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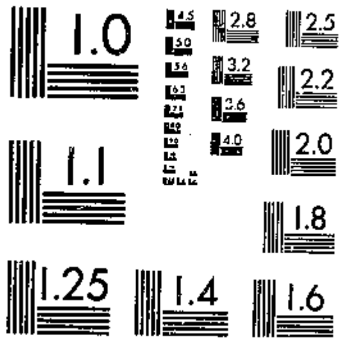

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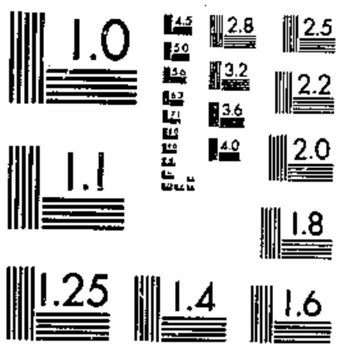

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NATIONAL BUREAU OF STANDARDS-1963-A

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Influence of Variety, Environment, and Fertility Level on the Chemical Composition of Soybean Seed[1]

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INTRODUCTION

The rapid rise in the importance of the soybean crop in American agriculture and the great interest in the industrial utilization of soybean seed products has resulted in a demand for improvement of varieties for industrial processing and for information on the influence of environment on the compositional factors of the seed. From the time the crop was introduced into the United States in 1804 until the soybean became an important commodity in domestic trade, the breeding and selection work was concerned mainly with yield and agronomic characteristics. Something over 10,000 introductions,

[1] Submitted for publication June 1941. This work was performed under an allotment from the Special Research Fund authorized by Title I of the Bankhead-Jones Act of June 29, 1935.

[2] The assistance of those who have made the progress of these investigations possible is gratefully acknowledged. The planting, observation, and harvesting of the field plots and rod-row tests were made under the supervision of the senior author by Leonard F. Williams, J. D. Vasvery, Albert H. Probst, C. K. Shuman, Denver I. Allen, and Martin G. Weiss of the Division of Forage Crops and Diseases, Bureau of Plant Industry, and by H. M. Munger and L. L. McHoney, formerly of that Division. The chemical analyses of the soybeans were made by the analytical section of the laboratory, first under the supervision of R. T. Milner of the Bureau of Agricultural Chemistry and Engineering, and later under that of the junior author. The following analysts assisted in the work: K. R. Majors, P. Krauczunas, H. J. Max, W. C. Bull, C. R. Scholfield, R. F. Kelly, M. E. Stickney, and L. E. Wener of the Bureau of Agricultural Chemistry and Engineering. Credit is also due to Ruth E. Schmutzler of the Division of Forage Crops and Diseases and O. R. Weber of the Divisions of Cereal Crops and Diseases and Forage Crops and Diseases, Bureau of Plant Industry, for their aid in the statistical work. The help of L. E. Thatcher, Ohio Agricultural Experiment Station, is acknowledged for his aid in handling the soil fertility-level plots. Acknowledgment is gratefully made of the valuable assistance of W. J. Morse, senior agronomist, Bureau of Plant Industry, in planning and guiding the agronomic work.

originating mainly in the Orient, have been distributed and studied. Most of the varieties now in commercial production have originated from them.

In the spring of 1936 the United States Regional Soybean Industrial Products Laboratory [3] was established at Urbana, Ill., under authority of the Bankhead-Jones Act of 1935. One of the objects of this laboratory, as given in the original memorandum, was "to obtain through basic research, facts and materials applicable to the industrial utilization of the soybean and soybean products and to develop methods whereby these facts and materials may be utilized for the benefit of agriculture." In the organization of the laboratory provision was made for chemical-composition studies of soybeans grown in the agronomic work program.

The present study was undertaken to measure the influence of environmental factors on the composition of a number of principal varieties adapted to the soybean belt of the North Central Region. This belt lies principally in the States of Ohio, Indiana, Illinois, Iowa, and Missouri. These States currently produce from 80 to 90 percent of the domestic production of commercial soybeans. The value of the results of the study lies in the information to be gained concerning the environmental and varietal variation in the composition of soybean seed as related to the selection of improved varieties and strains for processing and industrial utilization.

The soybean seed is not a simple chemical system. It contains all of the elements and constituent chemical compounds essential to restart the life cycle for the growth of a plant to produce more seed. In normally matured seed these elements and constituent compounds undoubtedly occur in such proportions as to meet the nutritional requirements of the germinating seed and young plant. However, it must be recognized that the composition of the seed is modified by genetic factors and environment; yet there is undoubtedly some regularity in such modifications that has not yet been adequately investigated, hence is not well understood.

From the standpoint of industrial processing the principal interest in the composition of soybean seed is in the percentages and characteristics of the oil and protein, as both substances have real and potential industrial as well as food and feed uses. Piper and Morse (*22*) [4] have reviewed a large amount of literature which showed that variety and environment influence the percentages of oil, protein, and ash constituents of soybeans and the iodine number of soybean oil.

Garner, Allard, and Foubert (*12*) observed that there is no critical period of intense oil formation at any stage of seed development. From their experiments with soybeans they concluded that, except for the period immediately following blooming and that directly preceding maturity, oil is formed in the seed at a fairly uniform rate, both relative and absolute. Their data for three varieties have been recalculated on a percentage basis of the maximum development of dry matter and of oil in the bean and are shown in figure 1. These data show a very uniform rate of development for both dry matter and oil for all three varieties, but at somewhat different percentage

[3] A cooperative organization participated in by the Bureau of Agricultural Chemistry and Engineering and by the Bureau of Plant Industry of the U. S. Department of Agriculture, and by the agricultural experiment stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

[4] Italic numbers in parentheses refer to Literature Cited, p. 65.

rates depending on varietal characteristics. Variety P. I. 21755,[5] which is an early selection somewhat similar in range of maturity to Mandarin of the present study, required approximately 27 days for the seed to reach maximum dry-matter and oil development. This period was about 22 days for P. I. 32907, which is Peking, and about 40 days for P. I. 19981, which is somewhat similar in range of maturity to P. I. 54563-3 of the present study. It is observed that after the maximum development was reached in each of the three varieties there was a decrease in dry matter and oil, this decrease being greater for oil than for dry matter on a percentage basis but not in absolute units. Some analyses of beans from the 1940 season confirm this decrease in dry substance and oil after maximum development and

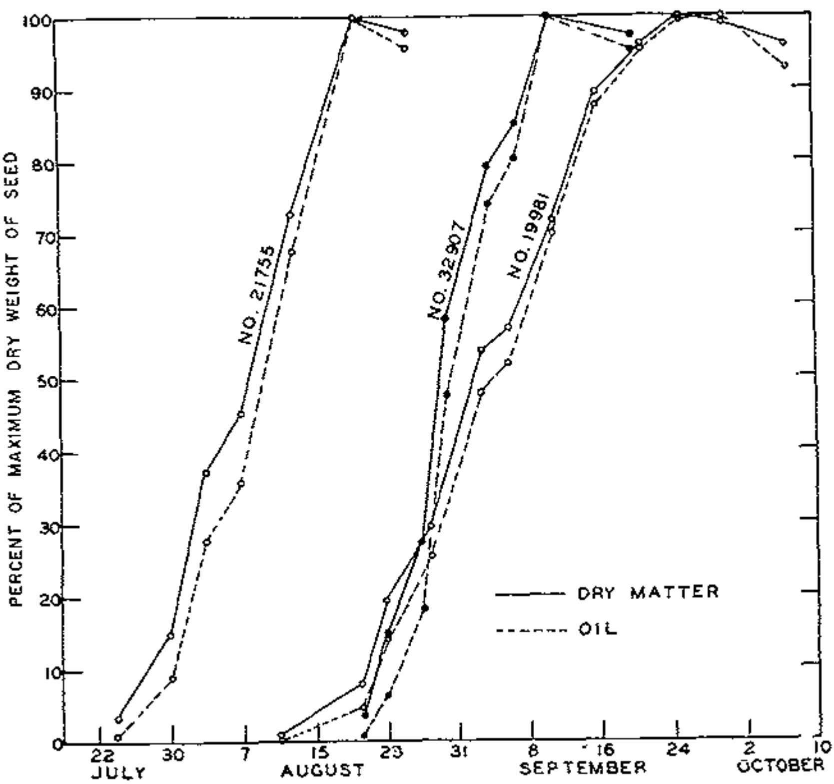

FIGURE 1.—Rate of development of dry matter and oil in the seed of three soybean strains (calculated from data by Garner, Allard, and Foubert (*12*)).

also show that there is some increase in protein and practically no change in iodine number of the oil.

It is reasonable to assume that the chemical composition of the soybean seed and the characteristics of the soybean oil will be influenced by the climatic factors affecting the growth and development of the plant, particularly during the period when the bean is developing in the pod. The period between blossoming and physiological

[5] Division of Plant Exploration and Introduction number.

maturity may be divided into two parts. The first is that of pod development and the second that of bean formation. The date of blooming will be governed by the date of planting and the photoperiodic characteristics of the variety. The length of the subsequent period of development, including the period of pod formation and the growth of seed in the pod, will be influenced by the characteristics of the variety and the nature of the season. Hence in studying the influence of environment on the composition of varieties of different maturity ranges, it is not possible to choose any particular part of the season as critical for all varieties with respect to the influence of climatic factors on composition.

EFFECT OF VARIETY, LOCATION, AND SEASON ON YIELD AND COMPOSITION OF SOYBEAN SEED

Materials and Methods

AGRONOMIC METHODS

To supply the laboratory with a large selection of samples of soybean seed of known history, seed of 10 varieties and strains, chosen to include the leading varieties in the region as well as a range in genotypes, was sent to each of the agricultural experiment stations of Illinois, Indiana, Iowa, Missouri, and Ohio for planting. This work was initiated in the spring of 1936, at which time the seedings were made in ¹⁄₁₀-acre field plots, following the usual cultural practice in use at each station. General agronomic notes were taken during the summer. When mature, the plots were harvested and bushel-sized samples sent to the laboratory. These were further subdivided on a Boernier sampler and 3-pound samples taken for chemical analysis.

The following year seed of the 10 varieties was again prepared and sent out for planting in drill plots, which, however, were replicated for the purpose of obtaining more representative composite samples. Yields were taken at all locations in the fall of 1937. By 1938 it was found that bushel lots of seed were no longer needed for processing studies, so for the next three seasons the varieties were planted in rod-row plots, using replications to obtain more representative chemical samples and to permit more accurate yield testing.

VARIETIES USED

The varieties were selected to include early and late types in order to study the effect of ripening at different periods on the composition of the seed. The varieties and strains, with the exception of Peking, are all yellow-seeded. Peking is a black-seeded type, used principally for hay; but, since its oil has a high iodine number, it has been used in breeding work to improve drying quality of soybean oil. Most of these varieties are described by Morse and Cartter (*20*), who give the relative maturity ranking of the varieties (expressed in days from planting to maturity at Arlington, Va.) as follows: Mandarin, 100 days; Mukden, 105 days; Dunfield, 110 days; Illini, 105 days; Manchu, 110 days; Scioto, 120 days; Peking, 125 days. The Illinois selection T–117 has about the same maturity as Scioto, whereas P. I. 54563–3 is a few days later than Peking. The two strains of Dunfield designated as A and B were obtained from the Illinois Agricultural Experiment Station and the Purdue Agricultural Experiment Station, respectively, in the spring of 1936 and were carried in the test in succeeding years by those designations.

A map of the North Central Region (fig. 2) shows the location of the six experiment stations where soybeans were grown for the study of the effect of location and season on composition of soybean seed.

The soil type on which the soybeans were grown at La Fayette, Ind., was a Crosby silt loam; at Urbana, Ill., a Muscatine silt loam; at Ames, Iowa, an O'Neill silt loam; at Columbia, Mo., a Putnam silt loam; at Wooster, Ohio, a Canfield Silt loam; and at Columbus, Ohio, a Miami silt loam.

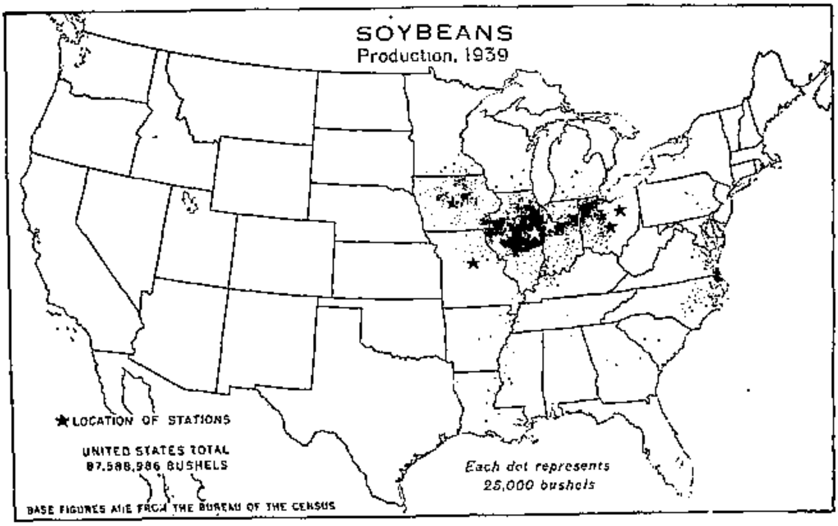

FIGURE 2.—Map of the United States showing 1939 soybean production and indicating the six locations where the field investigations were conducted.

METHOD OF STORING SAMPLES

All samples for chemical analysis, after being carefully composited, were placed in a constant-humidity storage room held at 18 percent relative humidity and 70° F. temperature for sufficient time to attain equilibrium under those conditions prior to analysis. Although this precaution may not be necessary for many types of oilseeds, it is especially desirable for soybeans, as moisture content has been found to affect the percentage of crude ether extract removed by petroleum ether (*1*).

Analyses of variance of the data have been made according to methods by Fisher (*11*), and the significant variances determined according to the *F* values of Snedecor (*25*).

METHODS OF CHEMICAL ANALYSIS

The samples of air-dry-conditioned soybeans were prepared for analysis by grinding in a Wiley mill, using a screen with 1-mm.-

diameter holes. Moisture was determined as the loss in weight on heating for 40 minutes at 130° C. in a forced-draft electric oven. Ash was determined as the weight of the residue remaining after ignition for 3 hours in a muffle furnace at a temperature of 600°.

In determining nitrogen (*4*), crude fiber (*3*), potassium (*6*), phosphorus (*5*), calcium (*2*), and total sugars (*7*), the official and tentative methods of analysis of the Association of Official Agricultural Chemists were used with but slight modifications occasioned by the characteristics of soybeans.

It has been shown by analysis of checkrows in a soybean nursery at Urbana during 1937 that the oil content of the same variety may vary as much as 1 to 1.5 percent, and the protein content may vary from 1 to 3 percent. These observations are in accord with the findings of Viljoen (*28*) and indicate the importance of obtaining samples for chemical analysis by compositing several replications. It was not possible to analyze replications separately because of the enormous number of analyses involved; however, all samples used in this study were obtained either by subsampling a large plot, as was done in 1936 and 1937, or by compositing five replications, as was done in 1938–40.

Since no replications were analyzed chemically, in the analysis of variance of the data the only error term available for the 5-year study is the three-way interaction "varieties × locations × years." Two samples were destroyed by mistake at Columbus, Ohio, in 1939, so values for the two strains T–117 and P. I. 54563–3 were supplied according to the method by Love (*19*), and that number of degrees of freedom deducted from the varieties × locations × years interaction.

In using the Kjeldahl-Gunning-Arnold method for nitrogen, mercury was used as the catalyst. The percentage of nitrogen was converted to the percentage of crude protein by multiplying by the 6.25 factor, as is customary in feed analyses. The sample from the oil determination was used for the crude-fiber determination. In ashing the sulfuric-acid-treated sample for the determination, the crucible containing the sample was placed in a cold muffle furnace and ignited for 3 hours at 700° C. after the furnace came to that temperature. The residue from the ash determination was used for the determination of phosphorus and calcium. Repeated trials in the analysis of soybeans for phosphorus have shown that nothing is gained through the use of the magnesium-nitrate-ignition procedure. There is apparently enough calcium and magnesium to retain the phosphorus. In using the Scales procedure for total sugars the solutions were standardized against a standard solution of pure sucrose, and the results expressed in terms of sucrose.

The percentage of oil in the seed and the iodine number (Wijs), acid number, unsaponifiable matter, and refractive index (25° C.) of the oil were determined according to the official and tentative methods of the American Oil Chemists' Society (*1*).

In determining the percentage of oil, 2 gm. of the ground sample were wrapped in two thicknesses of 15-cm.-diameter qualitative filter paper. A plug of cotton was placed on top of the sample, and the sample was extracted in a Butt extraction tube with petroleum ether (as specified by the American Oil Chemists' Association). After 2 hours of extraction the sample was removed from the extractor and reground for 1 minute, using a mortar and pestle. Two hundred revolutions of the pestle are very closely equivalent to a regrind of 1 minute. The sample was then extracted for 2 hours more. The solvent was removed from the extracted oil by a ¾-hour heating on a steam bath, and the percentage of oil was determined by the gain in weight of the extraction flask.

A ½-hour reaction time was used in the determination of the Wijs iodine numbers, and during the reaction period the sample and reagent mixtures were kept in a refrigerator maintained at 18° C. The refractive indexes on the oils obtained in the oil determinations were read to the fifth decimal place, using a water-jacketed double prism-head dipping refractometer. A reliable thermostatically controlled water supply was used to maintain constant refractometer-prism temperature.

In order to check the reproducibility of analytical results obtained, lots of the soybeans were frequently resampled and rerun or analyzed again in duplicate. The results of this checking on precision, shown in table 1, include not only the deviations encountered in chemical analysis but also those due to any variations in sampling. The calculated standard deviation within samples, in most cases of the specified determinations, are well within the maximum allowable deviation between duplicates allowed the analysts in reporting results. It may be assumed that any deviation between samples greater than twice the observed standard deviation within samples for any of the specified determinations is of agronomic significance and may be attributed to differences in variety or environment.

TABLE 1.—*Reliability of chemical analyses of soybeans, including sampling error*

Constituent	Allowable deviation between duplicates	Samples rerun in duplicate	Average value for samples	Deviation between rerun averages on individual samples		Standard deviation within samples
				Lowest	Highest	
		Number				
Protein (N × 6.25)	0.50	17	42.47	0.10	1.12	0.40
Oil	.25	17	19.99	.01	.75	.27
Iodine number (Wijs)	.8	17	128.7	.0	2.1	.5
Ash	.05	17	5.04	.00	.14	.05
Potassium	.10	8	1.74	.00	.11	.05
Calcium	.010	17	.288	.001	.018	.008
Phosphorus	.010	17	.660	.001	.035	.009

Except for the values determined on the oil, the constituents determined in the soybean seed are reported in the tables and discussed in the text on a moisture-free basis.

Climatological Data

The 1936 growing season in the North Central States was characterized in general by unusually hot weather accompanied by a deficiency in precipitation. The warm spell started about the last week in June and was not broken until the first of September. Iowa experienced an unprecedented number of days with maximum temperatures above 100° F., according to the records of the United States Weather Bureau.[5] At Columbia, Mo., the hot spell was probably the

[5] Compiled from Climatological Data issues of the U. S. Weather Bureau.

worst on record and the drought nearly as severe as at Ames, Iowa. Temperatures were high at Urbana, Ill., with a precipitation deficit in July but normal rainfall in August. July and August temperatures at La Fayette, Ind., with departures above the normal of 8.2° and 6.2° F., respectively, were similar to the temperatures for the same period at Urbana, Ill., and Ames, Iowa. This contrasted with the less severe departures from the normal at Columbus, Ohio, for the same 2 months of 4.7° and 4.8° F., respectively. At Columbus, Ohio, the last week of July and the month of August were marked by showers, thus breaking the drought much earlier than at either Ames or Columbia. Table 2 gives the mean and normal monthly temperatures and the total monthly precipitation during the summer seasons at the five locations for 5 years.

TABLE 2.—*Mean monthly temperatures and total monthly precipitation at locations where experiments were carried on during the summers of 1936–40* [1]

Year and location	Temperature					Precipitation				
	July	August	September	October	Mean	July	August	September	October	Total
1936	° F.	° F.	° F.	° F.	° F.	Inches	Inches	Inches	Inches	Inches
Ames, Iowa	82.2	78.2	67.4	50.4	69.55	0.09	1.41	9.10	1.08	11.68
Columbia, Mo.	86.6	85.1	72.9	56.5	75.28	.97	1.34	10.21	2.09	14.61
Urbana, Ill.	83.0	79.0	70.0	54.7	71.68	1.35	3.54	5.83	3.49	14.21
La Fayette, Ind.	83.8	80.2	70.8	55.4	72.55	.62	4.45	6.43	4.35	15.85
Columbus, Ohio	79.6	77.8	70.8	55.5	70.93	1.80	4.94	3.29	3.41	13.44
1937										
Ames, Iowa	75.3	76.6	65.2	49.8	66.73	1.38	5.00	.98	1.16	8.52
Columbia, Mo.	79.0	81.2	69.9	56.2	71.58	2.92	1.98	1.02	1.64	8.46
Urbana, Ill.	74.3	76.5	65.4	52.0	67.05	2.43	.80	5.34	3.92	12.49
La Fayette, Ind.	75.4	77.8	66.0	55.2	68.10	4.54	1.68	2.58	5.47	14.27
Columbus, Ohio	75.1	76.6	65.0	52.6	67.33	3.91	2.89	2.45	2.41	11.66
1938										
Ames, Iowa	77.0	75.5	66.8	59.3	69.65	4.04	1.87	3.19	.42	9.52
Columbia, Mo.	81.0	81.3	71.6	65.1	74.75	2.60	1.77	1.49	.59	6.45
Urbana, Ill.	76.0	75.7	68.6	59.9	70.05	6.45	4.28	.88	2.50	14.11
La Fayette, Ind.	77.0	77.2	69.1	59.8	70.78	5.59	2.86	3.88	.95	13.28
Columbus, Ohio	76.5	76.8	67.4	57.1	69.45	5.22	3.32	5.40	.70	14.64
1939										
Ames, Iowa	75.4	69.4	68.4	53.2	66.60	3.03	4.47	.83	1.53	9.86
Columbia, Mo.	80.8	75.4	75.4	61.1	73.18	2.33	8.71	.58	1.33	12.95
Urbana, Ill.	75.4	72.6	71.6	56.8	69.10	1.73	6.38	.32	2.54	10.97
La Fayette, Ind.	76.4	74.8	73.6	58.2	70.75	8.05	1.49	.47	3.48	13.49
Columbus, Ohio	74.6	74.9	72.4	57.2	69.78	2.55	.49	1.39	3.17	7.60
1940										
Ames, Iowa	75.4	69.8	65.0	56.9	66.78	6.38	6.67	.44	1.84	15.33
Columbia, Mo.	78.8	76.6	69.2	63.6	72.05	2.06	6.64	.32	2.60	11.62
Urbana, Ill.	76.0	74.8	66.0	60.0	69.20	.95	2.80	.48	1.93	6.16
La Fayette, Ind.	77.6	76.4	66.8	60.6	70.35	1.60	3.09	1.01	2.70	8.40
Columbus, Ohio	70.4	75.1	64.8	56.9	68.30	.49	2.27	1.55	1.38	5.69
38- to 65-year averages:										
Ames, Iowa	74.1	71.5	64.2	51.9	65.43	3.26	3.78	4.32	2.62	13.98
Columbia, Mo.	77.3	76.3	69.4	56.9	69.98	3.49	3.60	4.35	2.61	14.0[illegible]
Urbana, Ill.	74.8	72.8	66.2	54.3	67.03	3.20	3.53	3.24	2.71	12.68
La Fayette, Ind.	75.6	73.4	67.0	55.0	67.75	3.71	3.71	3.55	3.00	13.07
Columbus, Ohio	74.9	73.0	66.5	55.2	67.40	3.55	3.26	2.57	1.40	10.84

[1] U. S. Weather Bureau climatological data, Illinois, Indiana, Iowa, Missouri, and Ohio sections, 1936–40

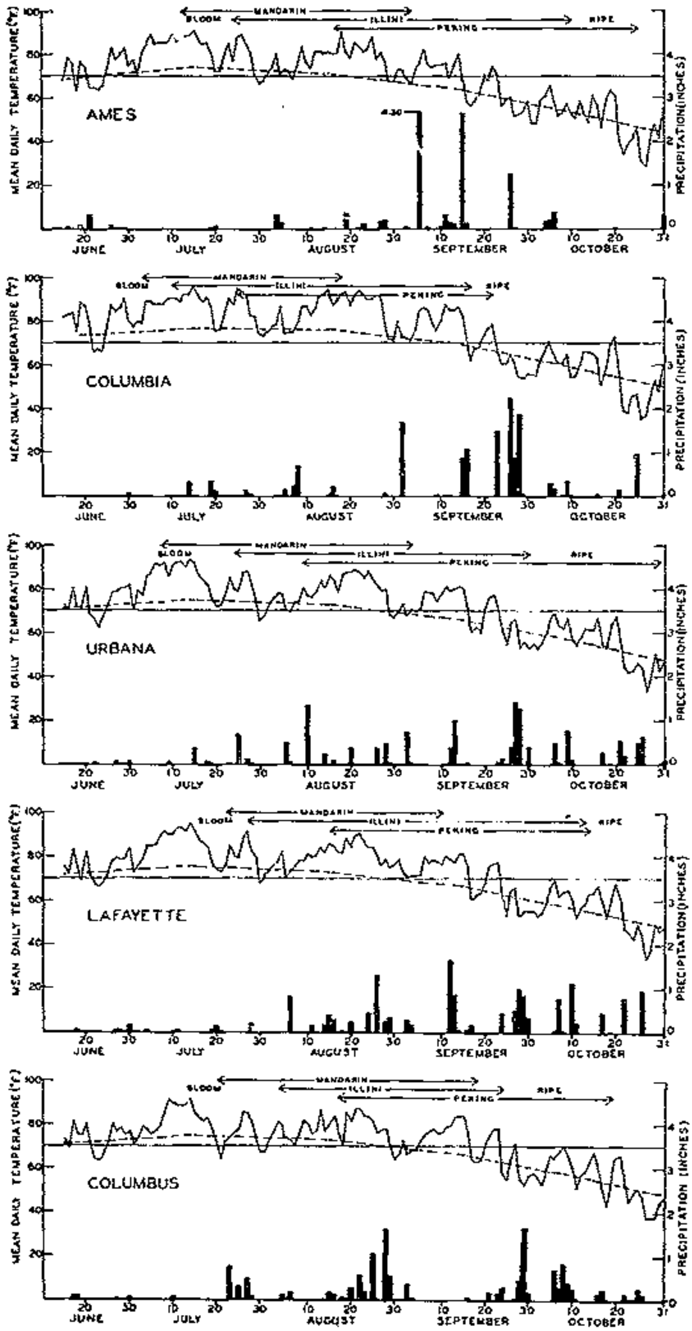

FIGURE 3.—Daily mean temperature, average mean monthly temperature, and daily precipitation at five locations during the 1936 growing season, together with date of blooming and ripening of three specified soybean varieties.

