheat grown in these rotations with wheat grown in a short three-year rotation of two crops of corn and one of wheat. The average of six years' results, 1916 and 1919 to 1923, inclusive, are shown in Table VI.

TABLE VI.—The influence of the cropping system on the yield and protein content of wheat.

(Average for six years, 1916 and 1919 to 1923, inclusive. Wheat sown in disked corn ground.)

CROPPING SEASON.	Yield per acre.	Per cent protein.
	Bushels.	
Sixteen-year rotation: Alfalfa four years; corn one year, wheat two years, alternating for 12 years	23.5	16.3
Sixteen-year rotation: Brome grass four years; corn one year, wheat two years, alternating for 12 years	28.0	12.9
Three-year rotation: Corn, corn, wheat	17.7	12.9

As an average of this six-year period, the wheat in the rotation with alfalfa produced a yield of 23.5 bushels per acre that analyzed 16.3 per cent protein. The wheat on the Brome grass ground averaged 28 bushels per acre but analyzed only 12.9 per cent protein. In the three-year rotation of corn and wheat, the yield was only 17.7 bushels per acre and the protein content, 12.9 per cent. While the yield of wheat after alfalfa was somewhat lower than after

Brome grass, the protein content was 3.4 per cent higher. The wheat after alfalfa was also much higher in both yield and protein content than that grown in the three-year rotation.

CARE NECESSARY IN ROTATING ALFALFA WITH WHEAT

Care must be used in rotating alfalfa with wheat. In wet years, there is danger of the wheat lodging. In dry years, there is danger of the wheat burning. In planning rotations with alfalfa, it is advisable, therefore, to arrange to plant kafir and corn and possibly oats or barley for three or four years after breaking up' alfalfa and before planting wheat. This is especially true when alfalfa has been grown for a period of several years. Some farmers have overcome the excessive straw growth that wheat makes after alfalfa by preparing the seed bed for wheat with a disk, without plowing. This helps to reduce straw growth and is a good plan. But a better plan is to grow a strong feeding crop like kafir or corn for a few years before planting wheat.

HOW THE PREPARATION OF THE SEED BED AFFECTS THE PROTEIN CONTENT OF WHEAT

That it is possible to increase the protein content of wheat from 1 to 2 per cent by good methods of seed-bed preparation has been amply demonstrated as a result of more than 15 years experimental work on the College Farm. In this work, one field was cropped continuously to wheat. The field was divided into a number of plots which were plowed and worked in different ways. One plot was plowed each season about the middle of July and worked after plowing sufficiently to keep down weeds and to prepare a good seed bed. Another plot was plowed about the middle of September and worked after plowing sufficiently to put the ground in excellent condition for seeding. A third plot was not plowed, but weeds and volunteer grain were allowed to grow until seeding time when the ground was thoroughly disked and seeded. All plots were sown the same day, usually about the first of October. As an average of nine years, 1912 to 1920, the ground plowed in July produced 18.6 bushels of wheat to the acre with a protein content of 14.1 per cent. The plots plowed in September gave an average yield of 14.2 bushels with a protein content of 12.2 per cent, while the plots disked at seeding time produced but 7.9 bushels of grain that analyzed 12.1 per cent protein. This is a difference in yield of more than four bushels per acre and a difference in protein of nearly 2 per cent between July and September plowing; and a difference of nearly 11 bushels in yield and 2 per cent in protein between the July plowed ground and the ground which was not plowed but disked at the time of seeding. The results are shown in detail in Table VII.

TABLE VII.—The effect of the method of preparing the seedbed on yield and protein content of wheat.

(Nine years, 1912 to 1920, Manhattan, Kan.)

TREATMENT.	Nitrates per acre in surface, three feet of soil at seeding time.	Yield per acre.	Per cent protein.
	Pounds.	*Bushels.*	
Plowed in July	113.3	18.6	14.1
Plowed in September	43.9	14.2	12.2
Not plowed but disked at seeding time	25.8	7.9	12.1

Ground that is plowed early and worked sufficiently through the summer to keep down weeds will accumulate a large supply of available nitrogen in the form of nitrates. On the other hand, ground that is not plowed until late in the summer usually grows a heavy crop of weeds and grasses, and this vegetation uses the nitrates so rapidly that very little accumulates in the soil. Thus, at seeding time the early-plowed ground will contain a large supply of nitrates while the quantity in the late-plowed ground will be small. This is shown by the fact that July plowed ground contained 113 pounds of nitrates per acre at seeding time; September plowed ground, 44 pounds; while unplowed ground disked at seeding time contained only 26 pounds. A further study of this table will show that the yield of wheat and the protein content of the grain was in direct proportion to the supply of nitrates in the soil at the time the crop was sown.

Early plowing and thorough preparation of the seed bed is, therefore, one of the best ways available to the farmer to increase the protein content of his wheat. It should be remembered, however, that those soils which have been under cultivation the longest are sometimes becoming so depleted in organic matter and nitrogen that it is not possible, even by means of early plowing, to produce high yields of high-protein wheat. Such soils should be planted to leguminous crops. Nitrogenous organic matter will then supply the material from which nitrates may be liberated and stored in the soil by early plowing. In this way, high yields of good wheat may be produced on most of the farms in Kansas.

SUMMARY

High-protein wheat commands a premium on the market because there is a scarcity of wheat of this character. Flour made from such wheat is in demand by commercial bakeries because it makes a strong dough and a large number of loaves of bread from a given volume of flour. High-protein wheat can usually be recognized by the hard vitreous texture and the dark deep red color of the grains. The protein content may be told with certainty by having the wheat analyzed. High-protein wheat may be produced by growing wheat of the Turkey type in almost any section of Kansas, providing soil and climatic conditions are favorable. A low rainfall, reasonably high temperatures, and a short ripening period favor the production of high-protein wheat. Climatic conditions favorable for the production of wheat of this character occurs the most frequently in central and western Kansas, and especially in the southwestern part of the state. Sandy soils have a tendency to produce wheat low in protein, while soils of a heavier character such as the silt and clay loams often produce high-protein wheat. This is especially true when these soils are well supplied with nitrogen. The protein content of wheat may be increased by early plowing and by a thorough preparation of the seed bed. It may be also increased by rotating alfalfa and other leguminous crops with wheat.

Since high-protein wheat commands a premium on the market, a farmer producing such wheat should see that his crop is marketed in such a way as to secure this premium. The proper premium for such wheat will usually be secured when the crop is marketed directly to a mill, or when sold in carload quantities on the terminal markets. Grain high in protein sold by the wagon or truckload country elevators, where most of the wheat is of low protein content, usually will not bring the premium that this quality of grain should command.

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