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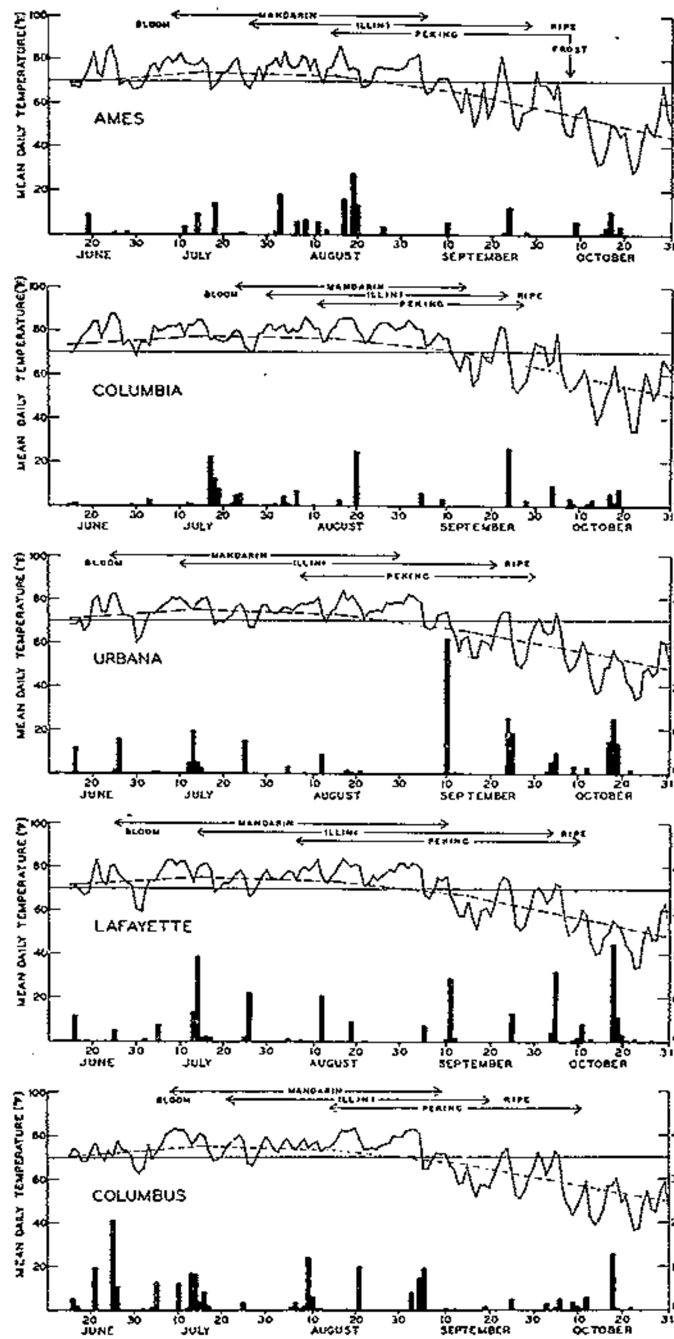

FIGURE 4.—Daily mean temperature, average mean monthly temperature, and daily precipitation at five locations during the 1937 growing season, together with date of blooming and ripening of three specified soybean varieties.

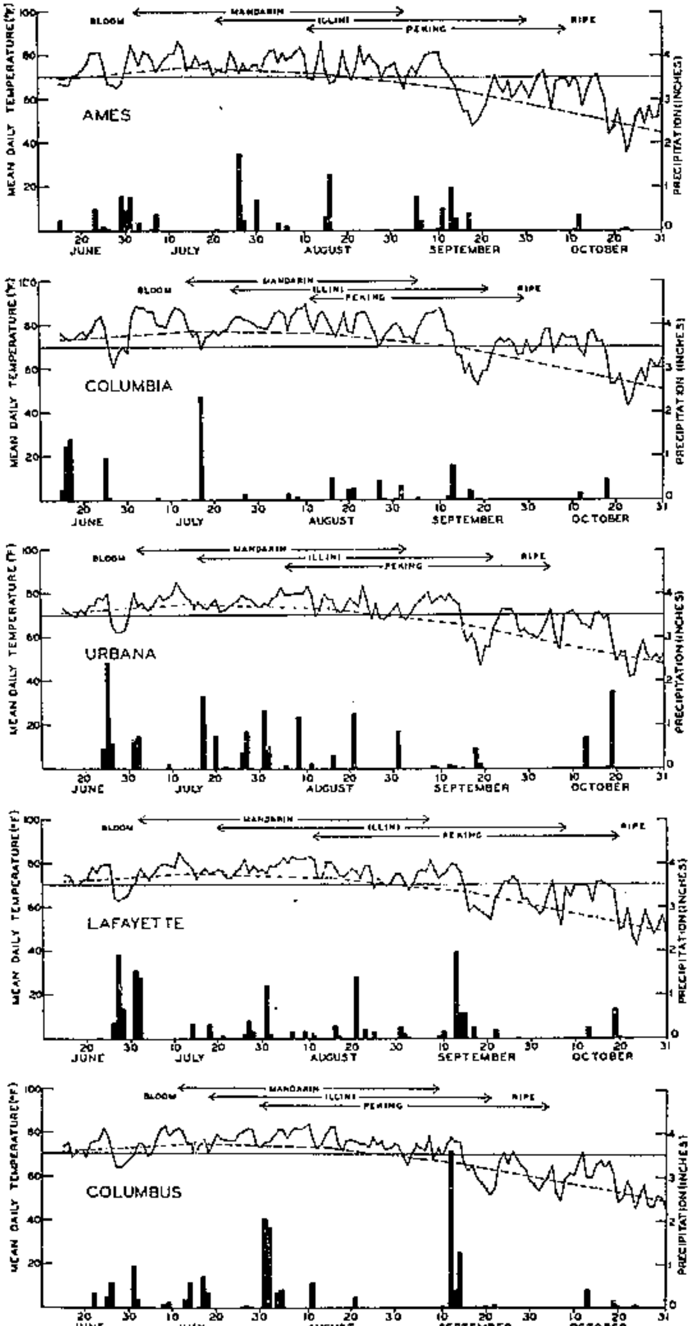

FIGURE 5.—Daily mean temperature, average mean monthly temperature, and daily precipitation at five locations during the 1938 growing season, together with date of blooming and ripening of three specified soybean varieties.

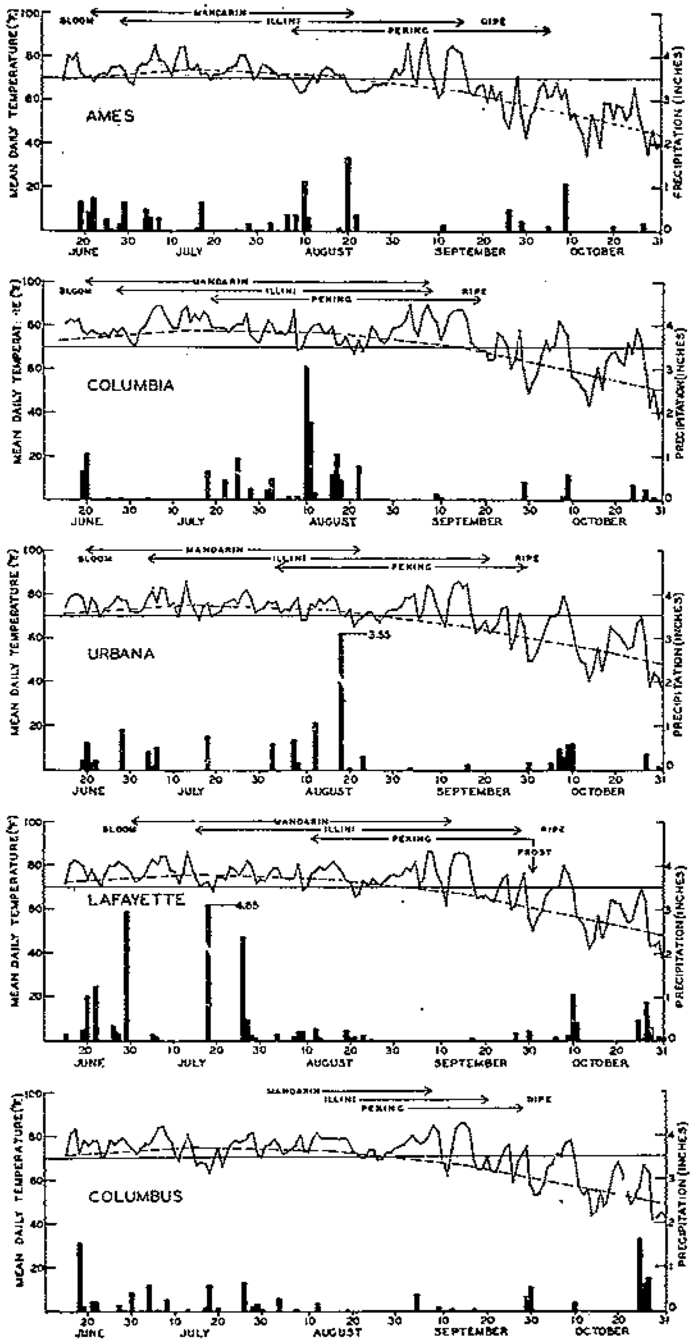

FIGURE 6.—Daily mean temperature, average mean monthly temperature, and daily precipitation at five locations during the 1939 growing season, together with date of blooming and ripening of three specified soybean varieties.

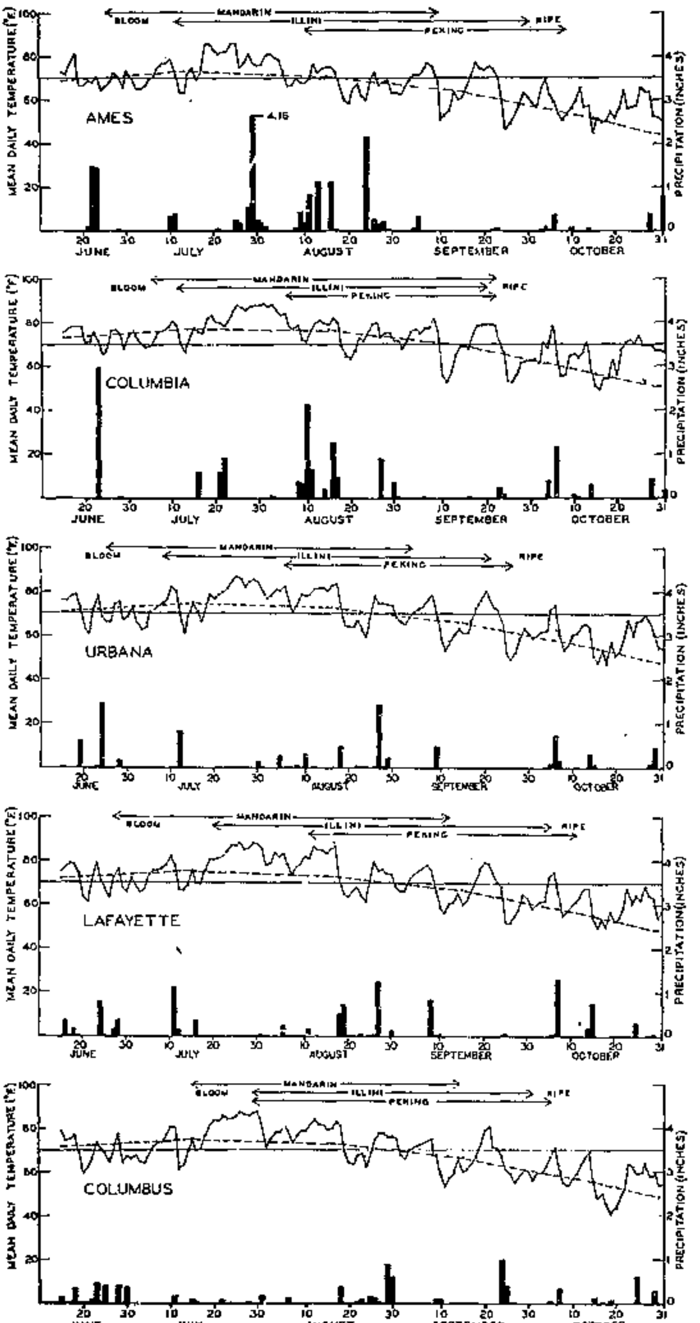

FIGURE 7.—Daily mean temperature, average mean monthly temperature, and daily precipitation at five locations during the 1940 growing season, together with date of blooming and ripening of three specified soybean varieties.

The 1937 season was cooler than that of 1936, with a better distribution of rainfall, as can be observed by examination of the weather graphs for the soybean-growing season of these 2 years (figs. 3 and 4). Temperatures during August varied only slightly from the average, being high at all locations. In general, a striking similarity is noticed in the weather at all five locations, the temperatures fluctuating together, though on slightly different levels.

The 1938 growing season was characterized by temperatures uniformly above average, with means for August 2° to 4° F. above at the five locations (fig. 5). Precipitation for July and August was fairly plentiful except at Columbia, where a drought beginning in July became more severe as the season progressed.

The 1939 growing season was characterized by near-normal temperatures at all locations during July and August and temperatures uniformly several degrees above average for the first half of September (fig. 6). Precipitation was adequate in the early part of the season. At Columbus the month of August, with a precipitation 60 percent of average, was the driest in many years, seriously affecting yield of medium and late soybean varieties. Temperatures, however, were not much above normal during the dry period.

Temperatures at the five locations during 1940 (fig. 7) were very similar. They were somewhat below average during the first half of July. A warm spell then occurred uniformly at all five locations and extended to the middle of August, after which the temperatures dropped off at the normal rate to the end of the season. Rainfall was about average and well distributed except for an abundance of precipitation at Ames and for a drought at Columbus, during July and early August, severe enough to affect seed yields.

Yield

The principal purpose of the present study has been to gain information on the variation in composition of soybean varieties when grown under different climatic conditions. Yield data were obtained for the last 4 years (1937–40) of the study and are recorded in table 3. Although the 1937 yields were taken on duplicated field plots and the 1938–40 yields on rod-row size plots with five replications and an extra variety included, the mean yields for the 4 years should be comparable.

TABLE 3.—*Yield of seed per acre of 11 varieties and strains of soybeans at each of 5 locations during 1937–40*

Year and location	Yield of seed per acre of the varieties indicated											Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P.I. 54563-3	Mandell	
1937	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
Ames, Iowa	20.9	21.3	26.9	27.9	23.3	21.2	20.5	26.3	9.4	19.1	------	21.7
Columbia, Mo	27.2	30.1	29.5	30.4	33.9	32.2	31.7	27.5	22.0	22.6	------	28.7
Urbana, Ill	23.8	22.0	21.0	19.4	20.8	22.2	21.6	28.7	21.7	24.4	------	22.6
La Fayette, Ind	29.0	33.1	30.2	34.4	35.8	32.7	31.2	33.2	24.7	24.2	------	30.9
Columbus, Ohio	4.2	14.1	13.3	17.4	13.7	14.1	18.5	18.0	17.3	9.4	------	14.0
Mean	21.0	24.1	24.2	25.9	25.5	24.5	24.7	26.7	19.0	19.9	------	23.6

TABLE 3.—*Yield of seed per acre of 11 varieties and strains of soybeans at each of 5 locations during 1937–40*—Continued

Year and location	Yield of seed per acre of the varieties indicated											Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P.I. 54563-3	Mandell	
1938	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
Ames, Iowa	16.6	20.1	23.1	22.4	22.6	21.3	26.2	22.9	23.1	27.7	20.5	22.4
Columbia, Mo	16.9	19.7	20.3	19.8	20.9	19.7	20.7	21.9	17.0	20.2	18.5	19.6
Urbana, Ill	29.8	39.1	35.8	36.3	35.4	36.2	45.4	44.6	32.2	37.2	42.4	37.8
La Fayette, Ind	30.0	38.8	34.5	35.4	37.1	37.0	33.4	34.3	28.9	37.2	35.5	34.7
Columbus, Ohio	28.8	18.7	22.4	19.8	28.8	18.7	20.7	20.1	18.1	19.3	25.4	21.9
Mean	24.4	27.3	27.2	26.7	29.0	26.6	29.3	28.8	24.1	28.3	28.5	27.3
1939												
Ames, Iowa	12.1	23.6	27.4	28.0	28.1	26.2	27.4	28.2	19.2	21.2	27.9	24.5
Columbia, Mo	8.2	7.3	17.8	14.8	14.0	18.0	24.6	18.0	19.0	19.1	13.8	15.4
Urbana, Ill	20.5	41.0	48.2	48.1	43.6	48.4	48.6	40.4	34.9	40.0	46.0	42.7
La Fayette, Ind	27.7	30.4	35.1	31.4	31.4	32.5	31.2	34.9	23.4	29.2	36.6	31.3
Columbus, Ohio	10.0	17.4	16.0	15.5	17.2	11.6	17.5	12.1	9.5	11.8	18.6	14.3
Mean	16.5	23.9	28.9	27.0	26.9	27.3	29.9	26.7	21.2	24.3	28.7	25.6
1940												
Ames, Iowa	14.6	23.0	32.2	32.2	32.4	31.5	30.7	25.1	21.9	23.1	30.4	27.0
Columbia, Mo	6.5	18.1	23.0	19.6	15.9	22.7	22.0	23.4	20.5	21.4	17.8	19.3
Urbana, Ill	20.9	25.0	29.9	27.7	29.4	34.9	34.4	33.1	31.9	26.5	30.2	29.4
La Fayette, Ind	17.5	32.3	20.6	23.6	33.1	30.6	28.7	29.8	20.5	29.8	27.1	27.5
Columbus, Ohio	14.5	18.1	19.1	17.0	18.7	18.6	22.0	20.8	20.7	19.2	17.3	18.8
Mean	14.8	23.3	26.8	24.3	25.9	27.7	27.7	26.4	23.1	24.0	24.6	24.4
4-year mean												
Ames, Iowa	16.1	22.0	27.4	27.6	26.6	25.0	26.2	25.6	18.4	22.8	[1]26.3	23.9
Columbia, Mo	13.5	18.8	22.7	21.2	21.2	23.2	25.0	22.7	19.6	20.8	[1]16.7	20.8
Urbana, Ill	26.0	31.8	33.7	32.9	32.3	35.4	37.5	36.7	30.4	32.0	[1]39.7	33.1
La Fayette, Ind	20.1	33.7	32.4	31.2	34.4	33.2	31.1	33.1	24.4	30.1	[1]33.1	31.1
Columbus, Ohio	14.4	17.1	17.7	17.7	18.6	15.8	19.7	17.8	16.4	14.9	[1]20.4	17.3
General mean	19.2	24.7	26.8	26.1	26.8	26.5	27.9	27.2	21.9	24.1	[1]27.3	25.2

[1] 3-year mean.

Maximum yields are obtained when a variety uses the entire growing season. However, yield may be sacrificed to obtain earliness as with the early variety Mandarin, which is adapted to the northern tier of States in the North Central Region. It is used in the main soybean States of Ohio, Indiana, Illinois, and Iowa only as an early variety to be harvested ahead of fall grain seeding. Mandarin has been significantly low in yield at each location during each year since 1938, with the exception of the 1938 season in Ohio, when it was significantly high in yield. In explanation of this, it can be seen from the 1938 weather graph (fig. 5) that abundant rains occurred at Columbus the last of July, during the critical filling period for Mandarin. The severe drought during August at the filling period for the later varieties seriously reduced yields below what could have been obtained with better rainfall distribution. Mukden, being later than Mandarin, has yielded higher for an average of the entire period.

An observation of interest in connection with the principal commercial varieties adapted to the States of Ohio, Indiana, Illinois, Missouri, and Iowa is the very close mean yields obtained. On the other hand, late varieties that frequently are caught by frost suffer reduced yield and may be difficult to harvest. Peking has averaged surprisingly well over the region, considering its lateness. The selection P. I. 54563-3 is even later than Peking and has suffered reduction in yield at Ames and Columbus in some seasons by being caught by frost. The 4-year average yields shown in table 3 may be helpful in studying the relative performance of the varieties. Further discussion of effect of season is given in the discussion of the effect of fertility level.

Size of Seed

One of the characteristics used to describe soybean varieties is seed size. Much variation exists in the size of seed from different soybean types. On an average, a range of from 0.75 gm. per 100 seeds for the small-seeded wild soybean to 35.0 gm. per 100 seeds for the large-seeded vegetable types can be expected. The more common commercial types average from about 13.0 to 16.0 gm. per 100 seeds. Farmers prefer medium- to small-seeded commercial strains for two reasons: First, the smaller seeded types emerge through a crusted soil surface with less difficulty than the large-seeded types and with fewer broken cotyledons; and second, the smaller seeded commercial varieties have a larger number of seed per bushel, thereby permitting a slightly lower seeding rate. For industrial-processing purposes there is no particular preference for either the large- or small-seeded types within the limits encountered between the commercial varieties.

Size of seed is given in this study as the weight in grams of 100 seeds, determined after the seed had been stored at 70° F. and 18 percent relative humidity for sufficient time to attain moisture-content equilibrium. Although seed size is of relatively little importance, moisture content exerts an influence upon this determination. Therefore, accurate results can only be obtained if uniform moisture conditions prevail.

The 10 varieties studied were known to differ significantly in seed size. Peking is shown to have a 5-year mean of 6.92 gm. per 100 seeds whereas Illinois T-117 has a mean of 15.37. P. I. 54563-3 and Illini have a smaller mean weight per hundred seeds than do Manchu, Scioto, Dunfield, Mandarin, and Mukden. It should be noted that the unusually low value of P. I. 54563-3 at Ames in 1937 was due to immaturity at the time of the first killing frost. Scioto, T-117, and Peking were also frosted, but they were sufficiently advanced toward maturity so that they did not decrease appreciably in size.

A separate study conducted on Illini in 1940 at six successive harvest dates, extending from the "full-podded bean stage" (late vegetable stage) to complete maturity, showed only a small change in seed size due to time of harvest. This indicates that beans frosted near maturity will decrease appreciably neither in size of seed nor in relative yield as an indirect result of frosting. The data showing the relation of maturity to size of seed are graphically represented in figure 8. This figure also shows the trend in percentages of protein and oil and iodine number of oil during the period of desiccation following physiological maturity.

In table 4 seed size is summarized for 10 strains of soybeans grown at 5 locations for 5 years. Seed size was noticeably smaller at Columbia than at any other location for the 5-year period. A possible explanation for this may be the higher temperatures at Columbia, accompanied by insufficient rainfall during the filling period. This relationship can be substantiated by reference to figures 3 to 7. In 1939 (fig. 6) it will be noted that there was an abundance of rainfall at Columbia during August. Therefore, larger seed size might be expected at Columbia for that season. Referring again to table 4, it can be seen that the average seed size for all varieties was larger at Columbia than at any other of the 4 locations in 1939. Apparently

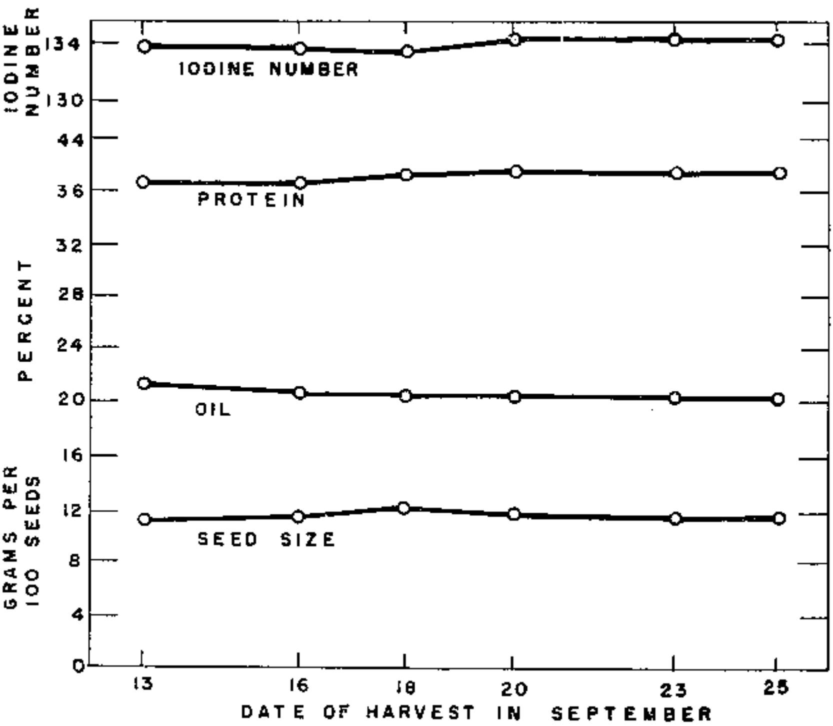

FIGURE 8.—Effect of stage of maturity on seed size and protein and oil content of soybean seed, and of the iodine number of the oil.

seasonal conditions play an important role in modifying size of soybean seed, one of the important factors being the stage of development of the whole plant and its parts when unfavorable weather conditions occur. During flowering and early ovule and seed development the soybean plant regulates, by physiological abortion, the number of seed that it can fill under existing environmental conditions. Thus, when unfavorable growing conditions occur early in the season the plants are smaller and less seed are set. Subsequent favorable conditions providing abundant food for those seeds set tend to produce larger seed than would be produced if reverse conditions occurred.

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TABLE 4.—*Size of seed, expressed in grams per 100 seeds, of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average seed size by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Weight of 100 seeds of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	Mean
1936	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Ames, Iowa	12.12	15.41	15.32	16.20	14.54	15.93	15.16	18.53	9.33	15.41	14.80
Columbia, Mo	10.50	11.71	11.39	13.06	10.62	10.35	10.82	12.17	7.96	14.39	11.30
Urbana, Ill	17.50	14.61	14.25	14.25	13.70	14.77	19.16	18.06	8.70	16.48	15.15
La Fayette, Ind	14.32	15.84	15.41	15.00	13.83	16.02	14.61	16.98	7.14	14.10	14.33
Columbus, Ohio	16.02	16.58	13.76	15.66	13.19	14.46	16.20	16.68	6.77	13.70	14.30
Mean	14.09	14.83	14.03	14.83	13.18	14.31	15.19	16.48	7.98	14.82	13.97
1937											
Ames, Iowa	16.29	13.50	13.00	13.25	12.22	14.10	11.86	13.25	5.33	7.11	11.99
Columbia, Mo	13.83	12.80	12.95	13.13	11.48	12.77	11.91	12.54	6.47	10.99	11.90
Urbana, Ill	13.97	14.03	13.76	13.63	11.96	12.89	13.06	14.18	6.33	13.44	12.73
La Fayette, Ind	15.75	14.77	15.49	15.75	14.25	15.24	14.46	14.84	6.72	12.54	13.98
Columbus, Ohio	16.88	12.38	13.06	13.25	12.17	13.06	14.25	14.32	6.75	12.83	12.90
Mean	15.34	13.51	13.65	13.80	12.42	13.61	13.11	13.83	6.32	11.38	12.70
1938											
Ames, Iowa	14.46	12.77	14.92	14.64	13.76	15.75	16.02	15.24	7.27	13.90	13.89
Columbia, Mo	12.89	13.90	14.03	14.46	12.06	13.63	13.56	15.08	6.88	11.71	12.82
Urbana, Ill	16.48	13.63	13.76	14.03	12.43	14.77	15.41	14.77	6.91	12.33	13.45
La Fayette, Ind	14.92	13.70	14.39	14.61	12.83	15.41	14.32	15.00	7.09	13.00	13.53
Columbus, Ohio	16.29	12.01	10.70	13.00	10.99	12.60	12.38	11.43	6.11	12.43	11.79
Mean	15.01	13.20	13.56	14.19	12.41	14.43	14.33	14.30	6.85	12.67	13.10
1939											
Ames, Iowa	16.58	15.00	15.49	15.75	15.08	16.11	15.24	14.54	6.62	12.38	14.28
Columbia, Mo	13.00	16.11	15.40	16.39	15.66	15.06	16.48	16.78	6.44	14.54	14.66
Urbana, Ill	15.32	14.09	15.06	16.98	14.61	15.93	15.93	14.54	6.26	11.67	14.16
La Fayette, Ind	16.02	13.97	13.70	14.18	13.25	14.03	13.50	14.46	6.24	11.57	13.09
Columbus, Ohio	13.44	13.31	17.08	18.53	13.63	13.97	15.16	[1]15.58	7.85	[1]12.60	14.12
Mean	14.87	14.62	15.48	16.37	14.45	15.14	15.26	15.18	6.68	12.55	14.06
1940											
Ames, Iowa	17.30	16.20	15.41	16.29	16.30	16.11	14.77	16.39	6.18	12.60	14.78
Columbia, Mo	14.10	15.10	13.97	15.16	14.77	15.16	14.92	15.32	6.14	12.08	13.68
Urbana, Ill	13.50	14.69	15.75	17.61	13.56	16.78	16.02	18.41	7.90	12.77	14.70
La Fayette, Ind	15.16	17.72	16.58	18.06	15.84	17.94	17.61	18.53	6.53	11.52	15.55
Columbus, Ohio	15.41	16.02	16.48	17.08	15.08	16.29	16.98	16.58	6.05	14.39	15.13
Mean	15.11	15.98	15.64	16.84	15.13	16.45	16.06	17.05	6.74	12.67	14.77
5-year mean											
Ames, Iowa	15.37	14.60	14.83	15.27	14.40	15.60	14.01	15.59	6.95	12.28	13.05
Columbia, Mo	12.86	13.95	13.57	14.44	12.92	13.51	13.54	14.38	6.78	12.74	12.87
Urbana, Ill	15.35	14.33	14.64	15.30	13.25	15.03	15.02	15.99	7.22	13.34	14.04
La Fayette, Ind	15.23	15.20	15.11	15.52	14.00	15.73	14.90	15.96	6.74	12.55	14.10
Columbus, Ohio	15.61	14.06	14.22	15.50	13.01	14.08	14.09	14.92	6.90	13.19	13.65
Mean	14.88	14.43	14.47	15.21	13.52	14.79	14.79	15.37	6.92	12.82	13.72

[1] Missing data supplied.

TABLE 4.—*Size of seed, expressed in grams per 100 seeds, of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average seed size by variety, location, and year; and analysis of variance of the data*—Continued

VARIETY AND LOCATION MEANS [1,2]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Mandarin	14.09	15.34**	15.01**	14.87	15.11	14.88**
Mukden	14.83	13.51	13.20	14.62	15.98	14.43*
Dunfield, A	14.03	13.68	13.56	15.48	15.64	14.47*
Dunfield, B	14.83	13.80	14.19	16.37**	16.84**	15.21**
Illini	13.18	12.42	12.41	14.45	15.13	13.52
Manchu	14.31	13.61	14.43*	15.14	16.45**	14.79**
Scioto	15.19	13.11	14.33*	15.26	16.06*	14.79**
T-117	16.48**	13.83	14.30*	15.18	17.05**	15.37**
Peking	7.98°°	6.32°°	6.85°°	6.68°°	6.74°°	6.92°°
P. I. 54563-3	14.82	11.38°	12.67	12.55°	12.67°°	12.82°°
Location:						
Ames, Iowa	14.80	11.99	13.89	14.28	14.78	13.95
Columbia, Mo	11.30°°	11.90	12.82	14.66	13.68°	12.87°°
Urbana, Ill	15.15	12.73	13.45	14.16	14.70	14.04
La Fayette, Ind	14.33	13.98*	13.53	13.09	15.55	14.10
Columbus, Ohio	14.30	12.90	11.79°°	14.12	15.13	13.65
Average of all samples	13.97	12.70°°	13.10°°	14.08	14.77**	13.72

ANALYSIS OF VARIANCE [2]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	25.92**	30.31**	27.50**	38.35**	47.40**	157.79**
Locations	4	23.62**	7.07**	6.80**	3.38**	4.84**	12.78**
Years	4						33.85**
Varieties × years	36						29.22**
Locations × years	16						8.23**
Varieties × locations	36	1.96	1.06	.84	1.24	.95	1.31
Varieties × locations × years	142						1.18

[1] Variety means represent 5 locations; location means represent 10 varieties.
[2] ° = significantly lower than general mean (5-percent level).
°° = highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

Because spring and early summer growing conditions of 1940 were generally unfavorable when compared with later conditions, larger than average seed was produced. Contrasted with these conditions were the very favorable spring and early summer conditions of 1939, which favored an abundant seed set, and the extremely dry weather in August and September of the same year, which produced the smallest mean seed size for all locations except Columbia.

As dry hot weather conditions ordinarily prevail during the month of August, the seed of an early maturing variety, such as Mandarin, would not be appreciably decreased in size, as would those of the later maturing varieties. This can be verified by numerous examples in this study, one of which is seed produced at Urbana in 1938.

Thus, the climatic influence on seed size becomes evident. The complex analysis of variance for seed size of these 10 varieties at 5 locations for 5 years, shown in table 4, bears out the above-mentioned point. This analysis shows that year contributes more variability to size of soybean seed than does location. However, both the mean square for location and year are highly significant statistically. The large varieties × years interaction is not surprising in view of the variable seasonal rainfall in the various regions. The varieties × locations interaction is low with respect to the error term (varieties × locations × years), indicating that varieties tended to remain in their same respective rank for size of seed at the different locations during the 5 years. Although seed size in soybeans is a heritable characteristic, environment has been found to play just as important a part as it does with other quantitative characters, such as yield and composition.

Protein Content

The protein of soybean seed contains many of the biologically essential amino acids and therefore is of value as a feed for livestock, for which purpose it is usually marketed as soybean-oil meal. The protein has many uses (*22*) in human nutrition and also serves as an excellent industrial raw material, especially in the field of plastics and adhesives. The largest single industrial use of soybean meal is for plywood adhesive. It is estimated that more than half of all the plywood in this country is glued with adhesive made from soybean meal. A much smaller use is for wallpaper coating, and an additional small tonnage is used for plastics.

Refined soybean protein is produced to an extent of about 10 tons per day and is used at present primarily for sizing and coating paper, for sizing cloth, and for water paints.

Variation in the percentage of protein metabolized in soybean seed due to environmental factors has been the subject of much study. The increase in protein resulting from applications of lime has been quite consistent (*10, 18*). Stark (*26*) found an increase in protein with lime applications and also to a lesser extent with phosphate. Stark also concludes from a study of protein content resulting from several soil treatments at two locations that the chief factors affecting the composition of soybeans grown in different localities are soil fertility and soil reaction. However, Stark was reporting data obtained from fields separated not over 50 miles and in a region of similar climatic conditions.

In the present study, seed of the 10 varieties and strains of soybeans grown at the 5 locations during the 5 seasons 1936–40 were analyzed for total nitrogen. Protein values were calculated as nitrogen × 6.25, the conversion factor in common use by the feed and processing industries.

Protein content of the seed varied considerably among the varieties and strains used in the study, Mandarin being the highest and Peking the lowest for all locations over the 5-year period, as shown in table 5. In this table are recorded the individual analyses of the 10 strains grown at the 5 locations during the 5 seasons 1936–40, together with their means. The lowest protein content was 36.62 percent for a sample of Peking at La Fayette in 1940, and the highest was 53.19 percent for Mandarin at Columbia in 1939, a range of 16.57 percent.

TABLE 5.—*Crude protein content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of protein by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Crude protein content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P.I. 54563-3	
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	47.38	49.25	45.19	46.00	44.94	47.31	47.50	45.44	40.88	46.60	46.66
Columbia, Mo	41.00	45.19	47.37	42.75	44.75	45.94	42.88	45.13	40.25	49.25	45.05
Urbana, Ill	45.31	44.44	42.00	41.31	43.88	45.13	44.69	42.56	41.63	44.31	43.53
La Fayette, Ind	47.13	49.31	42.56	41.56	43.38	46.25	43.31	43.06	40.00	42.63	43.92
Columbus, Ohio	46.88	43.38	42.63	38.75	45.44	45.31	40.25	39.81	43.03	40.25	42.63
Mean	45.54	46.31	43.95	42.07	44.48	45.99	43.73	43.20	43.68	44.63	44.36
1937											
Ames, Iowa	45.56	46.44	38.75	40.63	40.56	44.13	42.88	41.50	40.44	40.38	42.13
Columbia, Mo	44.19	42.63	40.88	39.94	42.06	43.13	41.25	41.56	43.50	41.94	42.11
Urbana, Ill	42.31	45.06	40.31	40.19	40.69	42.19	40.56	39.63	37.69	41.94	41.00
La Fayette, Ind	44.88	46.88	40.94	41.31	42.69	44.69	42.63	41.81	39.69	41.75	42.73
Columbus, Ohio	49.00	44.94	41.13	39.69	44.69	43.38	41.44	41.19	40.00	42.00	42.75
Mean	45.19	45.19	40.40	40.35	42.14	43.50	41.75	41.15	40.26	41.61	42.16
1938											
Ames, Iowa	47.75	46.38	40.88	40.81	41.56	44.88	45.75	42.88	40.19	42.62	43.37
Columbia, Mo	43.31	45.69	42.12	41.81	41.44	44.56	42.12	42.38	43.06	42.69	42.92
Urbana, Ill	43.44	41.50	37.19	36.81	38.25	40.75	40.88	39.50	39.88	38.38	39.66
La Fayette, Ind	49.12	49.19	44.75	44.81	45.50	47.69	42.50	42.12	38.94	42.88	44.85
Columbus, Ohio	45.25	44.56	39.00	42.56	40.19	42.19	40.50	38.50	36.38	41.12	41.03
Mean	45.77	45.46	40.79	41.36	41.39	44.01	42.35	41.08	39.89	41.54	42.37
1939											
Ames, Iowa	46.81	45.19	40.50	39.75	41.00	42.62	39.94	41.19	40.50	41.50	41.90
Columbia, Mo	53.19	48.69	41.31	43.31	43.06	42.75	42.56	42.62	39.94	40.50	43.79
Urbana, Ill	40.88	43.25	38.94	38.69	38.62	40.75	40.25	39.44	39.75	39.88	40.05
La Fayette, Ind	44.81	45.31	39.44	41.31	42.81	42.56	43.06	43.06	39.81	42.19	42.44
Columbus, Ohio	47.06	47.81	43.81	42.94	46.25	46.25	44.09	[1]41.17	39.75	[1]43.61	44.63
Mean	46.55	46.05	40.80	41.20	42.35	42.99	42.10	42.10	39.95	41.54	42.56
1940											
Ames, Iowa	49.56	45.81	41.38	42.25	42.38	43.88	42.75	41.94	39.38	43.50	43.28
Columbia, Mo	51.19	46.75	39.38	41.69	43.56	43.31	43.38	41.69	38.69	40.44	43.01
Urbana, Ill	47.62	44.50	40.75	41.19	41.75	43.44	42.25	41.81	40.94	40.94	42.52
La Fayette, Ind	48.31	46.81	41.44	43.25	43.44	44.69	40.94	42.19	36.62	40.25	42.79
Columbus, Ohio	48.56	45.06	41.88	42.31	41.75	43.62	42.75	41.19	40.06	42.81	43.00
Mean	49.05	45.78	40.97	42.14	42.58	43.70	42.41	41.76	39.14	41.59	42.92
5-year mean											
Ames, Iowa	47.41	46.61	41.34	41.89	42.09	44.56	43.76	42.60	41.49	42.94	43.47
Columbia, Mo	46.58	45.79	42.21	41.90	42.97	43.94	42.44	42.68	42.29	42.90	43.38
Urbana, Ill	43.91	43.75	39.84	39.64	40.64	42.45	41.73	40.59	39.98	41.09	41.36
La Fayette, Ind	46.85	47.50	41.83	42.45	43.56	45.18	42.49	42.45	39.21	41.04	43.35
Columbus, Ohio	47.35	45.15	41.69	41.25	43.66	44.15	41.93	40.97	39.96	41.97	42.81
Mean	46.42	45.76	41.38	41.42	42.59	44.06	42.47	41.80	40.58	42.18	42.87

[1] Missing data supplied.

TABLE 5.—*Crude protein content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of protein by variety, location, and year; and analysis of variance of the data*—Continued

VARIETY AND LOCATION MEANS [2] [3]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mandarin	45.54	45.19**	45.77**	46.55**	49.05**	46.42**
Mukden	46.31	45.19**	45.46**	46.05**	45.78**	45.76**
Dunfield, A	43.95	40.40°	40.79°	40.80	40.97°°	41.38°°
Dunfield, B	42.07	40.35°	41.36	41.20	42.14	41.42°°
Illini	44.48	42.14	41.39	42.35	42.58	42.59
Manchu	45.99	43.50	44.01	42.99	43.79	44.06**
Scioto	43.73	41.75	42.35	42.10	42.41	42.47
T-117	43.20	41.15	41.08	42.10	41.76	41.86°°
Peking	43.68	40.26°	39.89°°	39.95°	39.14°°	40.58°°
P.I. 54563-3	44.63	41.61	41.54	41.54	41.59	42.18°
Location:						
Ames, Iowa	46.66*	42.13	43.37	41.90	43.28	43.47
Columbia, Mo	45.05	42.11	42.92	43.79	43.01	43.37
Urbana, Ill	43.53	41.06	39.66°°	40.05°°	42.52	41.36°°
La Fayette, Ind	43.92	42.73	44.85**	42.44	42.79	43.34
Columbus, Ohio	42.63	42.75	41.03°	44.63**	43.00	42.81
Average of all samples	44.36**	42.16°	42.37	42.56	42.92	42.87

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	8.64	17.55**	20.48**	23.09**	38.19**	93.45**
Locations	4	24.08**	4.73*	41.54**	31.50**	.81	39.01**
Years	4						38.46**
Varieties × years	36						3.63*
Locations × years	16						15.91**
Varieties × locations	36	4.16	1.75	2.40	2.63	1.18	2.66
Varieties × locations × years	142						2.36

[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] ° = significantly lower than general mean (5-percent level).
°° = highly significantly lower than general mean (1-percent level).
* In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
** In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

The mean values of protein content and the analysis of variance of the data are also recorded in table 5. The varieties are remarkably consistent in their performance in the different years. Mandarin, which was highly significantly higher than the mean of all varieties for the 5-year period, had a high percentage of protein in all years. The variety Mukden is also characterized by high protein content.

Peking, the variety having the lowest mean protein content, was significantly low in all years except 1936. The differential severity of the drought in 1936 in the five locations may have been the cause of the greater variety × location interaction, and for that year no variety departed significantly from the mean.

The 5-year means show Dunfield, one of the principal commercial varieties in the region, to be significantly low in protein content with 41.4 percent, whereas Manchu, another of the leading varieties, is highly significantly high with 44.1 percent. These percentages and relative ranking agree quite closely with the values given by Odland and Lea (*21*) in Rhode Island for the same varieties, 41.87 percent for Dunfield and 45.10 percent for Manchu, respectively.

Analysis of variance for the 5-year period (table 5) gives additional information on this point, the low varieties × locations interaction indicating that within the area covered in this study location was without effect on the relative ranking of the 10 strains during those seasons. It should be pointed out that, since the samples for chemical analysis were composited and only one analysis was made for each variety at each location each year, no true error term is available for use in evaluating the interactions. This situation is always unfortunate in studies involving chemical analysis where the agronomist can produce more samples than there is wisdom in analyzing chemically. Snedecor (*25*) and Salmon (*23*) indicate that caution must be observed when using interactions as an error term.

Among the locations, Urbana has produced low-protein-content seed during four of the seasons, 1937 to 1940, and for the 5-year period a mean protein value highly significantly lower than the general mean of the test was obtained. The only season that Urbana was not the lowest of all locations was in 1936, the year of severely high summer temperatures. By referring to the 1936 weather graph (fig. 3) it can be observed that temperatures were not so severe at Columbus, and rainfall, while low, was fairly well distributed, which may explain the low protein at Columbus that season. Fitting into the explanation is the very high mean protein content of the Ames seed for the same season, Ames having an extremely severe drought and unusually high July and August temperatures. In 1939 the varieties averaged high in protein at Columbus, coinciding with a long period of drought and temperatures above normal. Another explanation, however, must be sought for the high average protein produced at La Fayette during 1938, a season of well-distributed rainfall and nearly normal temperature.

Among the five seasons, as has been previously indicated, the mean protein content of the seed of all the varieties at all locations was high in 1936. It is of interest to note in table 5 the high location mean square for that season in comparison with the varieties mean square. The dissimilarity of climates at the five locations may account for the higher location variance and also for the high varieties × locations interaction. This was observed to a lesser degree in 1938 and 1939. However, in 1937 and again in 1940, the effect of the seasons was evidently similar at the five locations, for there was relatively less variance due to locations and little varieties × locations interaction.

Oil Content

The oil which comprises from 18 to 20 percent of the total weight of the seed of the leading commercial soybean varieties is of value for edible purposes and many industrial applications. Because in price per pound the oil is the more valuable of the two constituents, oil and oil meal, ordinarily obtained by processing of soybean seed, it is only natural that much interest is centered by farmers and processors in the oil content of different commercial varieties and in the influence of location and season on this constituent.

Seed of the 10 varieties and strains of soybeans under test were found to differ significantly in oil content or crude ether extract. The analyses are given in table 6. The means of these analyses, together with the analysis of variance of the data, are also summarized.

The variety Mandarin was significantly low in oil content in every season except that of 1936. It will be recalled that over an average of all locations Mandarin seed was significantly high in protein content in these same years and was also high for the 5-year mean. It may be of interest to observe that during 1936 Manchu seed contained less oil than Mandarin, and at the same time more protein, even though Mandarin was higher in protein for the remainder of the years. Dunfield has been characterized as a variety prized in Manchuria for its high oil content (*20*), and in the present study this variety, with only one exception, has consistently maintained the highest mean percentage of oil of all the varieties and strains under test. The exception was Dunfield, B, for 1940, the data for which seem to be out of line with the other data for that season. It will be noted that the A strain in oil content was equal to, or higher than, the B strain in 1937, 1938, and 1940; and, by reference to the protein analyses (table 5), it will be found that for these same samples the reverse is true for protein content in most instances. A definite exception to this inverse relationship between protein and oil is found in the variety Peking, which has quite consistently been low in mean percentages of both these constituents. The one case in which Peking did not produce the lowest percentage of oil of all varieties in the test occurred in 1940, when, for all locations, Mandarin had a mean value of 16.28 percent, whereas Peking had 17.80 percent. A glance at table 5 reveals that in this season Mandarin metabolized into the seed the highest mean percentage of protein of all the varieties. Apparently the climatic conditions responsible for the low oil content also produced a high protein content.

TABLE 6.—*Oil content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years, average percentage of oil by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Location and mean	Oil content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	18.13	18.10	19.29	18.11	18.30	17.97	17.19	18.10	15.34	17.63	17.82
Columbia, Mo.	19.81	20.62	19.34	21.42	19.51	17.80	20.22	18.48	16.09	17.15	19.04
Urbana, Ill.	18.94	20.69	22.80	23.02	20.30	18.70	20.70	21.74	17.67	20.25	20.48
La Fayette, Ind.	18.14	18.61	21.71	21.80	20.04	19.25	20.36	20.69	16.04	19.45	19.68
Columbus, Ohio	18.68	21.45	21.01	23.00	19.65	19.02	22.03	22.25	16.25	21.18	20.01
Mean	18.74	19.89	21.01	21.49	19.56	18.67	20.10	20.25	16.40	19.13	19.53
1937											
Ames, Iowa	18.96	19.53	21.37	21.13	21.01	19.85	19.67	20.03	16.05	18.60	19.61
Columbia, Mo.	19.47	20.51	21.59	21.07	20.70	19.67	20.70	20.14	15.56	20.23	20.05
Urbana, Ill.	19.41	19.25	21.09	20.09	20.24	19.45	20.81	20.81	18.05	19.70	19.98
La Fayette, Ind.	19.11	18.36	21.19	21.23	19.94	19.51	19.37	20.35	16.86	19.50	19.55
Columbus, Ohio	17.81	19.19	20.74	20.63	19.28	19.28	20.18	20.00	15.98	18.60	19.17
Mean	18.95	19.37	21.19	21.19	20.23	19.55	20.15	20.27	16.59	19.32	19.67

TABLE 6.—*Oil content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of oil by variety, location, and year; and analysis of variance of the data*—Continued

EXPERIMENTAL DATA—Continued

Location and mean	Oil content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1938	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	17.29	18.16	21.50	20.22	20.15	18.48	19.81	19.82	16.86	20.28	19.26
Columbia, Mo	19.40	20.22	21.20	21.75	21.62	10.68	21.33	20.99	16.40	20.10	20.28
Urbana, Ill	10.48	20.65	22.66	22.94	21.76	20.61	21.22	21.71	17.72	21.33	21.01
La Fayette, Ind	17.86	18.50	20.77	20.69	19.74	19.25	20.05	20.39	17.28	19.87	19.44
Columbus, Ohio	19.24	18.68	20.88	19.33	20.42	19.23	20.51	20.26	18.11	20.10	19.68
Mean	18.67	19.24	21.40	20.99	20.74	19.45	20.58	20.63	17.27	20.34	19.93
1939											
Ames, Iowa	18.24	19.51	21.29	21.64	20.70	20.77	22.28	21.53	17.56	21.03	20.46
Columbia, Mo	14.95	18.89	21.35	20.98	20.58	20.49	21.22	21.02	17.00	22.17	10.57
Urbana, Ill	20.09	20.14	22.07	22.62	21.49	21.44	22.04	21.75	17.45	20.57	20.97
La Fayette, Ind	18.92	19.02	20.64	21.34	20.14	19.74	19.77	19.85	17.17	20.42	19.70
Columbus, Ohio	18.70	18.18	20.38	20.23	18.93	18.37	19.12	10.95	17.66	19.95	19.15
Mean	18.18	19.15	21.15	21.36	20.37	20.16	20.89	20.82	17.37	20.83	20.03
1940											
Ames, Iowa	16.54	18.24	19.57	19.19	18.67	18.90	19.27	19.60	17.23	18.97	18.62
Columbia, Mo	15.39	18.59	21.39	20.39	19.57	19.90	20.11	20.48	18.16	21.45	19.54
Urbana, Ill	16.80	19.49	20.37	20.14	19.71	19.53	19.86	20.19	17.45	20.22	19.38
La Fayette, Ind	16.81	18.22	19.73	18.92	18.80	18.93	19.62	19.68	18.91	19.91	18.95
Columbus, Ohio	15.85	18.75	19.49	19.00	18.55	18.53	19.86	19.54	17.24	18.99	18.58
Mean	10.28	18.66	20.11	19.53	19.06	19.16	19.74	19.90	17.80	19.91	19.01
5-year mean											
Ames, Iowa	17.63	18.71	20.60	20.06	19.77	19.19	19.64	19.82	16.61	19.28	19.15
Columbia, Mo	17.82	10.77	20.97	21.30	20.40	19.51	20.72	20.22	16.64	20.22	19.76
Urbana, Ill	18.94	20.04	21.79	21.94	20.70	19.05	20.92	21.24	17.67	20.41	20.36
La Fayette, Ind	18.17	18.54	20.81	20.81	19.73	19.34	19.83	20.19	17.37	19.85	19.46
Columbus, Ohio	18.06	19.25	20.68	20.45	19.37	19.01	20.34	20.40	17.05	19.76	19.44
Mean	18.16	19.26	20.97	20.91	19.99	19.40	20.29	20.37	17.07	19.91	19.63

VARIETY AND LOCATION MEANS [11]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mandarin	18.74	18.95°	18.67°°	18.18°°	16.28°°	18.16°°
Mukden	19.89	19.37	19.24	19.15°	18.66	19.26
Dunfield, A	21.01*	21.19**	21.40**	21.15*	20.11**	20.97**
Dunfield, B	21.49**	21.19**	20.99**	21.36*	19.53	20.91**
Illini	19.56	20.23	20.74*	20.37	19.06	19.99
Manchu	18.67	19.55	19.45	20.16	19.16	19.40
Scioto	20.10	20.15	20.58	20.89	19.74*	20.29**
T-117	20.25	20.27	20.63	20.82	19.90**	20.37**
Peking	16.40°°	16.50°°	17.27°°	17.37°°	17.80°°	17.07°°
P.I. 54503-3	19.13	19.32	20.34	20.83	19.91**	19.91
Location:						
Ames, Iowa	17.82°°	19.61	19.26°	20.46	18.62	19.15°°
Columbia, Mo	19.04	20.05	20.28	19.67	19.54*	19.76
Urbana, Ill	20.48*	19.98	21.01**	20.97*	19.38	20.36**
La Fayette, Ind	19.68	19.55	19.44	19.70	18.95	19.46
Columbus, Ohio	20.61*	19.17°	19.08	19.15°	18.58	19.44
Average of all samples	19.53	19.67	19.93*	20.03**	19.01°°	19.63

See footnotes at end of table.

TABLE 6.—*Oil content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years, average percentage of oil by variety, location, and year; and analysis of variance of the data*—Continued

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	10.20**	9.06**	7.93**	9.13**	7.05**	37.62**
Locations	4	13.15**	1.27	5.10**	4.93**	1.90**	10.57**
Years	4						8.01**
Varieties × years	36						1.45**
Locations × years	16						3.95**
Varieties × locations	36	.85	.30	.33	.74	.26	.39
Varieties × locations × years	142						.51

[1] Missing data supplied.
[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] °=significantly lower than general mean (5-percent level).
°°=highly significantly lower than general mean (1-percent level).
*In case of means=significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means=highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

To the plant breeder and the grower of soybeans for processing, information on the effect of location is as important as the effect of variety or genotype on the oil content. A few observations can be made relative to the tendency for certain places to produce seed of high or low oil content. Among the 5 locations, the 10 varieties averaged highest in oil content at Urbana in 2 out of the 5 years, standing highly significantly higher than the mean in 1938. Likewise, at Urbana for the entire period the 10 varieties also maintained an oil content highly significantly above the 5-year mean, and 1.21 percent above the value for Ames. Although this relationship may be valid, the very low mean oil content of the varieties for the 5 years at Ames was due in part to the low oil content of these varieties in 1936, a season of unusual climatic conditions.

Among the 10 varieties and strains included in the test were Mandarin, a northern variety too early for the locations in the study, and Peking, a black-seeded variety, not suited to processing on account of the black flecking in the resultant meal as well as the low oil content of the seed. These and other strains were included to enlarge the range of genotypes under test.

Table 7, giving mean values of 5 of the leading commercial varieties now comprising a large part of the acreage in the region, should be of special interest to growers and processors. This table presents the same relative picture for the 5 as was given earlier for all 10 of the varieties, as to the effect upon oil content of the region where the soybeans are produced. It will be seen that an average of these leading commercial varieties of the region at the 5 locations shows Urbana as producing the highest percentage of oil and Ames the lowest, although the difference is only 1.10 percent.

Studies of the effect of location on composition of soybean seed have been made previously by other workers. Garner, Allard, and Foubert (*12*) grew soybeans in pots of soil brought in from different locations and concluded from their studies that the relative effects of different soil types are not specific and constant, but depend largely on seasonal conditions. A similar investigation was undertaken by Viljoen (*28*), who arrived at the same conclusion.

TABLE 7.—*The average oil content (dry basis) of the five leading commercial varieties for the five-year period at each of the five locations calculated from the data given in table 6*

Location	5-year averages for varieties shown					
	Mukden	Dunfield, A	Illini	Manchu	Scioto	Mean
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ames, Iowa	18.71	20.60	19.77	19.19	19.64	19.58
Columbia, Mo	19.77	20.97	20.40	19.51	20.72	20.27
Urbana, Ill	20.04	21.79	20.70	19.95	20.92	20.68
LaFayette, Ind	18.54	20.81	19.73	19.34	19.83	19.65
Columbus, Ohio	19.25	20.68	19.37	19.01	20.34	19.73
Mean	19.26	20.97	19.99	19.40	20.29	

From these studies it may be concluded that climate is the more important in its effects of the two factors, soil and climate, that go to make up the location effect. In table 6 are tabulated the variances due to varieties and to locations for the individual years as well as for the 5-year period. In 1936 the mean square for locations exceeded that for varieties, though not by a statistically significant difference. It is of interest, however, to recall the severity of the drought and heat in the western part of the north central region during that year. The varieties × locations mean square is large, possibly indicating more interaction among the varieties in their response to location effects.

It is recognized in the present study that the climatic effects at the five locations are similar in most years, 1936 being an exception. When larger geographical areas are included in a test involving a wide range in varieties, more variance is apt to be found due to location than to variety. Morse [7] in 1917 grew such a test over the southeastern part of the United States extending from Maryland to Texas. Table 8 gives the variances found for oil and protein content [8] of the seed of 10 strains of soybeans grown at 12 locations.

TABLE 8.—*Analysis of variance of data on oil and protein content of seed of 10 strains of soybeans grown at 12 locations*

OIL CONTENT

Source of variation	Degrees of freedom	Mean squares	F
Varieties	9	30.64**	18.09
Locations	11	35.04**	20.69
Varieties × locations	99	1.69	

PROTEIN CONTENT

Source of variation	Degrees of freedom	Mean squares	F
Varieties	9	20.98**	4.50
Locations	11	163.95**	35.19
Varieties × locations	99	4.66	

[7] Private communication from W. J. Morse giving analyses of selections grown in 1917.
[8] Percentages of oil and protein obtained through the courtesy of the Division of Oils, Fats, and Waxes, Bureau of Agricultural Chemistry and Engineering.

From these F values for the one season it appears that possibly oil content is less affected by extreme changes in location and climate than is protein content.

In the present study the mean oil content of all the varieties at all locations has not varied much from year to year, averaging 20.03 percent in 1939, the high year, and 19.01 percent in 1940, the low year, a difference of only 1.02 percent.

Among the interactions there was a significant varieties × years and locations × years interaction, indicating a differential effect of climate on oil content of the varieties. Of more importance to the plant breeder is the low varieties × locations interaction, indicating that the varieties remained in the same relative order with respect to oil content at the locations included in this study. In general, it might be concluded that within the area covered by this study any selections made for high oil content at one breeding nursery should prove to be reasonably high in comparison with other varieties when planted elsewhere in the area.

Iodine Number

The degree of unsaturation of soybean oil, as measured by the iodine number, is of especial importance from the standpoint of its use in paints and varnishes. The greatest spread in iodine number of the oil has been from 103. 9 for a sample of the Dunfield grown in Columbia, Mo., in 1936 to 155 for a sample of the wild soybean grown in northern Manchuria. The percentages of linoleic and linolenic acid in the oil increase with increasing iodine number.. As these are the film-forming constituents of the oil, it can readily be seen that for use in paints and varnishes an oil with high iodine number is desirable. Properly to evaluate the iodine number of oil derived from introductions and selections some information on the effect of environmental factors as they affect unsaturation of the oil is helpful. From the standpoint of the utilization for food purposes, an oil of low iodine number is preferred, though this factor is of perhaps minor importance. An oil of high iodine number is of importance, however, in the drying oil industry.

Little information is available on the effect of the various factors of environment in modifying soybean oil. Washburn (*29*) in 1916 published the results of a comprehensive survey of the composition of soybean oil, including in his studies the percentage of oil obtained from soybean varieties and selections grown over a wide range of conditions, together with the characteristics of the oil. Selected data from this bulletin will be presented later (p. 30) under the discussion of climatic effects on degree of unsaturation of soybean oil.

To obtain information on the quality of the oil of the principal commercial varieties grown in the North Central Region, the iodine number of the oil from the seed of the 10 varieties was determined as well as the oil content. The varieties in the test varied among themselves significantly in iodine number, as shown in table 9, which gives the mean values for each of the varieties at the 5 locations for each of the years and for the 5-year period. The individual analyses also appear in the table. The strains Dunfield, Mukden, and T–117 appear to be consistently low in iodine number during all the seasons. It will be recalled that among these strains, Dunfield and T–117 were highly significantly high in oil content for the 5-year period, whereas Mukden was slightly below the mean of the test for the same period. Among the varieties suitable for processing, Scioto, which has a good oil content though somewhat under Dunfield for the 5 seasons, has given the highest iodine number, averaging 133 for the period, and being significantly high each season. It has been exceeded in iodine number of the oil only by Peking, which is not now considered suitable for processing on account of its black seed coat and its relatively low oil content. Peking is of value, however, for use in breeding work to improve the iodine number. For this purpose it appears to be superior to the wild soybean, because of its type of growth, better yield, and higher oil content.

TABLE 9.—*Iodine number of oil of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average iodine number of oil by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Iodine number of oil from seed of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	Mean
1936											
Ames, Iowa	117.7	125.7	127.6	127.1	133.2	131.8	138.7	126.0	143.2	136.5	130.8
Columbia, Mo	121.7	109.8	106.2	103.9	123.3	117.0	129.6	109.5	132.0	118.5	117.2
Urbana, Ill	120.8	123.6	124.3	125.5	129.8	131.5	128.8	121.8	136.8	132.2	127.5
La Fayette, Ind	123.6	123.6	123.2	122.9	130.5	126.8	130.0	123.2	139.7	132.5	127.8
Columbus, Ohio	129.8	124.5	123.3	122.0	131.9	129.3	131.5	124.7	140.4	133.5	129.1
Mean	122.7	121.4	120.9	120.3	129.7	127.7	131.7	121.0	138.4	130.6	126.5
1937											
Ames, Iowa	128.6	123.6	128.3	129.2	131.5	131.0	136.9	128.4	138.6	132.2	130.8
Columbia, Mo	124.2	120.5	123.4	123.1	127.9	127.7	130.8	124.0	134.8	125.1	126.2
Urbana, Ill	129.8	121.4	124.3	123.5	129.3	128.3	132.5	127.4	138.9	130.9	128.6
La Fayette, Ind	127.9	124.9	129.4	125.8	132.2	131.9	135.2	128.2	139.0	131.9	130.7
Columbus, Ohio	126.9	127.5	130.8	132.6	132.8	134.1	137.0	132.0	140.2	134.6	132.9
Mean	127.5	123.6	127.2	126.8	130.7	130.6	134.5	128.0	138.4	130.9	129.8
1938											
Ames, Iowa	128.3	126.5	127.3	127.2	131.7	131.7	135.0	125.6	139.4	130.9	130.4
Columbia, Mo	122.9	120.3	118.4	117.7	128.3	125.3	129.2	117.5	134.9	126.0	124.1
Urbana, Ill	129.0	127.4	126.4	125.7	131.1	132.1	132.7	123.7	138.7	130.7	129.7
La Fayette, Ind	129.4	126.6	126.8	123.7	132.2	132.4	134.4	125.4	139.5	132.5	130.3
Columbus, Ohio	130.5	124.5	127.5	128.7	130.7	130.8	133.6	127.2	138.4	132.8	130.5
Mean	128.0	126.1	125.3	124.6	130.8	130.5	133.0	123.9	138.2	130.6	129.0
1939											
Ames, Iowa	126.5	125.8	121.2	122.1	129.6	129.0	131.0	121.3	134.0	124.8	126.5
Columbia, Mo	130.2	121.6	123.9	122.5	126.0	129.6	131.8	119.6	133.9	122.6	126.3
Urbana, Ill	131.5	129.1	126.5	126.7	132.2	131.6	134.2	123.9	135.1	129.4	130.0
La Fayette, Ind	133.6	125.1	123.7	122.2	129.2	128.3	129.8	121.6	134.0	126.8	127.4
Columbus, Ohio	126.4	122.6	120.6	120.9	128.2	128.7	128.3	[1]119.5	135.8	[1]123.8	125.5
Mean	129.6	124.8	123.2	122.9	129.2	129.4	131.0	121.2	134.6	125.5	127.1
1940											
Ames, Iowa	130.2	129.1	125.4	123.0	130.7	132.9	136.7	124.0	141.6	132.0	130.7
Columbia, Mo	133.9	125.6	127.8	120.4	128.6	131.6	133.8	125.0	137.7	129.8	130.0
Urbana, Ill	126.1	125.4	127.3	126.3	131.1	131.1	132.7	124.3	136.0	128.4	128.9
La Fayette, Ind	125.8	129.2	130.8	130.1	134.6	134.6	136.0	127.6	139.9	133.4	132.2
Columbus, Ohio	134.2	130.1	129.2	129.1	133.9	133.3	135.0	127.0	139.8	132.3	132.4
Mean	130.0	127.9	128.1	127.2	131.8	132.7	134.8	125.6	139.0	131.2	130.8

[1] Missing data supplied.

TABLE 9.—*Iodine number of oil of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average iodine number of oil by variety, location, and year; and analysis of variance of the data*—Continued

EXPERIMENTAL DATA—Continued

Year and location	Iodine number of oil from seed of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	Mean
5-year mean											
Ames, Iowa	126.3	126.1	126.0	125.9	131.3	131.3	135.7	125.1	139.4	131.3	129.8
Columbia, Mo.	126.6	119.6	119.9	118.7	127.0	126.2	131.0	119.1	134.7	124.4	124.8
Urbana, Ill.	127.4	125.4	125.8	125.5	130.7	130.9	132.2	124.2	137.1	130.3	128.9
La Fayette, Ind.	128.1	125.9	126.8	124.9	131.7	131.2	138.1	125.2	138.5	131.4	129.7
Columbus, Ohio	129.6	125.8	126.3	126.7	131.5	131.2	133.1	126.1	138.9	131.4	130.1
Mean	127.6	124.6	124.9	124.4	130.5	130.2	133.0	123.9	137.7	129.8	128.6

VARIETY AND LOCATION MEANS [2,3]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:						
Mandarin	122.7	127.5	128.0	129.6*	130.0	127.6°
Mukden	121.4°	123.6°°	125.1°°	124.8°°	127.9°	124.6°°
Dunfield, A	120.9°	127.2°°	125.3°°	123.2°°	128.1°	124.9°°
Dunfield, B	120.3°°	126.8°°	124.6°°	122.9°°	127.2°°	124.4°°
Illini	129.7	130.7	130.8*	129.2*	131.8	130.5**
Manchu	127.7	130.6	130.5	129.4*	132.7	130.2**
Scioto	131.7*	134.5**	133.0**	131.0**	134.8**	133.0**
T-117	121.0°	128.0	123.9°°	121.2°°	125.6°°	123.9°°
Peking	138.4**	138.4**	138.2**	134.6**	139.0**	137.7**
P. I. 54563-3	130.6	130.9	130.6	125.5	131.2	129.8*
Location:						
Ames, Iowa	130.8**	130.8	130.4*	126.5	130.7	129.8**
Columbia, Mo.	117.2°°	126.2°°	124.1°°	126.3	130.0	124.7°°
Urbana, Ill.	127.5	128.6	129.7	130.0	128.9°°	128.9
La Fayette, Ind.	127.8	130.7	130.3*	127.4	132.2	129.7*
Columbus, Ohio	129.1	132.9**	130.5*	125.5°	132.4	130.0**
Average of all samples	126.5	129.8	129.0	127.1	130.8	128.6

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	187.71**	89.80**	102.15**	90.76**	80.65**	500.88**
Locations	4	287.24**	64.65**	76.85**	30.70**	22.10**	248.95**
Years	4						166.35**
Varieties × years	36						12.55**
Locations × years	16						58.15**
Varieties × locations	36	12.70	2.03	1.66	2.35	3.50	5.70
Varieties × locations × years	142						4.18

[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] °=significantly lower than general mean (5-percent level).
°°=highly significantly lower than general mean (1-percent level).
*In case of means=significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means=highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

A tabulation of analyses of soybean varieties, grown over the eastern part of the United States and analyzed by Washburn (*29*) several years ago, indicates a very interesting relationship between the area where the soybeans were grown and the iodine number of the oil. A limited number of these analyses, together with the mean monthly temperatures obtained from the Atlas of American Agriculture (*15*) for selected locations in the States, are given in table 10. From these analyses it is evident that a relationship exists between temperature during the growing season and iodine number of the oil. Washburn found Ito San to be very high in iodine number when grown in Maine but lower when grown in areas south of there. The variety Ito San uses the entire growing season in Maine, but in general matures earlier farther south. As soybeans are very critical in their reaction to length of day, in Maine the translocation of food materials to the seed and the metabolism of the oil occurred in a much cooler environment than at the other places from which Washburn collected seed. This was especially true in comparison with Kentucky conditions, where Ito San matures quite early in the fall. The same comparison can be made for the variety Guelph which, on account of it being a later type than Ito San although being too late for growing in Maine, would utilize the full growing season in Rhode Island, thus metabolizing oil in cooler fall weather. In Kentucky this variety, although maturing later than Ito San, would still develop its seed under warmer conditions. This relationship apparently holds also for Oklahoma, for, under the warmer drier conditions there, Webster and Kiltz (*30*) report much lower iodine numbers than have been obtained in the present study in the north central region. Based on a 5-year average at Stillwater, they give an iodine number of 120.9 for Manchu and 119.0 for Illini, whereas in the present study the 5-year average for the five northern locations gives Manchu a value of 130.2 and Illini 130.5. Thus the oil formed under the warmer conditions has less unsaturation than that formed in a cooler environment. According to Hopper and Johnson (*14*), this relationship also holds for flax.

TABLE 10. *Iodine number of soybean oil tabulated from data of Washburn,[1] with monthly weather data from Atlas of American Agriculture [2]*

Location	Monthly temperature		Iodine number of oil from seed of the varieties indicated				
	August	September	Ito San	Guelph	Wilson	Manchurian	Peking
	° F.	° F.					
Maine	64	58	140.8		-----	141.9	-----
Rhode Island	69	62	137.8	140.1	138.1	133.8	-----
New Jersey	73	67	130.3	127.9	134.8	129.7	137.5
Pennsylvania	71	65	125.1	127.3	133.3	-----	-----
Kentucky	78	70	125.0	116.0	120.3	116.5	120.8
Oklahoma	81	74				-----	-----

[1] Washburn, W. F. (*29*).
[2] Atlas of American Agriculture (Climate) (*15*).

If temperature during the period of soybean development does influence the type of fatty acids that are metabolized, then these effects should be observed on varieties maturing at different times in the fall. The period from blooming to maturity for three varieties—Mandarin, an early type; Illini, a medium early type; and Peking, a late type—have been included on the weather charts for the 5 years (figs. 3 to 7, inclusive). These varieties are listed as taking 100 days, 105 days, and 125 days, respectively, to reach maturity (*20*), so they should be expected to mature at different intervals in the fall. In table 9 the iodine numbers are given for the individual samples at each location for each year.

By referring to the weather graph for 1936 (fig. 3) it will be seen that the variety Mandarin matured the first week in September, thus making the period for filling of the beans and concurrent metabolism come at the period of intensely hot weather during the latter part of August following a severe drought that had extended for several months. This fits in well with the low iodine number for Mandarin at Ames during that particular season. The same relationships hold for Columbia and to some degree for Urbana and La Fayette. However, from the graph for weather at Columbus for this year it will be noted that a number of showers occurred the latter part of July and again around the latter part of August, materially delaying the ripening of Mandarin and bringing the filling period for this variety into a stretch of cool weather that started about the last of August. Following this hypothesis, we would therefore conclude that the iodine number of Mandarin at Columbus should be materially higher than for any of the other stations. This was found to be the case, as Mandarin at Columbus had an iodine number of 129.8, which was the highest attained at any location for that variety during that season.

By referring to figure 3, it will be noted that the variety Illini was not too far advanced at Ames during 1936 to take advantage of the heavy rain and succeeding showers that occurred during the first week of September, thereby considerably lengthening the vegetative period and bringing the period of seed development into the cooler weather of September. The expectation would be, therefore, that Illini would have a high iodine number at Ames, and by referring to table 9 it will be noted that Illini did have a high iodine number at Ames, in fact the highest of any location for that variety that season. By the same reason, the iodine number of Illini should be high at Urbana, La Fayette, and Columbus, but not at Columbia, for the filling period at Columbia probably came during the high temperatures experienced there during the first week of September.

The effect of the early September rains at Ames was felt even more by the variety Peking, as it lengthened the growing season to the latter part of October, making the period of oil metabolism in the seed come during the much cooler weather of that month. As a consequence, Peking at Ames during 1936 had the highest iodine number for that variety during the five seasons. This forms an interesting comparison with the early maturing variety Mandarin, showing the apparent effect of temperature on metabolism of oil, for at the same location during the year 1936 occurred almost the lowest iodine number obtained for any variety, namely Mandarin, with an iodine number of 117.7 and the highest iodine number obtained for any variety, namely Peking, with an iodine number of 143.2, due at least in part to the extreme differences in temperature that occurred during the periods in which these two varieties were metabolizing oil in the seed.

In this connection it will also be observed that at Columbia during 1936, as has been previously mentioned, there occurred the lowest iodine numbers that the authors have observed to have ever been recorded for soybean oil, when the Dunfield strains had iodine numbers of 106.2 and 103.9, respectively, probably due to the combination of the severe drought and unprecedentedly high temperatures that occurred in that year during July and August.

By referring to table 9 it can be seen that during the year 1936 the mean square for locations exceeded the mean square for varieties. The varieties × locations interaction was also highest in that year. This can possibly be explained by the differential severity of the drought at the five locations.

By referring to the weather data for 1937 in figure 4 it will be seen that the variety Mandarin, although maturing at a slightly different period at the five locations, nevertheless developed under very similar weather conditions. Temperatures at Columbia were slightly higher than at the other stations, and it will be seen that the iodine number of Mandarin oil at that station was slightly lower than at the other four locations. However, in general, no great differences were noted.

The same is true for the variety Illini with the exception that the oil from that variety tends to be a little lower in iodine number at Columbia. This difference is also noted for the variety Peking, which evidently was metabolizing oil during the warm spell the latter part of September and has an iodine number about four points below that at the other stations. From a study of iodine numbers obtained during 1937, it can be concluded that in general the climate at the five stations was quite similar.

During 1938 (fig. 5) the same weather relationships prevailed at the five stations during the period of seed development, and, therefore, it might be expected that the iodine numbers would be similar. However, Mandarin had an iodine number at Columbia some five points below that at the other locations, which is somewhat difficult to explain except that the mean daily temperatures did run slightly higher at Columbia than at the other locations during the middle third of the period between blooming and ripening.

For oil from the variety Illini, the drop in iodine number at Columbia was not so great as for that from Mandarin. The filling period for Peking occurred in a similar range of temperatures at all of the locations. The extreme dip in the mean daily temperatures during the third week in September at Ames also occurred at all of the other places giving a very similar environment to the five places. This observation agrees with the low varieties × locations interaction found for iodine number during 1938, in fact, the lowest interaction for any of the five seasons.

During the 1939 season (fig. 6), the iodine numbers for Mandarin oil at all the locations were quite similar, though the iodine number at Columbia was higher than might normally be expected for that location, probably because of a good distribution of rain, which lengthened the vegetative season for that variety and allowed filling to take place during a rather cool period in August.

No great differences were observed for oil from the variety Illini, although one might have expected a low iodine number as the result of high temperatures prior to ripening. However, this unusually warm spell, with a mean September temperature running something over 5° above the normal, carried rather consistently through all five locations and affected the varieties equally.

Practically no differences were observed for Peking oil, and an increase in iodine number that might have been expected at Ames did not occur.

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More variability in climate was experienced among the five locations during 1940 (fig. 7) than during the two previous seasons. The maturity of Mandarin was delayed at Columbia beyond its normal period of ripening, which undoubtedly caused oil to be laid down during the cooler period of weather encountered during the latter half of August. This delay in the ripening of Mandarin was approximately the same as that experienced for the variety in 1939, which then also produced oil with an iodine number considerably above that which would normally be expected for Mandarin at that location. The low iodine number of Mandarin oil at Urbana and La Fayette was probably due to the warm spell occurring during the second and third weeks of August. This warm period was more intense at these two locations than at the other three places. For the variety Illini, maturity was considerably delayed at La Fayette and Columbus, this delay allowing oil formation during the cooler period the first 2 weeks of September. This variety, as well as the other varieties of about the same maturity range, had oil with a higher iodine number at La Fayette and Columbus than elsewhere. For the variety Peking, ripening was hastened at Columbia and Urbana, and the period of filling of the beans thus occurred during warmer weather, whereas at Ames, La Fayette, and Columbus, filling undoubtedly took place during a period of cooler mean temperature.

Although there were several exceptions to this hypothesis during the 5-years' experience with these 10 strains at the 5 locations, it seems that there is a definite relationship between temperature during the time of metabolism of oil in the seed and the temperature of the air. If oil metabolism is considered as a physiological reaction governed by enzymes known to have optimum temperatures for development, it can be postulated that the enzyme responsible for production of the more unsaturated acids works better at a lower temperature.

Analysis of variance of the data on the iodine number of oil for the 5-year period shows that the varieties varied highly significantly with reference to the varieties × locations × years interaction. This was also true for locations and for years. As would be expected from inspection of the weather graphs for the 5 years, there was a highly significant locations × years interaction, possibly due in considerable part to the difference in weather conditions over the territory during the 1936 season. Of most importance to the plant breeder is the consistence with which a strain performs as compared with other varieties and strains included in nurseries located in different sections of the area for which the strains are being developed. The varieties × locations interaction with a mean square of 5.70 is low with respect to the three-way interaction of 4.16 for the 5-year analysis. Although, as was previously indicated, no true error term is available, as only single field samples (always obtained from compositing field replications, however) were analyzed chemically, it is felt that the agronomist is reasonably safe in concluding that varieties and strains tend to maintain their relative order with respect to iodine number of the oil when grown in different locations within the area covered by these studies.

Total Ash Content

The total ash of soybean seed and especially the amounts of the elements that comprise its constituents are of importance to the feeder, and at present about 95 percent of the soybean seed crushed goes into feed channels. For such use a high ash content is desirable. If the meal is to go into industrial channels after extraction of the oil, the mineral content is of less importance. Therefore, for industrial processing a low-ash variety with high oil and protein content would be preferred and would remove less minerals from the soil per unit of raw material produced.

A few analyses have been reported on the ash content of soybean seed, and among these have been the data by Viljoen (*28*) who concludes that ash, phosphorus, and fiber values remain very constant, whereas the oil and protein content of the different varieties shows relatively great variability. Smirnova and Lavrova (*24*), reporting on work done in the Union of Soviet Socialist Republics, where several varieties of soybeans were grown at different stations, concluded that, as regards the amount of ash accumulated, the soybean varieties within the limits of a station differ but little from one another. They state that greater variation is observed in dependence on conditions of growth; thus the amount of ash accumulated differed at the different stations.

Total ash was determined on the varieties and strains at the 5 locations during the 5 seasons 1936–40. The individual analyses and the means of the analyses, together with the analysis of variance of the data, are given in table 11.

TABLE 11.—*Total ash content of seed (dry basis) of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total ash by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Total ash content of seed of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P.I. 54563-3	Mean
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	4.60	4.43	4.25	4.31	4.54	4.68	4.85	4.64	4.79	4.65	4.58
Columbia, Mo	5.26	5.38	5.31	4.75	5.09	5.10	5.36	5.32	5.20	5.40	5.23
Urbana, Ill	5.32	5.36	4.81	4.76	4.81	5.11	5.27	5.07	5.19	5.02	5.07
La Fayette, Ind	4.87	4.61	4.28	4.20	4.52	4.90	5.06	4.91	5.15	4.84	4.73
Columbus, Ohio	5.03	5.13	4.10	4.70	4.37	4.68	5.17	5.25	4.93	4.97	4.84
Mean	5.03	4.98	4.57	4.55	4.67	4.89	5.14	5.04	5.06	4.98	4.89
1937											
Ames, Iowa	5.89	5.25	4.74	4.31	5.34	6.05	5.59	4.89	5.74	5.01	5.28
Columbia, Mo	5.55	5.20	5.28	4.53	5.10	5.13	5.10	5.00	4.91	4.93	5.08
Urbana, Ill	5.90	5.10	5.01	4.99	5.34	5.61	5.06	5.48	5.90	5.17	5.42
La Fayette, Ind	5.31	4.65	4.42	4.33	4.47	4.85	5.02	4.73	5.26	4.78	4.78
Columbus, Ohio	5.09	4.83	3.67	4.40	4.45	4.50	5.05	4.70	5.05	4.76	4.60
Mean	5.55	5.01	4.62	4.51	4.94	5.20	5.30	4.98	5.37	4.93	5.05
1938											
Ames, Iowa	5.13	4.60	4.33	4.32	4.46	4.93	4.84	4.60	4.40	4.70	4.64
Columbia, Mo	5.63	5.41	5.00	4.95	5.24	5.59	5.50	5.30	5.26	5.34	5.31
Urbana, Ill	5.52	5.33	5.11	5.08	5.21	5.53	5.10	5.37	5.37	5.31	5.33
La Fayette, Ind	5.30	4.89	4.46	4.43	4.62	5.02	5.05	4.33	5.19	4.81	4.82
Columbus, Ohio	5.49	5.12	5.07	4.70	5.49	5.39	5.50	5.81	5.47	4.78	5.28
Mean	5.49	5.07	4.79	4.70	5.00	5.27	5.22	5.09	5.14	5.00	5.08
1939											
Ames, Iowa	5.08	4.65	4.18	4.02	4.24	4.60	4.64	4.52	5.10	4.59	4.56
Columbia, Mo	5.43	5.25	4.97	5.06	4.99	5.34	5.33	5.25	5.41	5.20	5.22
Urbana, Ill	5.77	5.20	5.01	5.04	5.04	5.53	5.32	5.31	5.62	5.00	5.37
La Fayette, Ind	5.39	4.72	4.69	4.44	4.65	4.85	5.02	4.87	5.36	4.87	4.88
Columbus, Ohio	4.64	4.55	3.91	4.45	4.17	4.83	4.53	[1] 4.52	5.13	[1] 4.67	4.54
Mean	5.26	4.87	4.53	4.60	4.62	5.03	4.97	4.89	5.32	5.05	4.91

[1] Missing data supplied.

TABLE 11.—*Total ash content of seed (dry basis) of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total ash by variety, location, and year; and analysis of variance of the data*—Continued

EXPERIMENTAL DATA—Continued

Year and location	Total ash content of seed of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	Mean
1940	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	5.51	4.87	4.61	4.49	4.46	4.83	4.96	4.87	5.37	4.83	4.88
Columbia, Mo	5.45	5.22	5.01	4.91	5.09	5.38	5.40	5.33	5.40	5.17	5.25
Urbana, Ill.	5.70	5.11	4.56	4.62	4.83	5.12	5.20	4.99	4.32	4.32	4.88
La Fayette, Ind.	5.74	4.80	4.59	4.51	4.62	4.82	5.02	4.91	5.40	4.90	4.94
Columbus, Ohio	5.18	5.34	4.93	4.93	5.20	5.38	5.53	5.40	5.26	5.25	5.24
Mean	5.52	5.08	4.74	4.69	4.84	5.11	5.22	5.10	5.18	4.80	5.04
5-year mean											
Ames, Iowa	5.20	4.76	4.42	4.29	4.01	5.02	4.98	4.72	5.08	4.77	4.70
Columbia, Mo	5.46	5.20	5.11	4.85	5.10	5.29	5.36	5.24	5.27	5.21	5.22
Urbana, Ill	5.70	5.22	4.90	4.90	5.05	5.38	5.33	5.24	5.28	5.14	5.21
La Fayette, Ind	5.34	4.75	4.47	4.38	4.58	4.89	5.03	4.75	5.28	4.84	4.83
Columbus, Ohio	5.09	4.90	4.35	4.64	4.74	5.01	5.16	5.15	5.17	4.89	4.92
Mean	5.37	5.00	4.65	4.61	4.81	5.12	5.17	5.02	5.21	4.97	4.99

VARIETY AND LOCATION MEANS [1, 2]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mandarin	5.03	5.55**	5.49**	5.26**	5.52**	5.37**
Mukden	4.98	5.01	5.07	4.87	5.08	5.00
Dunfield, A	4.57°°	4.62°°	4.70°	4.53°°	4.74°	4.65°°
Dunfield, B	4.55°°	4.51°°	4.70°°	4.60°°	4.69°	4.61°°
Illini	4.67°°	4.94	5.00	4.62°°	4.84	4.81°°
Manchu	4.89	5.20	5.27	5.03	5.11	5.12*
Scioto	5.14*	5.30	5.22	4.97	5.22	5.17**
T-117	5.04	4.98	5.09	4.89	5.10	5.02
Peking	5.06	5.37*	5.14	5.32**	5.18	5.21**
P. I. 54563-3	4.98	4.93	5.00	5.05	4.80	4.97
Location:						
Ames, Iowa	4.58°°	5.28*	4.64°°	4.56°°	4.88	4.79°°
Columbia, Mo	5.23**	5.08	5.31*	5.22**	5.25*	5.22**
Urbana, Ill	5.07*	5.42**	5.33**	5.37**	4.88	5.21**
La Fayette, Ind	4.73°	4.78°	4.82°°	4.88	4.94	4.83°°
Columbus, Ohio	4.84	4.69°°	5.28*	4.54°°	5.24	4.92
Average of all samples	4.80°°	5.05	5.08*	4.91	5.04	4.99

ANALYSIS OF VARIANCE [2]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	0.23**	0.54**	0.26**	0.30**	0.31	1.49**
Locations	4	.67**	.98**	1.05**	1.43**	.36	2.16**
Years	4						.36**
Varieties × years	36						.57**
Locations × years	16						.58**
Varieties × locations	36	.03	.06	.04	.03	.06	.07*
Varieties × locations × years	142						.04

[1] Variety means represent 5 locations; location means represent 10 varieties.
[2] ° = significantly lower than general mean (5-percent level).
°° = highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

The seed of varieties tested varied significantly among themselves in ash content. Seed of the variety Mandarin accumulated a high ash content in each season, the percentages being highly significantly above the mean of the varieties during the last four seasons and for the 5-year period. Dunfield seed was significantly lower than the mean during all five seasons. As might be expected, in view of the consistently high mean ash content of Mandarin and low mean ash content of Dunfield seed, the greatest ranges for the entire test occurred in these varieties, the highest analysis being 5.90 percent for Mandarin at Urbana during 1937 and the lowest ash value being 3.67 percent for seed of Dunfield, A, at Columbus for the same season. The next lowest analysis (3.91) was for Dunfield, A, at the same location 2 years later.

Consistent differences were observed among the locations, the ash content of seed grown at Ames and La Fayette being low and that of seed grown at Columbia and Urbana being high. In considering the variance of the data (table 11) it will be observed that the mean squares are always of greater magnitude for location than those for variety. This is in contrast with the variance found for protein and oil percentages and iodine number, where the relative effect of variety and location varied in the individual seasons, depending probably upon how similar the seasonal conditions were at the five locations during each season. Apparently the factors of environment that influenced protein and oil metabolism do not influence total ash accumulations in the seed in the same manner.

Total ash accumulation in soybean seed is affected by climate, as the mean ash content of the 10 strains at the 5 locations (4.89 percent) was highly significantly low in the 1936 season. The ash content for 1939 was 4.91, which was nearly as low as the value for 1936, though on the border line of being statistically significant.

The varieties × locations interaction is significant, indicating less consistency in rank of the varieties with regard to ash content at the five locations than was found for protein and oil.

Phosphorus Content

The phosphorus content of soybean seed has been noted in the literature, but apparently no attempt has been made to study its variation as affected by varietal and environmental factors. It has been generally observed that soybeans give little response in yield to phosphate applications. Hartwell (*13*, *p. 15*) states:

> The ability of soy beans to supply their needs for phosphorus, where none had been added to the soil for a quarter of a century, was found to rank between that of carrots, which obtained their full requirements, and turnips which were practically unable to grow without phosphatic application.

Smirnova and Lavrova (*24*), reporting on composition of soybean seed, indicate that the composition of the ash does not remain the same and that its phosphorus content varies in direct proportion to the total amount of ash.

Among the 10 varieties and strains, the percentages of phosphorus in the seed (table 12) ranged from the low value of 0.419 for the variety Mukden at Columbus, Ohio, during 1937, to a high of 0.822 for Peking at La Fayette, Ind., during 1940, a spread of 0.403, or nearly double the low value. The mean of all varieties for the entire test is 0.659 percent. It is interesting to note that the next lowest value found during the entire 5-year study was at Ames, Iowa, during 1939. This was for seed of the varieties Scioto and Illini. By referring to table 12 it will be noted that seed of the variety Illini had the lowest mean phosphorus content for the entire test and that the varieties differed significantly in the percentage of phosphorus accumulated in the seed. Among the varieties, Peking seed stored the greatest amount of phosphorus both for the 5-year period and in each of the single years, the values being highly significantly higher than the mean during the last 4 seasons. The variety Mandarin was second with 0.696 for the 5-year average, its seed having had a phosphorus content significantly above the mean for three of the seasons. It will be recalled that the variety Mandarin stood highest among the 10 varieties and strains in percentage of total ash and Peking stood second (table 11). Thus there appears to be a relationship between the phosphorus and the ash contents of the seed.

TABLE 12.—*Phosphorus content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years: average percentage of total phosphorus by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Phosphorus content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1936											
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	0.550	0.620	0.546	0.638	0.585	0.620	0.708	0.686	0.747	0.721	0.643
Columbia, Mo	.620	.690	.760	.646	.607	.664	.603	.629	.616	.712	.657
Urbana, Ill	.760	.743	.660	.646	.633	.699	.734	.668	.769	.708	.702
La Fayette, Ind	.681	.708	.638	.642	.655	.708	.721	.699	.782	.664	.690
Columbus, Ohio	.686	.699	.629	.673	.633	.655	.703	.708	.703	.640	.674
Mean	.661	.696	.647	.649	.623	.669	.694	.678	.723	.690	.673
1937											
Ames, Iowa	.688	.617	.618	.539	.605	.619	.612	.509	.691	.637	.623
Columbia, Mo	.734	.670	.634	.590	.634	.694	.655	.634	.648	.628	.652
Urbana, Ill	.812	.680	.687	.684	.714	.748	.742	.728	.830	.751	.738
La Fayette, Ind	.661	.625	.595	.586	.579	.650	.665	.620	.738	.653	.630
Columbus, Ohio	.680	.419	.584	.584	.610	.656	.666	.604	.718	.638	.620
Mean	.715	.600	.624	.597	.628	.675	.668	.639	.725	.661	.654
1938											
Ames, Iowa	.671	.506	.572	.572	.550	.637	.556	.574	.717	.564	.602
Columbia, Mo	.715	.710	.666	.656	.637	.729	.689	.650	.720	.670	.697
Urbana, Ill	.758	.708	.700	.710	.675	.733	.660	.703	.745	.702	.709
La Fayette, Ind	.676	.646	.602	.601	.625	.647	.657	.617	.718	.633	.642
Columbus, Ohio	.584	.591	.584	.564	.635	.619	.615	.694	.756	.560	.620
Mean	.681	.650	.625	.621	.626	.673	.635	.649	.731	.628	.652
1939											
Ames, Iowa	.608	.554	.495	.466	.456	.510	.435	.404	.640	.400	.512
Columbia, Mo	.779	.751	.650	.712	.708	.720	.696	.715	.714	.683	.710
Urbana, Ill	.758	.656	.661	.683	.634	.707	.677	.659	.758	.697	.694
La Fayette, Ind	.691	.635	.622	.617	.609	.637	.676	.636	.728	.644	.650
Columbus, Ohio	.635	.617	.486	.607	.537	.639	.561	.586	.716	.574	.596
Mean	.694	.640	.589	.617	.580	.643	.609	.624	.712	.612	.634

See footnote at end of table.

TABLE 12.—*Phosphorus content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total phosphorus by variety, location, and year; and analysis of variance of the data*—Continued

EXPERIMENTAL DATA—Continued

Year and location	Phosphorus content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1940											
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	0.704	0.651	0.619	0.628	0.628	0.634	0.610	0.623	0.731	0.640	0.647
Columbia, Mo.	.790	.754	.713	.703	.744	.740	.726	.724	.775	.702	.737
Urbana, Ill.	.757	.697	.597	.620	.589	.670	.682	.641	.631	.647	.653
La Fayette, Ind.	.742	.676	.622	.631	.604	.667	.679	.669	.822	.668	.678
Columbus, Ohio	.650	.738	.668	.670	.678	.730	.718	.736	.753	.720	.707
Mean	.730	.703	.644	.650	.649	.688	.683	.679	.742	.675	.684
5-year mean											
Ames, Iowa	.644	.609	.570	.569	.566	.604	.584	.595	.706	.604	.605
Columbia, Mo.	.729	.723	.691	.661	.666	.709	.674	.672	.695	.681	.690
Urbana, Ill.	.769	.697	.661	.669	.649	.711	.699	.686	.747	.701	.699
La Fayette, Ind.	.690	.658	.616	.615	.614	.664	.680	.650	.758	.652	.660
Columbus, Ohio	.649	.613	.590	.620	.619	.660	.653	.666	.729	.628	.643
Mean	.696	.660	.626	.627	.623	.670	.658	.654	.727	.653	.659

VARIETY AND LOCATION MEANS [2,3]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mandarin	0.661	0.715*	0.681	0.694**	0.730*	0.696**
Mukden	.696	.602°	.650	.649	.703	.660
Dunfield, A	.647	.624	.625	.589°	.644	.626°°
Dunfield, B	.649	.597°	.621	.617	.650	.627°°
Illini	.623	.628	.626	.580°	.649	.623°°
Manchu	.660	.675	.673	.643	.688	.670
Scioto	.694	.668	.635	.609	.683	.658
T-117	.678	.639	.649	.624	.679	.654
Peking	.723	.725**	.731**	.712**	.742**	.727**
P. I. 54563-3	.690	.601	.625	.612	.675	.653
Location:						
Ames, Iowa	.643	.623	.602°°	.512°°	.647°	.605°°
Columbia, Mo.	.657	.652	.686*	.719**	.737**	.690**
Urbana, Ill.	.702	.738**	.710**	.692**	.653°	.699**
La Fayette, Ind.	.690	.639	.642	.650	.678	.660
Columbus, Ohio	.674	.616°	.620°	.596°	.707	.642°
Average of all samples	.673*	.654	.652	.634°°	.684**	.659

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	0.0043	0.0098**	0.0060**	0.0087**	0.0056**	0.0268**
Locations	4	.0057*	.0241**	.0203**	.0076**	.0143**	.0715**
Years	4						.0195**
Varieties × years	36						.0019*
Locations × years	16						.0152**
Varieties × locations	36	.002	.0014	.0010	.0012	.0011	.0022**
Varieties × locations × years	142						.0011

[1] Missing data supplied.
[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] °=significantly lower than general mean (5-percent level).
°°=highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

Limited analytical work in the laboratory (*9*) has suggested that there is little variation in the phosphatide phosphorus of soybean seed and that the greatest variation occurs in the phytin phosphorus fraction.

Among the five locations, Urbana and Columbia have produced soybeans with a high percentage of phosphorus. Soybeans grown at these two locations also had ash contents highly significantly above the mean of the five locations. Soybean seed from Ames had a phosphorus content highly significantly below the mean of all locations, and it will be recalled that the total ash content of soybeans grown at Ames was the lowest for all the locations. However, at La Fayette the seed phosphorus content was slightly above the mean for all locations, whereas the ash content was highly significantly below the mean, so it is not safe to make the general statement that a location producing a low ash content in the seed necessarily produces a low phosphorus content.

Among the five seasons the 1936 phosphorus content of the seed of the varieties studied was next to the highest, whereas the percentage of total ash during that year was the lowest. During 1938 when the phosphorus content for all varieties was nearly at the mean, the total ash was the highest of the five seasons, and again during 1940 when the phosphorus content was the highest of the five seasons, the ash content was barely above the mean. Therefore, the factors of climate that affect phosphorus content are not necessarily those which affect the total ash accumulated in the seed.

The analysis of variance of the data shows, in general, the same relationships between variety and location mean squares as was found for total ash, indicating that location may affect phosphorus content and total ash content of the seed more than it affects protein and oil content. Whereas the varieties × locations interaction for percentage of protein, percentage of oil, and iodine number of the oil was not significant with relation to the three-way interaction, this interaction was highly significant for phosphorus content. This may indicate that, should it become desirable to attempt by breeding and selection to increase or decrease the phosphorus content of soybean varieties, it would be necessary to analyze selections from many locations throughout the soybean belt of the North Central Region, as the varieties do not maintain the same relative ranking with respect to one another as they did for protein and oil contents.

Potassium Content

Information is available on the effect of potassium fertilizers on yield and on the percentages of organic constituents metabolized in the seed, but little has been published on the variations in potassium content of the seed as affected by varietal and environmental factors. Borst and Thatcher (*8, p. 93*) determined the composition of the plant parts at different stages of maturity and noted that—

> Potassium in the mature seed was relatively higher both in percentage and amount per acre than in other plant parts. There was some indication that the percentage of potassium in the seed decreased slightly in the final stages of ripening.

Their data for the mature soybeans in a 6-year period showed a considerable fluctuation between seasons. When reporting on the variation in chemical composition of different soybean varieties obtained under Russian conditions, Smirnova and Lavrova (*24*) state, with reference to their work on ash, that the content of another ash element, potassium, is not relatively stable either in soybeans of one variety or in those grown at one station. They record, for the same variety of soybeans, a difference in potassium content of the seed of 0.60 percent, from a low of 1.56 percent to a high of 2.16, depending upon geographical location.

The potassium content of the seed of the 10 varieties and strains of soybeans planted at the 5 locations during the 5 seasons was determined, and individual analyses are recorded in table 13. The range for the entire test was from a low of 1.29 percent for seed of the strain T–117 grown at Urbana, Ill., during 1936 to a high of 2.17 for seed of the strain P.I. 54563–3 grown at the same location during the same year. The mean analyses are also recorded in table 13, together with the analysis of variance of the data. It will be seen that seed of the 10 varieties differed significantly in potassium content, Peking having a mean content of 1.75 and Mukden 1.74 percent, which were the highest, and the two strains of Dunfield with percentages of 1.62 and 1.58 giving the lowest potassium values. If the mean percentage of potassium for the varieties grown at all locations during the individual years is compared with the percentage of ash and the percentage of phosphorus, it will be seen that the potassium content of the varieties does not remain as constant statistically through the seasons as does either phosphorus or total ash.

TABLE 13.—*Total potassium content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total potassium by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Potassium content of seed of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T–117	Peking	P.I. 54563–3	Mean
1936	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ames, Iowa	1.47	1.59	1.50	1.41	1.44	1.43	1.45	1.52	1.41	1.56	1.48
Columbia, Mo	1.71	1.41	1.64	1.73	1.83	1.69	1.83	1.93	1.84	1.63	1.72
Urbana, Ill	1.46	2.04	1.68	1.70	1.38	1.59	1.97	1.29	1.39	2.17	1.67
La Fayette, Ind	1.78	1.60	1.55	1.43	1.76	1.67	1.48	1.38	1.96	1.52	1.61
Columbus, Ohio	1.43	1.50	1.48	1.49	1.57	1.59	1.40	1.41	1.73	1.90	1.55
Mean	1.57	1.63	1.57	1.55	1.60	1.59	1.63	1.51	1.67	1.76	1.61
1937											
Ames, Iowa	1.53	1.71	1.56	1.64	1.64	1.70	1.79	1.84	1.72	1.79	1.69
Columbia, Mo	1.86	1.77	1.64	1.68	1.94	1.74	1.80	1.76	1.76	1.78	1.77
Urbana, Ill	2.06	1.90	1.96	1.82	1.98	1.99	2.03	1.93	1.97	1.90	1.95
La Fayette, Ind	1.63	1.68	1.58	1.59	1.59	1.67	1.62	1.79	1.74	1.73	1.66
Columbus, Ohio	1.62	1.85	1.48	1.56	1.56	1.64	1.81	1.64	1.74	1.60	1.65
Mean	1.74	1.78	1.64	1.66	1.74	1.75	1.81	1.79	1.79	1.76	1.75
1938											
Ames, Iowa	1.43	1.52	1.48	1.39	1.51	1.51	1.41	1.53	1.64	1.52	1.49
Columbia, Mo	1.72	1.76	1.61	1.49	1.74	1.65	1.62	1.60	1.72	1.65	1.66
Urbana, Ill	1.85	2.06	1.80	1.91	1.97	1.71	1.60	1.77	1.73	1.72	1.81
La Fayette, Ind	1.59	1.71	1.50	1.47	1.56	1.71	1.64	1.59	1.69	1.69	1.62
Columbus, Ohio	1.55	1.70	1.62	1.46	1.69	1.66	1.63	1.72	1.81	1.64	1.65
Mean	1.63	1.75	1.59	1.54	1.69	1.65	1.58	1.64	1.72	1.64	1.64

TABLE 13.—*Total potassium content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total potassium by variety, location, and year; and analysis of variance of the data*—Continued

EXPERIMENTAL DATA—Continued

Year and location	Potassium content of seed of the varieties indicated										
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	Mean
1939	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ames, Iowa	1.47	1.60	1.62	1.41	1.61	1.59	1.56	1.56	1.90	1.74	1.61
Columbia, Mo.	1.56	1.65	1.52	1.46	1.50	1.50	1.50	1.51	1.51	1.51	1.52
Urbana, Ill.	1.88	1.86	1.78	1.86	1.96	1.95	1.77	1.82	1.96	1.86	1.87
La Fayette, Ind.	1.54	1.71	1.55	1.39	1.62	1.61	1.80	1.49	1.74	1.59	1.60
Columbus, Ohio	1.41	1.60	1.44	1.47	1.39	1.53	1.54	[1] 1.40	1.78	[1] 1.54	1.52
Mean	1.57	1.68	1.58	1.52	1.62	1.64	1.63	1.57	1.78	1.65	1.62
1940											
Ames, Iowa	1.49	1.76	1.59	1.56	1.56	1.63	1.79	1.79	1.76	1.76	1.67
Columbia, Mo.	1.72	1.75	1.75	1.64	1.71	1.80	1.66	1.86	1.89	1.88	1.77
Urbana, Ill.	1.84	1.96	1.67	1.68	1.78	1.84	1.78	1.80	1.72	1.59	1.77
La Fayette, Ind.	1.72	1.86	1.69	1.63	1.67	1.65	1.70	1.80	1.88	1.82	1.74
Columbus, Ohio	1.68	1.90	1.78	1.65	1.82	1.80	1.77	1.99	1.77	1.73	1.79
Mean	1.69	1.85	1.70	1.63	1.71	1.74	1.74	1.85	1.80	1.76	1.75
5-year mean											
Ames, Iowa	1.48	1.64	1.54	1.48	1.55	1.57	1.60	1.65	1.69	1.67	1.59
Columbia, Mo.	1.71	1.67	1.63	1.60	1.74	1.68	1.68	1.73	1.74	1.69	1.69
Urbana, Ill.	1.82	1.96	1.78	1.79	1.81	1.82	1.83	1.72	1.75	1.85	1.81
La Fayette, Ind.	1.65	1.71	1.57	1.50	1.64	1.66	1.65	1.61	1.80	1.67	1.65
Columbus, Ohio	1.54	1.71	1.56	1.53	1.61	1.64	1.63	1.64	1.77	1.68	1.63
Mean	1.64	1.74	1.62	1.58	1.67	1.67	1.68	1.67	1.75	1.71	1.67

VARIETY AND LOCATION MEANS [2] [3]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mandarin	1.57	1.74	1.63	1.57	1.69	1.64
Mukden	1.63	1.78	1.75*	1.68	1.85*	1.74*
Dunfield, A	1.57	1.64°	1.59	1.58	1.70	1.62
Dunfield, B	1.55	1.66	1.54°	1.52	1.63°	1.58°°
Illini	1.60	1.74	1.69	1.62	1.71	1.67
Manchu	1.59	1.75	1.65	1.64	1.74	1.67
Scioto	1.63	1.81	1.58	1.63	1.74	1.68
T-117	1.51	1.79	1.64	1.57	1.85*	1.67
Peking	1.67	1.79	1.72	1.78**	1.80	1.75**
P. I. 54563-3	1.76	1.76	1.64	1.65	1.76	1.71
Location:						
Ames, Iowa	1.48	1.69	1.49°°	1.61	1.67°	1.59°°
Columbia, Mo.	1.72	1.77	1.66	1.52°°	1.77	1.69
Urbana, Ill.	1.67	1.95**	1.81**	1.87*	1.77	1.81**
La Fayette, Ind.	1.61	1.66°	1.62	1.60	1.74	1.65
Columbus, Ohio	1.55	1.65°°	1.66	1.52°°	1.79	1.63
Average of all samples	1.61°°	1.75**	1.64	1.62°	1.75**	1.67

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year—					
		1936	1937	1938	1939	1940	5 years
Varieties	9	0.024	0.015	0.0201*	0.0261**	0.0244**	0.0682**
Locations	4	.093	.168**	.1325**	.2070**	.0215**	.3736**
Years	4	------	------	------	------	------	.2310**
Varieties × years	36	------	------	------	------	------	.1038**
Locations × years	16	------	------	------	------	------	.0597**
Varieties × locations	36	.038	.006	.0070	.0073	.0064	.0132
Varieties × locations × years	142	------	------	------	------	------	.0131

[1] Missing data supplied.
[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] ° = significantly lower than general mean (5-percent level).
°° = highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

If the performance of the varieties at the different locations during the seasons is compared, it will be found that the potassium content of seed at Ames tends to be low and that for Urbana tends to be high for the 5-year period. However, there is not as consistent a trend during the individual years as was observed for phosphorus or ash. When the means of the varieties at all locations in the individual seasons are examined, a more pronounced seasonal effect than was experienced for either of the other ash constituents will be noted. Also, when the variance of the mean squares for varieties, locations, and years for the 5-year period are studied, it will be seen that the potassium mean square for years is much larger in proportion to the mean square for locations than is found for either ash or phosphorus. This gives some indication that season possibly has more effect on potassium than on phosphorus metabolism. In spite of this, it may be simpler to develop soybean varieties with high or low potassium content for the soybean belt, if this should prove desirable, since the varieties × locations interaction is low compared to the three-way interaction used as the error term, indicating that the varieties tend to remain in the same order of potassium content with respect to one another at the different locations.

In interpreting these data, it must be borne in mind that these results are perhaps limited to areas of fairly similar climates, such as occur in the five States in which these studies have been made.

Calcium Content

There is little direct information on the calcium content of the seed of soybean varieties as affected by geographical location and climate. Borst and Thatcher (*8*) in their study on the life history of the soybean give the calcium content of the soybean variety used in their studies at Wooster for the six harvest seasons. They found the percentage of calcium in the seed to vary from a low of 0.18 to a high of 0.32, indicating that the metabolism of calcium is dependent upon seasonal conditions.

In the present study involving 10 soybean varieties that were grown at 5 locations for 5 years, it can be seen from table 14 that the calcium content varied from a low of 0.163 for seed of Dunfield, A, at Columbus during 1939 and of Mukden at Ames in 1940, to a high of 0.470 for seed of the variety Mandarin grown at Ames in 1936, with a mean value of 0.275 percent. The varieties varied significantly among themselves, as shown in table 14, and the seed were more consistent in their calcium content in the different years than in their content of some of the other ash constituents. It will be noticed that the calcium content of seed of the variety Mandarin was highly significantly higher than the mean of all the varieties at the five places during the 5 years, and also in each of the individual years. This was also true for seed of the variety Scioto. On the other hand, the calcium content of seed of the variety Dunfield, which is highly significantly below the 5-year mean, was consistently low during all the seasons.

TABLE 14.—*Calcium content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total calcium by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Calcium content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	0.470	0.269	0.280	0.292	0.317	0.369	0.426	0.292	0.307	0.251	0.327
Columbia, Mo	.440	.365	.394	.299	.356	.451	.447	.377	.327	.379	.384
Urbana, Ill	.395	.269	.233	.233	.254	.334	.364	.242	.281	.242	.285
La Fayette, Ind	.456	.302	.277	.262	.336	.351	.413	.297	.314	.300	.331
Columbus, Ohio	.394	.234	.214	.217	.252	.317	.326	.264	.247	.249	.271
Mean	.431	.288	.280	.261	.303	.364	.395	.294	.295	.284	.320
1937											
Ames, Iowa	.437	.216	.233	.209	.267	.326	.384	.250	.327	.309	[illegible]
Columbia, Mo	.356	.253	.224	.208	.258	.290	.317	.219	.228	.237	.260
Urbana, Ill	.370	.293	.252	.255	.289	.331	.399	.270	.289	.225	.297
La Fayette, Ind	.346	.205	.206	.206	.227	.276	.310	.213	.267	.269	.253
Columbus, Ohio	.383	.446	.216	.203	.250	.301	.327	.218	.275	.220	.285
Mean	.378	.283	.226	.216	.260	.307	.347	.234	.277	.252	.278
1938											
Ames, Iowa	.389	.222	.208	.211	.243	.309	.328	.236	.294	.243	.267
Columbia, Mo	.382	.284	.279	.268	.289	.374	.443	.309	.285	.325	.324
Urbana, Ill	.376	.205	.198	.196	.221	.284	.291	.207	.239	.224	.244
La Fayette, Ind	.387	.201	.190	.182	.221	.285	.308	.216	.251	.233	.247
Columbus, Ohio	.382	.225	.198	.195	.261	.303	.339	.254	.245	.210	.261
Mean	.383	.227	.215	.210	247	.311	.342	.242	.261	.247	.269
1939											
Ames, Iowa	.425	.225	.217	.225	.246	.331	.368	.270	.286	.299	.289
Columbia, Mo	.410	.244	.281	.278	.230	.342	.382	.242	.363	.325	.310
Urbana, Ill	.340	.222	.236	.227	.263	.337	.363	.260	.314	.307	.289
La Fayette, Ind	.404	.215	.220	.204	.204	.268	.288	.217	.249	.229	.250
Columbus, Ohio	.267	.203	.163	.185	.221	.275	.297	[1] .193	.217	[1] .231	.225
Mean	.369	.222	.223	.224	.233	.311	.339	.240	.286	.278	.273
1940											
Ames, Iowa	.401	.163	.179	.177	.181	.231	.230	.194	.250	.211	.224
Columbia, Mo	.325	.192	.207	.211	.224	.296	.330	.224	.284	.249	.254
Urbana, Ill	.365	.166	.170	.177	.228	.244	.290	.188	.204	.187	.222
La Fayette, Ind	.418	.179	.180	.195	.216	.241	.266	.313	.251	.189	.245
Columbus, Ohio	.332	.194	.200	.210	.226	.349	.339	.206	.195	.185	.244
Mean	.308	.179	.187	.194	.215	.272	.293	.225	.239	.204	.238
5-year mean											
Ames, Iowa	.424	.219	.223	.223	.251	.313	.349	.248	.293	.263	.281
Columbia, Mo	.383	.268	.277	.253	.271	.352	.384	.274	.297	.303	.306
Urbana, Ill	.369	.231	.218	.218	.251	.306	.341	.237	.265	.237	.267
La Fayette, Ind	.402	.220	.215	.210	241	.294	.317	.251	.266	.244	.265
Columbus, Ohio	.352	.200	.198	.202	.244	.309	.326	.227	.236	.219	.257
Mean	.386	.240	.226	.221	.252	.313	.343	.248	.272	.253	.275

[1] Missing data supplied.

TABLE 14.—*Calcium content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total calcium by variety, location, and year; and analysis of variance of the data*—Continued

VARIETY AND LOCATION MEANS [1] [2]

Variety and location	1936	1937	1938	1939	1940	5 years
Variety:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mandarin	0.431**	0.378**	0.383**	0.369**	0.368**	0.386**
Mukden	.288°	.283	.227°°	.222°°	.179°°	.240°°
Dunfield, A	.280°°	.226°	.215°°	.223°°	.187°	.226°°
Dunfield, B	.261°°	.216°	.210°°	.224°°	.194°	.221°°
Illini	.303	.260	.247	.233°°	.215	.252°°
Manchu	.364**	.307	.311**	.311**	.272	.313**
Scioto	.395**	.347**	.342**	.339**	.293*	.343**
T-117	.294	.234	.244°	.240°°	.225	.248°°
Peking	.295	.277	.261	.286	.239	.272
P. I. 54563-3	.284°	.252	.247	.278	.204	.253°°
Location:						
Ames, Iowa	.327	.296	.267	.289	.224	.281
Columbia, Mo	.384**	.260	.324**	.310**	.254	.306**
Urbana, Ill	.285°°	.297	.244°°	.289	.222	.267
La Fayette, Ind	.331	.253	.247°	.250	.245	.265
Columbus, Ohio	.271°°	.285	.261	.225°°	.244	.257°
Average of all samples	.320**	.278	.269	.273	.238°°	.275

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	0.0161**	0.014**	0.0166**	0.0141**	0.017*	0.0743**
Locations	4	.0195**	.004**	.0104**	.0117**	.002	.0185**
Years	4						.0430**
Varieties × years	36						.0009
Locations × years	16						.0074**
Varieties × locations	36	.0005	.001	.0003	.0007	.001	.0013*
Varieties × locations × years	142						.0007

[1] Variety means represent 5 locations; location means represent 10 varieties.
[2] °= significantly lower than general mean (5-percent level).
°°= highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

Among the locations there was a tendency for soybean seed grown at Columbia to be highly significantly high in calcium content during three of the seasons and for the 5-year period. Among the seasons also there were significant differences, the 1936 season producing, for an average of all varieties at all locations, seed with a high calcium content, whereas during the 1940 season the calcium content was significantly low. By reference to figures 3 to 7, it will be seen that there is a decided tendency for percentage of calcium to be high in soybean seed during the warmer seasons. This can be brought out by a study of table 15, which gives the mean August temperatures at the 5 locations for the 2 seasons, 1936 and 1940. For example, the mean August temperature for Columbia during 1936 was 85.1° F., whereas for 1940 the mean temperature was 76.6°. Table 14 shows that the mean calcium content of seed of all 10 varieties at this location was 0.384 for 1936 and 0.254 for 1940. For Ames, Iowa, where the 1936 temperatures were also severely high, with a mean temperature of 78.2° as compared to a 1940 mean temperature of 69.8°, the mean calcium content of seed of all varieties was 0.327 and 0.224 percent, respectively, showing a trend in the same direction as at Missouri during the two seasons. As contrasted with these differences between 1936 and 1940, the mean August temperatures at Columbus, Ohio, did not differ so greatly, the mean temperature being 77.8° for 1936 and 75.1° for 1940. The corresponding mean percentages of calcium in the soybeans were 0.271 and 0.244, respectively, showing that accompanying the lesser differences in temperature between 1936 and 1940 was a lesser difference in percentage of calcium in the seed. From these data it can be inferred that temperature plays an important part in determining the amount of calcium stored in soybean seed.

TABLE 15.—*Mean August temperatures at the five locations for 1936 and 1940*

Location	1936	1940	Location	1936	1940
	° F.	° F.		° F.	° F.
Columbus, Ohio	77.8	75.1	Ames, Iowa	78.2	69.8
La Fayette, Ind	80.2	76.4	Columbia, Mo	85.1	76.6
Urbana, Ill	79.0	74.8			

This effect of season is further shown by the analysis of variance for the calcium data. Although the variances due to varieties, locations, and years are all significant with respect to the three-way interaction, yet the mean square for years is greater than the mean square for locations. This has not been true for any of the other ash constituents and indicates that season has had a more profound influence on calcium metabolism than has soil under the conditions of this study.

TOTAL SUGAR CONTENT

The sugars in soybeans have received very little attention in agronomic studies. The total sugars determined and reported here are calculated as sucrose (table 16). The values for the 10 varieties and strains grown at the 5 locations during 5 years ranged from 2.70 to 11.97 and averaged 7.97 percent. The greater number of the values vary less than 1 percent from the mean. The lowest station averages were for the 1936 season when the crop was injured by excessive heat and lack of precipitation.

Garner, Allard, and Foubert (*12, p. 247*) noted:

> As a consequence of the physiological relationship of oil to carbohydrates, it appears that maximum oil production in the plant requires conditions of nutrition favorable to the accumulation of carbohydrate during the vegetative period and to the transformation of carbohydrate into oil during the reproductive period.

From inspection of tables 16, 6, and 5, it is seen that the percentages of sugar increase and decrease with the percentages of oil and that when total sugar and oil contents change in one direction, the protein content changes in the other.

TABLE 16.—*Total sugar content (dry basis, calculated as sucrose) of seeds of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total sugar by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Total sugar content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	6.33	6.44	7.49	7.66	8.66	7.34	7.87	8.82	7.18	8.31	7.61
Columbia, Mo	7.33	5.61	2.70	6.18	5.73	5.55	5.55	5.74	4.96	6.07	5.54
Urbana, Ill	6.43	6.78	6.94	6.60	7.64	6.67	7.32	7.75	6.72	8.43	7.14
La Fayette, Ind	5.75	5.47	7.27	7.14	7.26	6.39	8.28	8.18	7.19	8.76	7.17
Columbus, Ohio	6.52	7.07	6.95	8.43	7.43	7 16	7.85	9.03	6.21	8.35	7.50
Mean	6.47	6.27	6.27	7.22	7.34	6 62	7.37	7.90	6.45	7.98	6.99
1937											
Ames, Iowa	6.91	6.94	10.77	11.34	9.27	7.93	10.22	11.33	7.80	8.75	9.13
Columbia, Mo	5.92	6.83	7.58	7.77	7.80	6.59	7.63	7.81	6.83	7.68	7.24
Urbana, Ill	7.28	6.97	8.21	8.21	8.41	7.58	8.27	7.60	7.33	9.55	7.94
La Fayette, Ind	6.54	6.81	8.32	8.11	8.39	7.50	8.55	8.10	7.64	9.50	7.95
Columbus, Ohio	7.96	0.60	8.01	8.70	8.03	8.10	8.93	10.38	8.47	11.97	8.77
Mean	6.92	6.83	8.58	8.83	8.38	7.54	8.72	9.14	7.61	9.49	8.20
1938											
Ames, Iowa	6.65	6.26	8.53	8.11	11.42	8.17	7.97	8.93	7.93	8.67	8.26
Columbia, Mo	6.85	5.74	6.64	6.75	7.26	6.86	6.58	6.64	7.19	7.03	6.75
Urtana, Ill	7.77	7.28	9.42	0.46	10.37	9.63	10.43	10.16	8.89	10.03	9.34
La Fayette, Ind	7.03	7.40	8.35	8.62	8.96	8.09	9.04	8.85	8.43	7.87	8.26
Columbus, Ohio	6.37	7.61	9.36	8.80	9.20	8.77	9.04	9.83	8.24	8.99	8.62
Mean	6.93	6.86	8.46	8.35	9.44	8.30	8.61	8.88	8.14	8.52	8.25
1939											
Ames, Iowa	6.42	6.27	9.07	8.89	9.87	8.22	8.17	8.12	6.74	8.11	7.99
Columbia, Mo	5.92	6.37	8.36	7.95	8.59	7.72	7.99	7.79	7.31	8.36	7.64
Urbana, Ill	7.81	7.43	8.22	9.18	9.87	8.12	7.92	7.74	7.02	8.04	8.14
La Fayette, Ind	7.13	6.92	8.21	7.98	8.60	7.81	8.84	8.72	8.07	8.68	8.10
Columbus, Ohio	7.22	7.22	8.12	9.05	8.36	8.63	8.80	[1] 8.41	8.41	[1] 8.65	8.29
Mean	6.90	6.84	8.40	8.61	9.06	8.10	8.34	8.16	7.51	8.37	8.03
1940											
Ames, Iowa	6.46	6.70	9.55	8.78	10.18	7.94	6.08	8.89	7.62	7.95	7.92
Columbia, Mo	5.90	6.76	7.87	8.12	7.94	8.09	7.94	8.02	6.94	8.31	7.59
Urbana, Ill	8.44	9.17	11.19	10.28	11.68	8.22	8.25	9.22	8.05	8.46	9.30
La Fayette, Ind	5.72	5.95	9.72	9.44	10.07	8.91	9.20	9.51	8.58	9.24	8.63
Columbus, Ohio	7.28	8.26	9.23	8.42	9.70	8.55	8.60	9.20	7.64	8.75	8.57
Mean	6.56	7.39	9.51	9.01	9.91	8.34	8.05	8.97	7.77	8.54	8.40
5-year mean											
Ames, Iowa	6.35	6.52	9.08	8.90	9.88	7.92	8.06	9.22	7.45	8.30	8.18
Columbia, Mo	6.38	6.26	6.63	7.35	7.46	6.96	7.14	7.20	6.65	7.49	6.95
Urbana, Ill	7.55	7.58	8.80	8.76	9.59	8.04	8.44	8.40	7.60	8.90	8.37
La Fayette, Ind	6.43	6.51	8.37	8.26	8.66	7.74	8.78	8.67	7.98	8.81	8.02
Columbus, Ohio	7.07	7.35	8.33	8.68	8.54	8.24	8.60	9.47	7.79	9.34	8.35
Mean	6.76	6.83	8.24	8.40	8.83	7.78	8.22	8.61	7.50	8.58	7.97

[1] Missing data supplied.

Table 16.—*Total sugar content (dry basis, calculated as sucrose) of seeds of 10 varieties and strains of soybeans grown at 5 locations during 5 years; average percentage of total sugar by variety, location, and year; and analysis of variance of the data*—Continued

VARIETY AND LOCATION MEANS [2, 3]

Variety and location	1936	1937	1938	1939	1940	5 years
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Variety:						
Mandarin	6.47	6.92°	6.93°°	6.90°°	6.56°°	6.76°°
Mukden	6.27	6.83°	6.86°°	6.84°°	7.39°°	6.83°°
Dunfield, A	6.27	8.58	8.46	8.40**	9.51**	8.24
Dunfield, B	7.22	8.83	8.35	8.61**	9.01**	8.40*
Illini	7.34	8.38	9.44**	9.06*	9.91**	8.83**
Manchu	6.62	7.54	8.30	8.10	8.34	7.78
Scioto	7.37	8.72	8.61	8.34**	8.05°	8.22
T-117	7.90	9.14	8.88	8.16	8.97**	8.61**
Peking	6.45	7.61	8.14	7.51°°	7.77°°	7.50°
P. I. 54563-3	7.98*	9.49*	8.52	8.37**	8.54	8.58**
Location:						
Ames, Iowa	7.61	9.13*	8.26	7.99	7.92°°	8.18
Columbia, Mo	5.54°°	7.24°	6.75°°	7.64°°	7.59°°	6.95°°
Urbana, Ill	7.14	7.94	9.34**	8.14	9.30**	8.37**
La Fayette, Ind	7.17	7.95	8.26	8.10	8.63*	8.02
Columbus, Ohio	7.50	8.77	8.62	8.29**	8.57	8.35**
Average of all samples	6.99°°	8.20	8.25*	8.03	8.40**	7.97

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year					
		1936	1937	1938	1939	1940	5 years
Varieties	9	2.16*	4.27**	3.20**	2.62**	5.13**	13.50**
Locations	4	6.99**	5.55**	8.93**	.60	4.45**	17.31**
Years	4						15.99**
Varieties × years	36						.07**
Locations × years	16						2.30**
Varieties × locations	36	.57	.71	.38	.28	.50	.88**
Varieties × locations × years	142						.42

[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] ° = significantly lower than general mean (5-percent level).
°° = highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

The analysis of variance (table 16) shows that the average total sugar content is highly significantly high for seed of Illini, T-117, and P. I. 54563-3 and highly significantly low for those of Mandarin and Mukden, with reference to the mean of all samples of 7.97 percent. During the 5 years the values for the soybeans grown at Urbana and Columbus were highly significantly above and those for Columbia highly significantly below the mean. The soybeans from the 1936 crop injured by drought averaged highly significantly below and those from the 1940 crop highly significantly above the mean. The mean squares indicate that under the conditions of the study, location and year influence total sugar content more than differences in variety.

Crude Fiber Content

Recent work in the field of nutrition has indicated that the determination of crude fiber is of questionable value. Determinations of cellulose, lignin, and hemicelluloses are considered as of more specific value. Viljoen (*28*) found that the fiber seemed to remain very constant irrespective of variety and the conditions under which the soybeans are grown.

The crude fiber was determined on the seed of the 10 varieties grown at the 5 locations during 1936 to 1939, inclusive, and was found to vary from 4.34 to 7.60, and averaged 5.52 percent of the dry substance (table 17). The analysis of two samples of soybean-seed hulls showed a crude fiber content of 31.37 and 28.10 percent on the dry basis, respectively. From this it would appear that the crude fiber content may vary with seed size and thickness of hulls. These two factors do not appear to vary regularly for any one variety, as the crude fiber does not appear to vary regularly with the weight per 100 seeds. It is observed that the seed of the Peking variety, which has the smallest seed size of the varieties studied, has the highest crude fiber content and is the only variety in the list that has consistent significant variance from the mean. The mean squares indicated that greater variability in crude fiber is attributed to varietal differences than to location and season.

Table 17.—*Crude fiber content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 4 years; average percentage of crude fiber by variety, location, and year; and analysis of variance of the data*

EXPERIMENTAL DATA

Year and location	Crude fiber content of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	5.83	5.00	5.43	5.63	5.23	4.98	5.01	4.50	6.15	5.64	5.37
Columbia, Mo	6.25	5.58	6.09	5.29	5.38	5.62	5.32	6.11	6.27	6.41	5.83
Urbana, Ill	5.43	4.38	5.01	5.85	5.02	5.44	4.89	5.18	6.22	5.26	5.27
La Fayette, Ind	5.60	4.98	5.12	5.74	5.50	5.51	5.37	5.77	7.18	6.10	5.70
Columbus, Ohio	5.58	5.62	5.78	5.28	5.50	6.03	5.39	5.47	6.36	6.28	5.73
Mean	5.74	5.11	5.49	5.56	5.34	5.52	5.20	5.47	6.44	5.04	5.58
1937											
Ames, Iowa	5.15	5.28	5.86	5.83	5.26	5.30	5.87	6.07	7.51	7.00	5.97
Columbia, Mo	5.21	5.50	4.94	5.31	4.83	5.03	5.64	5.48	6.41	5.83	5.43
Urbana, Ill	5.54	5.12	5.37	5.44	5.21	5.82	5.42	5.53	6.22	5.33	5.50
La Fayette, Ind	5.39	5.86	5.25	5.88	5.69	5.44	5.35	5.71	6.92	6.15	5.76
Columbus, Ohio	5.46	5.75	6.17	5.85	5.78	5.91	5.30	5.39	7.44	6.12	5.92
Mean	5.35	5.52	5.53	5.67	5.35	5.50	5.52	5.64	6.90	6.21	5.72
1938											
Ames, Iowa	5.41	5.54	5.17	5.99	4.95	5.01	4.87	5.28	6.31	5.15	5.37
Columbia, Mo	5.63	5.03	5.35	5.44	5.00	5.18	4.88	5.20	6.12	5.46	5.33
Urbana, Ill	5.20	5.55	5.41	5.60	5.27	5.41	4.04	5.18	6.07	5.50	5.41
La Fayette, Ind	5.52	5.23	5.40	5.40	5.42	5.17	5.17	5.63	6.39	5.43	5.48
Columbus, Ohio	5.11	5.51	5.80	5.54	5.61	5.76	5.55	6.11	6.55	5.57	5.71
Mean	5.37	5.37	5.43	5.01	5.25	5.31	5.08	5.48	6.29	5.42	5.46
1939											
Ames, Iowa	4.71	5.15	4.91	4.96	4.79	5.01	4.90	5.27	5.89	5.89	5.15
Columbia, Mo	4.68	4.34	4.67	4.82	4.59	4.90	5.04	5.10	6.29	5.04	4.95
Urbana, Ill	5.26	5.27	4.82	4.63	5.41	5.09	4.64	5.40	6.28	5.65	5.25
La Fayette, Ind	5.29	5.61	4.59	4.96	5.05	5.95	5.49	5.61	6.86	5.41	5.48
Columbus, Ohio	5.63	6.24	5.67	5.34	5.68	5.76	5.56	[1] 5.94	6.13	[1] 6.10	5.81
Mean	5.11	5.32	4.93	4.95	5.10	5.34	5.13	5.46	6.29	5.62	5.33
4-year mean	5.39	5.33	5.34	5.45	5.26	5.42	5.23	5.51	6.48	5.80	5.52

[1] Missing data supplied.

TABLE 17.—*Crude fiber content (dry basis) of seed of 10 varieties and strains of soybeans grown at 5 locations during 4 years; average percentage of crude fiber by variety, location, and year; and analysis of variance of the data*—Continued

VARIETY AND LOCATION MEANS [2] [3]

Variety and location	1936	1937	1938	1939	4 years
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Variety:					
Mandarin	5.74	5.35	5.37	5.11	5.39
Mukden	5.11°	5.52	5.37	5.32	5.33
Dunfield, A	5.49	5.52	5.43	4.93°	5.34
Dunfield, B	5.56	5.67	5.61	4.95	5.45
Illini	5.34	5.35	5.25	5.10	5.26
Manchu	5.52	5.50	5.31	5.34	5.42
Scioto	5.20	5.52	5.08°°	5.13	5.23
T-117	5.47	5.64	5.48	5.46	5.51
Peking	6.44**	6.90**	6.29**	6.29**	6.48**
P. I. 54563-3	5.94	6.21*	5.42	5.62	5.80
Location:					
Ames, Iowa	5.37	5.97	5.37	5.15	5.46
Columbia, Mo	5.83	5.43	5.33	4.95°°	5.38
Urbana, Ill	5.27	5.50	5.41	5.25	5.36
La Fayette, Ind	5.70	5.76	5.48	5.48	5.61
Columbus, Ohio	5.73	5.92	5.71*	5.81**	5.79
Average of all samples	5.58	5.72	5.46	5.33	5.52

ANALYSIS OF VARIANCE [3]

Source of variation	Degrees of freedom	Mean square for indicated year				
		1936	1937	1938	1939	4 years
Varieties	9	0.74**	1.16**	5.20**	0.82**	2.77**
Locations	4	.60**	.60**	.23**	1.09**	1.29**
Years	3					1.39**
Varieties × years	27					.16*
Locations × years	12					.41**
Varieties × locations	36	.11	.15	.05	.09	.11
Varieties × locations × years	108					.09

[2] Variety means represent 5 locations; location means represent 10 varieties.
[3] ° = significantly lower than general mean (5-percent level).
°° = highly significantly lower than general mean (1-percent level).
*In case of means = significantly higher than general mean (5-percent level). In case of mean squares, significant (5-percent level).
**In case of means = highly significantly higher than general mean (1-percent level). In case of mean squares, highly significant (1-percent level).

Unsaponifiable Matter in Crude Soybean Oil

The unsaponifiable matter in the crude soybean oil consists of a mixture of sterols, waxes, hydrocarbons, etc. The oil for this determination was obtained from the ground seed by three percolation extractions with petroleum ether (as specified by the American Oil Chemists' Association). The first solvent flooding was allowed to stand overnight before draining. The values were determined on the 10 varieties of soybeans grown at 5 stations during 4 years (table 18). They ranged from 0.50 to 1.25 percent and averaged 0.71. They do not represent the total unsaponifiable matter extractable from the soybean seed, but only that obtained in a lipid extract by a comparable empirical method.

TABLE 18.—*Unsaponifiable matter in crude soybean oil of 10 varieties and strains of soybeans grown at 5 locations during 4 years*

Year and location	Unsaponifiable matter in crude oil of seed of the varieties indicated										Mean
	Mandarin	Mukden	Dunfield, A	Dunfield, B	Illini	Manchu	Scioto	T-117	Peking	P. I. 54563-3	
1936	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Ames, Iowa	0.81	0.83	0.83	0.87	0.82	0.93	0.90	0.80	1.14	0.77	0.87
Columbia, Mo	1.11	.82	1.07	.62	.85	1.07	.77	.86	1.09	.80	.91
Urbana, Ill	.97	.82	.81	.73	.81	.88	.81	.89	.96	.95	.86
La Fayette, Ind	.98	.81	.72	.73	.95	.87	.76	.73	1.25	.67	.85
Columbus, Ohio	.82	.76	.64	.73	.75	.76	.90	.67	1.05	.75	.78
Mean	.94	.81	.81	.74	.84	.90	.83	.79	1.10	.79	.85
1937											
Ames, Iowa	.63	.59	.56	.57	.53	.74	.74	.57	1.03	.71	.67
Columbia, Mo	.82	.65	.66	.61	.69	.71	.79	.71	1.01	.72	.74
Urbana, Ill	.77	.82	.65	.69	.70	.77	.76	.66	.92	.75	.75
La Fayette, Ind	.70	.73	.63	.59	.61	.63	.74	.67	.79	.69	.68
Columbus, Ohio	.69	.72	.60	.68	.71	.73	.64	.69	.93	.64	.70
Mean	.72	.70	.62	.63	.65	.72	.73	.66	.94	.70	.71
1938											
Ames, Iowa	.78	.67	.62	.56	.59	.64	.63	.53	.75	.52	.63
Columbia, Mo	.68	1.06	.98	.88	.59	.66	.82	.53	.77	.58	.76
Urbana, Ill	.67	.83	.60	.71	.61	.62	.57	.53	.87	.55	.64
La Fayette, Ind	.63	.66	.54	.51	.59	.54	.55	.54	.75	.54	.59
Columbus, Ohio	.62	.67	.60	.55	.59	.65	.62	.61	.81	.58	.61
Mean	.68	.74	.67	.64	.59	.62	.64	.55	.70	.55	.65
1939											
Ames, Iowa	.74	.62	.55	.53	.55	.58	.62	.61	.86	.59	.63
Columbia, Mo	.86	.68	.56	.66	.55	.65	.61	.61	.89	.57	.66
Urbana, Ill	.68	.60	.52	.55	.54	.62	.54	.54	.89	.59	.61
La Fayette, Ind	.66	.62	.50	.50	.56	.64	.62	.58	.89	.60	.62
Columbus, Ohio	.67	.64	.51	.51	.63	.64	.60	------	.79	------	.63
Mean	.72	.63	.53	.56	.57	.63	.60	.56	.86	.59	.63
4-year mean	.76	.72	.66	.64	.66	.72	.70	.64	.92	.66	.71

As seed-coat waxes contribute materially to the unsaponifiable matter in the lipid extract, it is reasoned that, for smaller seeds with narrower ratios between seed coat and cotyledon and for varieties having thicker seed coats, larger values of unsaponifiable matter should be found in lipids extracted under comparable conditions. Crude lipids obtained by exhaustive extraction should yield higher relative values.

The values for the Peking variety, which has the smallest seed of the varieties studied, averaged the highest. In this connection the following tabulation, giving some information on the percentage of hulls or seed coats found on the 10 varieties of soybeans, may be of interest. The highest station-year average percentage of unsaponifiable matter was for Columbia, Mo., in 1936, which also had the lowest station-year average seed size (table 4).

Percentage of hulls or seed coats obtained from the seed of 10 varieties and strains of soybeans grown at 1 location during 1 season

Variety:	Hull percent	Variety—Continued	Hull percent
Mandarin	8.49	T-117	7.40
Mukden	7.51	Peking	12.98
Dunfield, A	7.71	P. I. 54563-3	8.25
Dunfield, B	7.61	Average percentage of hull	8.28
Illini	8.14	Average percentage without Peking	7.75
Manchu	7.36		
Scioto	7.32		

The acid numbers were determined on the oils extracted for the determination of the unsaponifiable matter. As the results were consistently low and showed no noticeable variability, they were not statistically analyzed and are not presented. The average value, approximating 0.15, indicates that the harvesting and storage of the soybean samples for chemical analysis were uniformly satisfactory.

EFFECT OF VARIETY, FERTILITY LEVEL, AND SEASON ON THE YIELD AND COMPOSITION OF SOYBEAN SEED

The extent to which the fertility level of a soil affects the yield and composition of the seed of soybean varieties and strains is of importance when locating nurseries for testing new selections. A study of this effect was made possible in the spring of 1937 through the cooperation of the Ohio Agricultural Experiment Station.

Materials and Methods

An experiment bearing on this problem was started in 1928, according to Stringfield and Salter (*27*), in cooperation with the Bureau of Plant Industry. The study, as initiated then, involved a 3-year rotation of corn, oats, and wheat on a Canfield silt loam soil at Wooster, Ohio. Stringfield and Salter describe the soil as derived from sandstone and shale and as naturally low in fertility but responding well to fertilizers and manure. The treatments established on the four levels, as shown in table 19, were designed to provide four distinct gradations in fertility. The corn, oats, and wheat cropping was continued until 1937 when soybeans replaced oats in the rotation. It is evident from table 20, showing the response of corn (*27*), oats (*17*), and wheat (*16*), that distinct levels of fertility have been established.

TABLE 19.—*Plot treatments*[1] *at the four fertility levels used in the 3-year rotation tests with corn, oats, and wheat (on Canfield silt loam)*

Fertility level	Treatment used for crop indicated		
	Corn	Oats	Wheat
A	None	None	None.
B	4 tons manure, 100 pounds 0-16-0 broadcast, 100 pounds 4-12-4 in hill.	do	200 pounds 2-14-4 in fall, 50 pounds nitrate of soda in spring.
C	8 tons manure, 200 pounds 0-16-0 broadcast, 200 pounds 4-12-4 in hill.	do	400 pounds 2-14-4 in fall, 100 pounds nitrate of soda in spring.
D	16 tons manure, 400 pounds 0-16-0 broadcast, 400 pounds 4-12-4 in hill.	do	800 pounds 2-14-4 in fall, 200 pounds nitrate of soda in spring.

[1] From a table by Lamb and Salter (*16, p. 131*).

TABLE 20.—*Average yield response per acre of grain crops to the four levels of fertility established on Canfield silt loam*

Fertility level	Crop yield for—		
	Corn	Oats	Wheat
	Bushels	*Bushels*	*Bushels*
A	33.6	33.6	15.3
B	44.8	42.9	27.3
C	52.6	45.8	35.7
D	53.6	49.5	38.7

Since the spring of 1937 eight soybean varieties, involving a wide range in genotypes, were planted across the four fertility levels. The varieties Mandarin, Dunfield, Mandell, Illini, and Peking were common to the varieties × locations study and the varieties × levels study. The varieties Morse, Virginia, and Jogun were added to enlarge the range of types. Morse, a grain type, and especially Virginia, a hay type, do well on relatively infertile soils. Jogun, a large-seeded vegetable soybean variety, is a short bushy type that does well on more fertile soil.

Seed yields only are available for the 1937 season, but yields as well as representative samples have been analyzed for protein, oil, and iodine number of the oil for each of the 3 following years and are presented to indicate the effect of fertility level on the composition of soybean varieties and strains.

CLIMATOLOGICAL DATA

Mean monthly temperatures and total precipitation for the four seasons, 1937–40, are given in figure 9 and table 21.

TABLE 21.—*Mean monthly temperatures and precipitation at Wooster, Ohio, during 1937–40* [1]

TEMPERATURES

Year	May	June	July	August	September	October	Mean
	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1937	58.6	68.2	71.9	73.2	61.4	51.4	64.1
1938	59.6	65.7	71.6	73.2	63.4	53.6	64.5
1939	61.0	70.8	71.2	71.6	67.7	53.8	66.0
1940	56.1	68.2	71.2	70.4	60.4	51.4	62.9
Normal	58.6	67.8	71.9	69.9	64.1	51.9	64.0

PRECIPITATION

Year	May	June	July	August	September	October	Total
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1937	3.52	4.08	3.13	2.75	2.62	4.31	21.31
1938	4.40	4.71	3.83	3.56	3.19	.49	20.18
1939	1.45	4.90	1.75	2.93	1.90	2.84	15.77
1940	4.11	5.76	4.02	5.12	1.16	1.65	21.82
Normal	3.65	3.86	4.06	3.72	3.28	2.60	21.17

[1] Compiled from Climatological Data issues of the U. S. Weather Bureau.

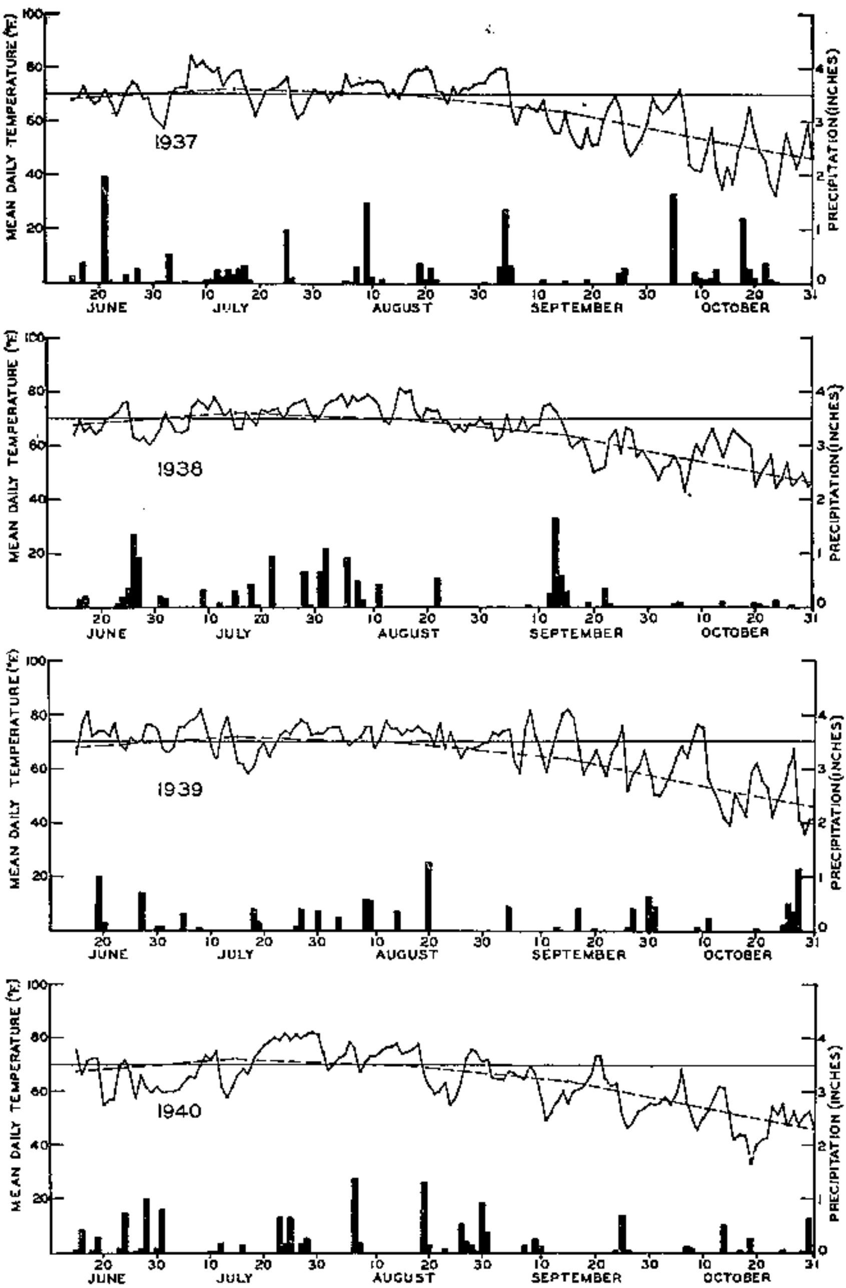

FIGURE 9.—Daily mean temperatures, average mean monthly temperatures, and daily precipitation for four seasons at Wooster, Ohio.

YIELD

In general, the yield of soybean seed, like that of any other crop, is the resultant of the interaction of soil, climate, and variety. This fact explains why low yields result from a combination of fertile soil, good variety, and unfavorable climate, or from fertile soil, poor variety, and favorable climate, or from infertile soil, good variety, and favorable climate. In other words, low yields may be obtained if any one of the three elements becomes a limiting factor. On the other hand, maximum yields may be obtained year after year if a favorable combination of soil fertility, variety, and climate occur. Since this favorable combination occurs infrequently under general farming practices, it was deemed expedient to plant several soybean varieties, comprising a wide selection of genotypes, across these four distinct levels of soil-fertility plots adjacent one to the other for the purpose of studying scientifically the interrelationship of soil fertility, variety, and climate upon plant characteristics such as growth, yield, and chemical composition. By this method information was obtained concerning the degree of those elements necessary for maximum yield as well as the evaluation of each in its effect upon yield. It is from this point of view that the yield data will be presented.

The effect of soil-fertility level on yield of each of eight varieties of soybeans may best be observed from a study of the 1938 yield data given in table 22 and shown graphically in figure 10. During this year the favorable climatic conditions permitted each variety to attain its maximum potential yield as limited only by soil fertility. The data show in a general way that all varieties responded advantageously to increasing levels of soil fertility and, with but few exceptions, the magnitude of the response, in bushels per acre, from the lowest to the highest levels was similar. This was true despite the rather large differences in range of yield. For example, on the A level of fertility Mandarin and Mandell yielded 12.7 and 18.5 bushels per acre, respectively, whereas on the D level they yielded 24.6 and 29.9 bushels, respectively. The range in yield for Mandarin was 11.9 bushels and for Mandell 11.4. The range in yield for the other varieties, except Virginia, was about the same. The similarity of these values indicates that all varieties but one possess the genetic constitution to produce seed in proportion to the fertility of the soil on which they are grown, though not in proportion to the same average yield. That is, whereas Mandarin increased its yield 11.9 bushels from fertility level A to D, and Mandell increased its by 11.4 bushels, it is highly improbable that at this location Mandarin would ever exceed Mandell in production of seed per acre, unless Mandell were killed by a very early frost. So, although soil fertility exerts a definite influence on yield under favorable climatic conditions, it cannot alter the limitation set upon yield of a given variety by genetic make-up and thereby cause each variety to produce equally.

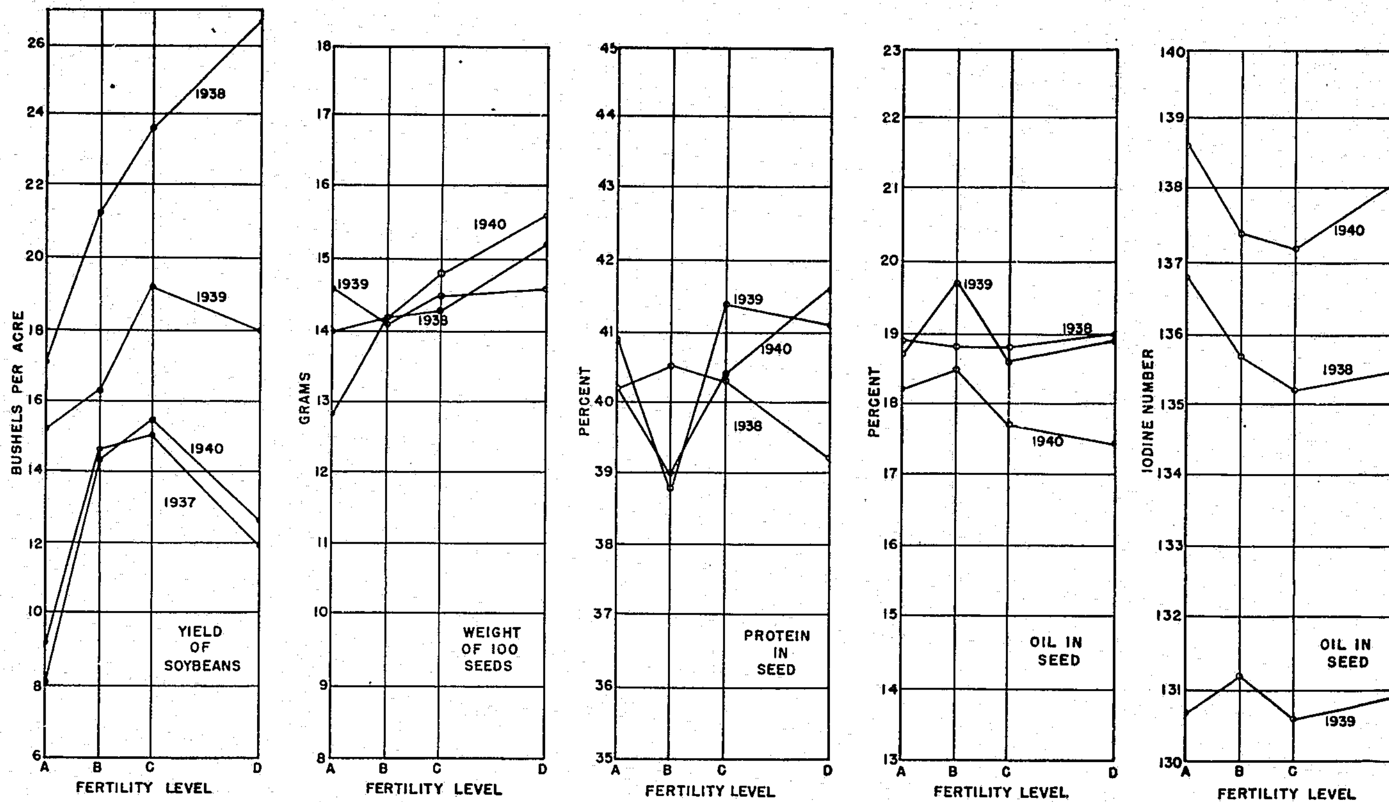

FIGURE 10.—Average response of eight varieties of soybeans to four levels of soil fertility, showing total yield, seed size in grams per 100 seed, protein content of seed, oil content of seed, and iodine number of oil.

TABLE 22.—*Yield per acre of eight varieties of soybeans grown on four levels of soil fertility, 1937–40; analysis of variance of yield by seasons and for the 3-year period 1938–40*

EXPERIMENTAL DATA

Year and fertility level	Yield of seed per acre of the varieties indicated								Mean
	Mandarin	Mandell	Dunfield	Illini	Jogun	Morse	Peking	Virginia	
1937	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
A	10.3	11.6	9.5	10.9	4.7	10.4	6.9	9.3	9.2
B	14.6	16.8	14.6	16.8	9.2	18.5	11.3	15.2	14.6
C	14.0	17.5	14.7	15.4	10.6	19.8	13.3	14.8	15.0
D	10.2	15.5	10.5	13.6	8.3	16.5	10.3	10.4	11.9
Mean	12.3	15.4	12.3	14.2	8.2	16.3	10.5	12.4	12.7
1938									
A	12.7	18.5	20.7	17.4	10.6	19.1	16.4	21.4	17.1
B	18.6	23.2	22.6	22.5	15.4	22.8	22.3	22.4	21.2
C	23.1	26.2	26.6	25.5	17.2	22.9	24.9	22.2	23.6
D	24.6	29.9	28.8	28.2	24.4	26.2	25.8	25.8	26.7
Mean	19.8	24.5	24.7	23.4	16.9	22.8	22.4	23.0	22.2
1939									
A	8.8	16.4	17.2	21.3	7.5	17.3	14.9	17.9	15.2
B	10.8	18.0	18.0	22.4	10.0	17.7	15.5	17.7	16.3
C	13.4	21.6	20.6	24.4	11.4	22.4	19.3	20.6	19.2
D	14.8	20.1	21.4	21.8	13.0	17.9	20.2	15.0	18.0
Mean	12.0	19.0	19.3	22.5	10.5	18.8	17.5	17.8	17.2
1940									
A	8.0	8.4	8.6	9.9	2.5	9.0	9.6	8.7	8.1
B	15.6	16.6	15.4	17.2	5.3	15.4	15.4	12.4	14.3
C	13.2	20.2	12.5	22.1	4.6	17.3	16.6	16.9	15.4
D	7.0	20.2	9.1	21.0	3.5	12.5	12.7	14.4	12.6
Mean	11.0	16.4	11.4	17.6	4.0	13.5	13.6	13.1	12.6
3-year mean (1938–40)	14.2	19.9	18.5	21.1	10.5	18.4	17.8	18.0	17.3

ANALYSIS OF VARIANCE[1]

Source of variation	Degrees of freedom	1937		1938		1939		1940		3-year period, 1938–40	
		Mean square	*F* value	Mean square	*F* value	Mean square	*F* value	Mean square	*F* value	Mean square	*F* value
Varieties	7	27.30**	24.7	27.20**	10.3	63.67**	28.2	68.12**	11.2	130.43**	36.8
Levels	3	58.46**	52.9	131.21**	49.5	26.02**	11.5	82.08**	13.5	179.85**	47.4
Years	2									737.18**	194.5
Varieties × levels	21	1.11		2.65		2.26		6.10		3.43	
Varieties × years	14									9.78**	2.6
Levels × years	6									29.73**	7.8
Varieties × levels × years	42									3.79	

[1] *=significant (5-percent level). **=highly significant (1-percent level).

Although such varieties as Mandarin and Mandell responded well to increased fertility in 1938, Virginia, which had the largest yield of all the varieties on the low fertility level, failed to give much response to increase in fertility. Virginia is noted for its ability to grow well on poor soil and probably can forage more successfully than other varieties for its mineral needs.

The yield data for the remainder of the years 1937, 1939, and 1940 show the influence of climate in varying degrees upon the reaction of varieties to soil fertility. Reduction in yield, on a given fertility level, below the 1938 value may be ascribed to interaction of that variety with fertility and climate, whereas the magnitude of reduction of all varieties from their 1938 yields on a given fertility represents differential varietal reaction to a modified climate-fertility relationship.

In further evaluating the importance of soil fertility on production of soybean seed, the data in table 23 warrant careful study. It may be observed that for any given season, and therefore for a given set of similar conditions of variety and climate, the B level of soil fertility produced a significant mean increase in yield over the A level for all varieties. The mean increase of C over B, while significant, brings into the picture the differential interaction of variety to a specific soil and climate relationship. This is indicated by the mean increases in yield of Mandarin and Mandell for C over D. The former variety would not, on an average, benefit by being produced on a fertility level higher than B, whereas Mandell would justify a fertility level higher than B. Other varieties may similarly be compared. The mean increase of D over C proves that the D level of soil fertility could not be justified for the production of soybean seeds.

TABLE 23.—*Increase in yield per acre of two soybean varieties over a 4-year period, due to level of soil fertility*

Variety	Year	Increase or decrease between levels			Variety	Year	Increase or decrease between levels		
		A and B	B and C	C and D			A and B	B and C	C and D
		Bushels	*Bushels*	*Bushels*			*Bushels*	*Bushels*	*Bushels*
Mandarin	1937	4.3	−0.6	−3.8	Mandell	1937	5.2	0.7	−2.0
	1938	5.0	4.5	1.5		1938	4.7	3.0	3.7
	1939	2.0	2.6	1.4		1939	1.6	3.6	−1.5
	1940	7.6	−2.4	−6.2		1940	8.2	3.6	.0
Mean		4.9	1.0	−1.7	Mean		5.0	2.7	.0

As observed in the analysis of variance, table 22, the varieties differ significantly among themselves. The mean squares for levels and years are also highly significant, with years contributing the most variance. Among the first-order interactions the varieties × years and levels × years mean squares were highly significant with respect to the varieties × levels × years mean square. The varieties × levels variance was nonsignificant, indicating that, over a period of years of yield testing, the fertility levels were without much effect on the rank of the varieties with respect to yield, especially within the range usually experienced in farm practice.

SIZE OF SEED

Among the varieties included in the study was Jogun, a large seeded vegetable variety averaging 29.78 gm. per hundred seeds for the 3-year period. Contrasted with this was the small-seeded Peking, which averaged 5.96 gm. per hundred seeds. As would be expected from including such types, the mean square for varieties was large and highly significant statistically. Likewise this was true for all the individual seasons.

TABLE 24.—*Size of seed (grams per hundred) of eight varieties of soybeans grown on four levels of soil fertility, 1938–40; analysis of variance of size of seed by seasons and for the 3-year period 1938–40*

EXPERIMENTAL DATA

Year and fertility level	Weight of 100 seeds of the varieties indicated								Mean
	Mandarin	Mandell	Dunfield	Illini	Jogun	Morse	Peking	Virginia	
1938	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
A	14.46	13.13	12.54	11.52	29.23	15.24	6.39	9.15	13.96
B	14.25	13.25	12.89	10.86	29.53	16.39	6.62	9.98	14.22
C	14.84	13.83	13.44	10.58	28.35	16.39	6.80	10.09	14.29
D	14.54	13.90	13.37	10.66	35.44	16.68	6.67	10.46	15.21
Mean	14.52	13.53	13.06	10.91	30.64	16.18	6.62	9.92	14.42
1939									
A	15.08	13.90	14.10	11.67	29.53	16.11	6.37	9.74	14.56
B	15.16	13.50	12.95	11.48	27.79	16.58	6.30	9.06	14.10
C	15.66	14.18	13.13	11.57	29.53	16.68	6.29	9.20	14.53
D	15.84	14.54	13.44	11.39	28.93	16.58	6.34	9.51	14.57
Mean	15.44	14.03	13.41	11.53	28.95	16.49	6.33	9.38	14.44
1940									
A	13.63	12.89	11.81	11.25	28.07	12.27	4.97	7.62	12.81
B	14.10	14.61	14.25	12.06	28.93	12.54	4.62	12.17	14.16
C	16.56	15.32	15.16	12.89	30.48	13.37	4.91	9.30	14.75
D	15.58	15.66	14.84	13.31	31.50	13.70	5.25	14.54	15.55
Mean	14.97	14.62	14.02	12.38	29.75	12.97	4.94	10.91	14.32
3-year average for each level									
A	14.39	13.31	12.82	11.48	28.94	14.54	5.91	8.84	13.78
B	14.50	13.79	13.36	11.47	28.75	15.17	5.85	10.40	14.16
C	15.69	14.44	13.91	11.68	29.45	15.48	6.00	9.53	14.52
D	15.32	14.70	13.88	11.79	31.96	15.65	6.09	11.50	15.11
Mean	14.98	14.06	13.49	11.61	29.78	15.21	5.96	10.07	14.39

ANALYSIS OF VARIANCE [1]

Source of variation	Degrees of freedom	1938		1939		1940		3-year period, 1938–40	
		Mean square	*F* value	Mean square	*F* value	Mean square	*F* value	Mean square	*F* value
Varieties	7	206.97**	153.89	181.02**	123.67	196.46**	168.83	576.25**	680.80
Levels	3	2.41	1.79	.41	2.81	10.63**	9.14	7.20**	9.24
Years	2							.14	
Varieties × levels	21	1.34		.15		1.16		.98	1.18
Varieties × years	14							4.10**	4.90
Levels × years	6							2.86**	3.43
Varieties × levels × years	42							.84	

[1] * = significant (5-percent level). ** = highly significant (1-percent level).

Among the levels there was variation in seed size with the seasons, this response being nonsignificant in 1938 and 1939, but for the 3-year period the levels variance was highly significant. Among the seasons the average seed size for 1938 was 14.42 gm. per 100, for 1939 it was 14.44 gm., and for 1940 it was 14.32; so, as would be expected, years showed a nonsignificant variance. There was not a great difference in the type of weather in the 3 years, as far as temperature and distribution of rainfall was concerned. There was a more abundant supply of moisture in 1938, resulting in higher yields but not affecting size of seed. Although there was significant varieties × years and levels × years interaction, yet the varieties × levels interaction for size of seed was nonsignificant, indicating that in general the levels were without significance in affecting the order or ranking of the varieties with respect to this character.

The individual determinations of seed size for the eight varieties on the four fertility levels, together with the analysis of variance of these data, are given in table 24.

PROTEIN CONTENT

Among the varieties there was a significant variance in protein content of the seed each season and for the 3-year period. Several varieties were common to the varieties × locations study, and from a study of table 5 and table 25 consistency is noticed in their performance. Mandarin was high in protein content in both studies, whereas Peking was low. This would be expected from the low varieties × locations interaction in the one test and low varieties × levels interaction in the other.

TABLE 25.—*Crude protein content (dry basis) of seed of eight varieties of soybeans grown on four levels of fertility, 1938–40; analysis of variance of percentage of protein by seasons and for the 3-year period 1938–40*

EXPERIMENTAL DATA

Year and fertility level	Crude protein content of the varieties indicated								Mean
	Mandarin	Mandell	Dunfield	Illini	Jogun	Morse	Peking	Virginia	
1938	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	43.94	41.94	37.13	37.75	42.38	40.63	37.94	39.81	40.10
B	43.50	42.50	37.13	40.63	42.56	41.31	37.13	39.31	40.51
C	42.44	42.13	36.88	39.69	42.00	41.44	37.13	40.38	40.26
D	41.00	40.69	36.13	39.13	40.69	41.25	35.50	39.50	39.24
Mean	42.72	41.82	36.82	39.30	41.91	41.16	36.93	39.75	40.05
1939									
A	45.06	41.88	37.94	39.12	41.88	40.12	40.19	41.06	40.91
B	41.75	40.00	33.25	36.50	40.62	42.12	37.00	38.88	38.77
C	45.44	43.06	36.44	38.69	42.62	43.94	40.56	40.06	41.35
D	45.31	43.75	35.88	37.19	43.44	43.44	39.50	40.06	41.07
Mean	44.39	42.17	35.88	37.88	42.14	42.41	39.31	40.02	40.52
1940									
A	43.38	43.50	37.75	39.81	44.06	37.19	38.69	37.31	40.21
B	42.69	42.25	38.56	37.81	43.19	37.19	32.25	37.75	38.96
C	45.31	42.19	39.31	37.06	43.94	39.13	38.31	37.81	40.38
D	45.56	42.81	40.75	38.13	44.00	40.50	39.38	41.56	41.59
Mean	44.24	42.69	39.09	38.20	43.80	38.50	37.16	38.61	40.29
3-year mean	43.78	42.23	37.26	38.46	42.62	40.69	37.80	39.46	40.29

ANALYSIS OF VARIANCE [1]

Source of variation	Degrees of freedom	1938		1939		1940		3-year period, 1938–40	
		Mean square	*F* value	Mean square	*F* value	Mean square	*F* value	Mean square	*F* value
Varieties	7	20.45**	39.60	30.94**	28.46	31.57**	16.09	70.15**	60.85
Levels	3	2.50*	4.84	11.20**	10.30	9.23*	4.70	8.40**	7.29
Years	2							1.80	1.56
Varieties × levels	21	.52		1.09		1.96		1.26	1.09
Varieties × years	14							6.41**	5.56
Levels × years	6							7.30**	6.33
Varieties × levels × years	42							1.15	

[1] *=significant (5-percent level). **=highly significant (1-percent level).

As seen in table 25, there was a nonsignificant variance for years but significant varieties × years and levels × years interaction. The average performance of the varieties was therefore quite similar in the three seasons, as was noticed for size of seed. The environment at the critical period for carbohydrate metabolism in the plant and for oil and protein metabolism in the seed for each variety must play an important role in determining protein composition as well as size of seed. This relationship is indicated in Mandarin, which had larger seed and lower protein in 1938 and smaller seed with higher protein in 1939 compared with 1940. More work is necessary, with very careful observance of the stage of plant development in relation to climate, to establish this relation. Such a relationship, however, would not be unexpected, as slightly shrunken wheat usually contains a high percentage of protein.

Oil Content

One of the most important of the present objectives in plant breeding work with soybeans is the development of high-oil strains. Preliminary selection work must be done on a soil that will permit the identification of those strains that will produce high oil in the area for which the selection is being developed. Therefore, information on the response of varieties to fertility level as well as geographical location is of value.

The individual analyses for seed oil content of the eight soybean varieties on the four fertility levels during the three seasons are given in table 26. The average performance of the eight varieties is shown in figure 10, *D*. The variety Mandarin was high in protein content and low in oil content in the varieties × locations study and this same relationship is found for the fertility-level study. Similarly, Dunfield was high in oil content in both studies, whereas Peking was low.

Among the fertility levels there was a significant variance (table 26), the B level producing seed with an oil content significantly above the other three for the entire period. Conversely, protein content of seed was significantly lower on the B level than on the other three levels. Although distinct responses in yield were noted due to fertility, the effect on composition has been relatively small.

Although there is significant varieties × years and levels × years interaction, it is of importance that the varieties × levels interaction is nonsignificant with respect to the three-way interaction. This indicates fertility level to be without much effect on the relative order or rank of the varieties for oil content within the range of soil fertility levels ordinarily encountered in breeding work.

TABLE 26.—*Oil content (dry basis) of seed of eight varieties of soybeans grown on four levels of fertility during three seasons, 1938–40; analysis of variance of percentage of oil by seasons and for the 3-year period 1938–40*

EXPERIMENTAL DATA

Year and fertility level	Oil content of seed of the varieties indicated								Mean
	Mandarin	Mandell	Dunfield	Illini	Jogun	Morse	Peking	Virginia	
1938	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	19.03	19.12	20.86	19.65	17.26	18.92	17.41	18.74	18.87
B	19.29	18.78	20.33	19.44	17.29	18.21	18.10	18.55	18.75
C	19.81	18.70	20.55	19.19	17.33	17.88	18.27	18.27	18.75
D	20.14	19.20	20.52	19.23	17.40	18.23	18.79	18.43	18.99
Mean	19.57	18.95	20.57	19.38	17.32	18.31	18.14	18.50	18.84
1939									
A	18.91	18.78	20.12	20.28	17.64	19.19	17.00	17.61	18.69
B	19.78	20.32	23.16	21.68	17.74	18.51	18.11	18.33	19.70
C	17.77	18.92	21.81	20.26	16.85	17.00	17.12	18.10	18.60
D	18.15	18.32	21.98	21.50	16.30	18.48	16.87	19.15	18.86
Mean	18.65	19.09	21.77	20.95	17.16	18.52	17.28	18.31	18.97
1940									
A	18.36	18.20	19.46	19.31	15.32	19.37	16.46	18.72	18.15
B	18.50	18.74	19.62	19.64	15.85	19.40	17.87	18.20	18.48
C	17.52	18.75	18.57	19.47	15.26	18.55	16.24	17.21	17.70
D	16.92	18.41	18.03	18.01	15.38	17.85	15.47	16.93	17.24
Mean	17.83	18.53	18.92	19.44	15.45	18.79	16.51	17.77	17.89
3-year mean	18.68	18.85	20.42	19.89	16.64	18.54	17.31	18.10	18.57

ANALYSIS OF VARIANCE [1]

Source of variation	Degrees of freedom	1938		1939		1940		3-year period, 1938–40	
		Mean square	*F* value	Mean square	*F* value	Mean square	*F* value	Mean square	*F* value
Varieties	7	4.00*	32.76	10.65**	24.11	6.99**	38.30	18.31**	63.38
Levels	3	.11		2.04*	4.62	2.34**	12.81	2.05**	7.11
Years	2							11.05**	38.24
Varieties × levels	21	.12		.44		.18		.17	
Varieties × years	14							1.66**	5.75
Levels × years	6							1.26**	4.21
Varieties × levels × years	42							.29	

[1] * = significant (5-percent level). ** = highly significant (1-percent level).

IODINE NUMBER

Iodine number of the oil was determined for seed of the eight varieties of soybeans for each soil-fertility level for each of the seasons, 1938–40. These analyses are recorded in table 27. Among the varieties, Peking seed oil is the highest in iodine number and Jogun and Dunfield the lowest. The iodine number of oil from seed of all the varieties is high at Wooster when compared with that found in the varieties × locations study, the mean values being 134.9 and 128.6, respectively. From the analysis of variance for iodine number (table 27) it is apparent that varieties and years contribute much variation and levels comparatively little, though all three are highly significant statistically.

TABLE 27.—*Iodine number of oil in the seed of eight varieties of soybeans grown on four levels of fertility during three seasons, 1938–40; analysis of variance of iodine number of oil by seasons and for the 3-year period 1938–40*

EXPERIMENTAL DATA

Year and fertility level	Iodine number of the oil from seed of varieties indicated								Mean
	Mandarin	Mandeli	Dunfield	Illini	Jogun	Morse	Peking	Virginia	
1938									
A	133.0	135.6	135.3	135.2	130.2	140.6	142.8	141.7	136.8
B	132.4	134.0	133.2	134.2	129.7	140.0	142.2	140.0	135.7
C	131.5	132.6	132.7	133.0	130.4	139.2	143.0	139.5	135.2
D	132.6	132.3	132.6	133.5	130.0	140.5	142.8	139.7	135.5
Mean	132.4	133.7	133.5	134.0	130.1	140.1	142.7	140.2	135.8
1939									
A	129.8	132.0	126.4	132.1	126.2	133.6	137.0	128.2	130.7
B	130.7	130.9	126.5	131.4	126.5	133.8	137.7	132.2	131.2
C	129.6	129.0	127.4	130.3	126.0	131.4	138.9	131.5	130.6
D	129.0	130.9	127.2	131.4	125.5	132.8	139.1	131.2	130.9
Mean	129.8	131.1	126.9	131.3	126.1	132.9	138.2	130.8	130.9
1940									
A	135.6	138.7	135.0	139.5	136.3	140.2	143.4	140.3	138.6
B	135.9	136.3	133.4	137.7	135.2	139.1	142.3	138.0	137.4
C	135.0	135.2	133.3	136.4	137.6	138.0	142.9	139.5	137.2
D	135.5	136.0	133.7	136.9	137.5	139.3	144.7	141.1	138.1
Mean	135.5	136.6	133.9	137.6	136.7	139.2	143.3	140.0	137.8
3-year mean	132.6	133.8	131.4	134.3	130.9	137.4	141.4	137.0	134.9

ANALYSIS OF VARIANCE [1]

Source of variation	Degrees of freedom	1938		1939		1940		3-year period, 1938–40	
		Mean square	*F* value	Mean square	*F* value	Mean square	*F* value	Mean square	*F* value
Varieties	7	81.91**	180.13	56.06**	52.39	34.73**	44.04	150.79**	325.1
Levels	3	3.90**	8.58	.52	------	3.41**	4.33	4.32**	9.31
Years	2				------		------	410.62**	885.3
Varieties × levels	21	.45	------	1.07	------	.79	------	1.39**	3.00
Varieties × years	14	------	------	------	------	------	------	10.96**	23.62
Levels × years	6	------	------	------	------	------	------	1.76**	3.79
Varieties × levels × years	42	------	------	------	------	------	------	.46	------

[1] * = significant (5-percent level). ** = highly significant (1-percent level).

In the previous discussion on iodine number as affected by geographical location (p. 31) it was pointed out that climate, or more specifically the temperature at the time of rapid translocation of food materials into the seed, influenced the degree of unsaturation of the oil. From figure 9 it is evident that the last part of August and the first part of September in 1939 was much warmer than the same period in 1938, whereas 1940 was even cooler than 1938. From table 27 it is evident that the mean iodine number of soybean oil for the three seasons is inversely related to the temperatures, for in 1939 the value was 130.9, in 1938 it was 135.8, and for 1940 it was 137.8.

Among the first-order interactions, although all were significant statistically, the one for levels × years was small, indicating that in general the soybeans on the four levels performed similarly in the three seasons. The varieties did not react similarly to the seasons, a dissimilarity to be expected due to fluctuation from year to year in temperature at the critical filling period for each variety. This is readily seen when it is recalled that the soybean varieties used differ in their date of blooming and period of bean development, and when it is noticed in figure 9 how the temperature cycles varied from season to season. In other words, as far as environment in the critical filling period is concerned, among the eight varieties grown in three seasons there are more than three crop years of climate represented. Although the varieties × levels interaction is significant, yet there was not sufficient reversal in the order of the varieties to be of concern to the plant breeder, provided no appreciable differences in date of filling and ripening is experienced between soil-fertility levels.

SUMMARY AND CONCLUSIONS

Soybean varieties were grown under different conditions of climate and soil in the five leading soybean-producing States of the North Central Region during the five seasons, 1936–40, inclusive, by the United States Regional Soybean Industrial Products Laboratory. The purpose of the investigation was to determine the influence of variety and environment on the chemical composition of the seed produced, as an aid in breeding and testing new varieties of soybeans for industrial utilization.

The 10 varieties selected for study ranged from early to late in maturity and provided a good cross section of genotypes. The chemical-composition data were studied statistically by analysis of variance. The seasons occurring during the period of study included as adverse and as favorable climatic conditions as may be anticipated in the area.

The percentages of carbohydrate, nitrogenous, lipid, and mineral constituents in the soybean appear to be influenced by the physiological vigor as controlled by the environment during the entire growth period of the plant. The iodine number of the oil from the seed of a variety appears to be critically influenced by the prevailing temperatures during the period of bean development and oil metabolism. High temperatures depress and low temperatures raise the iodine number.

In general, the oil content of the soybean seed is most specifically a varietal characteristic, and the iodine number of the oil is about equally influenced by variety and climate under the conditions observed in these investigations.

The influence of adverse environment during the period of development of the seed on the seed size is greatly offset by abortion during the period of ovule formation through which the individual plant adjusts the number of beans it produces to its physiological resources.

In general, the percentages of oil and total sugars vary in the same direction and inversely with the percentages of protein.

In general, no large variations were observed in the percentages of crude fiber in the seed and unsaponifiable matter in the oil. However, there is some variation in these constituents due to variation in seed size and ratio of seed coat to cotyledon.

Temperature levels significantly influenced the calcium content of the seed produced by a given variety. Invariably high calcium content resulted when the soybeans were grown at high temperatures.

Total ash, phosphorus, and potassium content of the seed appeared to be influenced more by soil type and fertility than by variety or variations in climate.

Eight varieties of soybeans were grown at one location on four widely different levels of soil fertility. Fertility level affected yield but was without noticeable effect on composition of soybean seed with respect to oil and protein content and iodine number of the oil. Within the limits ordinarily encountered in breeding and variety-testing work, soil fertility does not appear to affect the relative rank or order of varieties and strains of soybeans with respect to these chemical factors.

Under the conditions of this study varieties were found to differ significantly in the compositional factors determined. Pedological and climatic factors did not greatly influence the relative standing or ranking of the several varieties with reference to the percentages of oil, protein, phosphorus, and calcium. Hence, with respect to composition of seed, the performance of a variety or strain of soybeans at one location gives an indication of the relative performance that may be expected by it at other locations in the area.

The importance of this work is in the finding that varieties and strains of soybeans seem to inherit their characteristic chemical composition, making possible progress in breeding for desired chemical composition as well as yield and other agronomic factors.

LITERATURE CITED

(1) American Oil Chemists' Society.
1938. report of the soybean analysis committee. Oil and Soap 15: 214.

(2) Association of Official Agricultural Chemists.
1940. calcium. *In* Official and Tentative Methods of Analysis, ed. 5, ch. 12, procedure 11, pp. 127–128, illus.

(3) ———
1940. crude fiber. *In* Official and Tentative Methods of Analysis, ed. 5, ch. 27, procedure 27, p. 358.

(4) ———
1940. nitrogen. *In* Official and Tentative Methods of Analysis, ed. 5, ch. 2, procedure 23, p. 26.

(5) ———
1940. phosphorus. *In* Official and Tentative Methods of Analysis, ed. 5, ch. 2, procedure 12 (a), pp. 22–23; ch. 12, procedures 5, pp. 125–126, and 30 (b), p. 133.

(6) ———
1940. potassium. *In* Official and Tentative Methods of Analysis, ed. 5, ch. 2, procedures 41 (c), p. 31, and 42 (a), p. 31.

(7) ———
1940. sugars. *In* Official and Tentative Methods of Analysis, ed. 5, ch. 27, procedures 28 and 29, pp. 358–359; ch. 34, procedures 24 (c), p. 495, and 36, pp. 499–500.

(8) Borst, H. L., and Thatcher, L. E.
1931. life history and composition of the soybean plant. Ohio Agr. Expt. Sta. Bul. 494, 96 pp., illus.

(9) Earle, F. R., and Milner, R. T.
1938. the occurrence of phosphorus in soybeans. Oil and Soap 15: 41–42.

(10) Fellers, C. R.
1918. the effect of inoculation, fertilizer treatment, and certain minerals on the yield, composition and nodule formation of soybeans. Soil Sci. 6: 81–129, illus.

(11) Fisher, R. A.
1936. statistical methods for research workers. Ed. 6, rev. and enl., 339 pp., illus. Edinburgh and London.
(12) Garner, W. W., Allard, H. A., and Foubert, C. L.
1914. oil content of seeds as affected by the nutrition of the plant. Jour. Agr. Res. 3: 227–249.
(13) Hartwell, Burt L.
1920. field experiments which included the soy bean. R. I. Agr. Expt. Sta. Bul. 183, 15 pp.
(14) Hopper, T. H., and Johnson, Muriel.
1941. flax production and climate of north dakota and minnesota, 1919–1937. N. Dak. Agr. Expt. Sta. Bul. 298, 71 pp., illus.
(15) Kincer, J[oseph] B.
1922. precipitation and humidity. *In* Atlas of American Agriculture, Part II, Climate, Sect. A, U. S. Dept. Agr. Adv. Sheets 5, 48 pp., illus.
(16) Lamb, C. A., and Salter, Robert M.
1936. response of wheat varieties to different fertility levels. Jour. Agr. Res. 53: 129–143, illus.
(17) ——— and Salter, Robert M.
1937. response of oat varieties to different fertility levels. Jour. Agr. Res. 55: 785–793, illus.
(18) Lipman, Jacob G., and Blair, A. W.
1916. factors influencing the protein content of soybeans. Soil Sci. 1: 171–178.
(19) Love, Harry H.
1936. application of statistical methods to agricultural research. 501 pp., illus. Shanghai.
(20) Morse, W. J., and Cartter, J. L.
1939. soybeans: culture and varieties. U. S. Dept. Agr. Farmers' Bul. 1520, 39 pp., illus. [Revised.]
(21) Odland, T. E., and Lea, G. F.
1939. soybean varieties for hay and grain. R. I. Agr. Expt. Sta. Bul. 271, 19 pp., illus.
(22) Piper, Charles V., and Morse, William J.
1923. the soybean. 329 pp., illus. New York and London.
(23) Salmon, S. C.
1940. the use of modern statistical methods in field experiments. Amer. Soc. Agron. Jour. 32: 308–320.
(24) Smirnova, M. I., and Lavrova, M. N.
1934. variation of the chemical composition in different soybean varieties. Trudy Prikl. Bot., Genet., i Selek. (Bul. Appl. Bot., Genet., and Plant Breeding), Ser. III, No. 5, pp. 1–103, illus. [In Russian. English summary, p. 103.]
(25) Snedecor, George W.
1940. statistical methods applied to experiments in agriculture and biology. Ed. 3, 422 pp., illus. Ames, Iowa.
(26) Stark, Robert W.
1924. environmental factors affecting the protein and the oil content of soybeans and the iodine number of soybean oil. Amer. Soc. Agron. Jour. 16: 636–645.
(27) Stringfield, G. H., and Salter, Robert M.
1934. differential response of corn varieties to fertility levels and to seasons. Jour. Agr. Res. 49: 991–1000, illus.
(28) Viljoen, N. J.
1937. an investigation into the composition of the soybean in south africa. Union So. Africa Dept. Agr. and Forestry Sci. Bul. 169, 68 pp.
(29) Washburn, W. F.
1916. soya bean oil. N. Dak. Agr. Expt. Sta. Bul. 118, pp. 33–48.
(30) Webster, James E., and Kiltz, Burton F.
1935. oil and protein studies of oklahoma grown soy beans. Okla. Acad. Sci. Proc. (1934) 15: 32–36.

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