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SOIL TREATMENTS FOR WINTER WHEAT

A SUMMARY OF FIELD EXPERIMENTS

By L. B. Miller and F. C. Bauer

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Soil Treatments for Winter Wheat

A Summary of Field Experiments

By L. B. Miller, Assistant Chief in Soil Experiment Fields,
and F. C. Bauer, Chief in Soil Experiment Fields

WHEAT is an important field crop in Illinois. It is seeded on about one-tenth of the cropland and ranks fourth in crop values. It is easily fitted into crop rotations, is a satisfactory companion crop for legume seedings, and is a reliable cash crop for many farmers. As a cover crop it has considerable value, providing protection against erosion and nutrient losses. Its heaviest requirements for labor come at a time when other field work is not urgent. For these and other reasons wheat production is well established in the agricultural economy of this state.

Illinois wheat growers are confronted with wide variation in acre-yields, ranging from failures and near failures to more than 50 bushels an acre. The average yield for the state during the years 1933-1942 was only 17.9 bushels. Altho there are a number of reasons for low yields, soil conditions are an important one.

Compared with other commonly grown nonlegume grains, wheat ranks high in total percentage of certain plant nutrients, especially nitrogen and phosphorus (Table 1). This characteristic makes it somewhat sensitive to nutrient deficiencies in the soil and rather responsive to practices that conserve, maintain, and increase the soil's supply of usable nutrients.

Variations in soil productivity and increasing impoverishment of the soil make it essential for Illinois wheat growers to give more attention to the treatment of their soils. Treatment systems designed to raise productivity levels, direct fertilizer applications at planting time, or a

Table 1.—Nutrient Elements in Nonlegume Grains[a]

Crop	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Total
	perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
Wheat	2.20	.41	.43	.04	.15	3.23
Oats	1.96	.36	.48	.08	.12	3.00
Rye	1.87	.37	.49	.04	.10	2.87
Barley	1.84	.37	.47	.05	.12	2.85
Corn	1.78	.27	.34	.02	.13	2.54

[a]Average of analyses from several sources.

combination of these methods is needed. This publication reviews and summarizes the field experiments conducted by the Illinois Agricultural Experiment Station dealing with the effects of these practices on the yields of winter wheat.

PLAN OF EXPERIMENTS

Many of the data presented were obtained from twenty Illinois soil experiment fields (Fig. 1). The other data were obtained in cooperative experiments with farmers.

Fields Where Tests Were Made

The Illinois experiment fields that provide information for this study were established twenty-five to thirty years ago. They were designed primarily for the study of the merits of different systems of soil treatment and were located on soils varying widely in productivity.

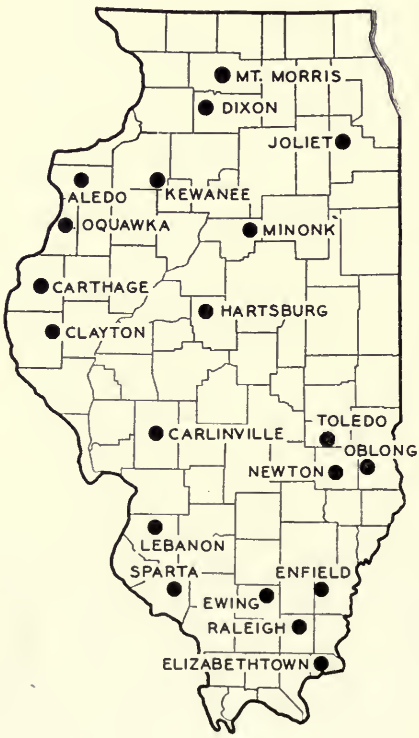

Fig. 1.—Location of soil experiment fields furnishing data for this publication. The twenty experiment fields on which the long-time studies were made are widely distributed over the state and represent a wide range of soil conditions.

Many of the fields had additional space on which supplementary tests could be made with specific fertilizer materials.

Systems of Soil Treatment

Nine soil treatments were established on each experiment field—four of them illustrating those that would be used in livestock farming and five illustrating those for grain farming. Still being used, these treatments, with the symbols to represent them, are as follows:

Plot	*Treatment symbol*	*Treatment materials*
		Manure (Livestock) Systems
1	0	None
2	M	Manure
3	ML	Manure, limestone
4	MLrP	Manure, limestone, rock phosphate
		Residues (Grain) Systems
5	0	None
6	R	Crop residues
7	RL	Crop residues, limestone
8	RLrP	Crop residues, limestone, rock phosphate
9	RLrPK	Crop residues, limestone, rock phosphate, potash

The field procedures used in handling the treatment materials are as follows:

None. All top growth of crops was removed.

Manure. Animal manure, including litter, was applied in proportion to the weight of the crops grown during the previous rotation and was plowed under for the corn crop.

Crop residues. The residues of crops, including corn stover, grain straws, green sweet clover, and the second crop of legume hays, were plowed under at convenient times. During some years the grain straws were removed.

Limestone. Crushed limestone was applied initially at the rate of 4 tons an acre and thereafter once during each rotation at the annual rate of ½ ton an acre on plowed soil, usually ahead of wheat. After twelve years this procedure was discontinued. No limestone has been applied to the dark-colored soils since, but a 2-ton application was made to the light-colored and sandy soils during the past few years.

Rock phosphate. Finely ground rock phosphate was applied once during the rotation, usually at wheat seeding time, at the annual acre-rate of 500 pounds. Applications ceased after a total of 4 tons an acre had been applied. Only a small amount of rock phosphate has been applied since 1924.

Potash. Kainit (containing about 12 percent of K_2O) was applied once during the rotation at the rate of 200 pounds an acre a year, usually ahead of wheat. Since 1932, muriate of potash (50 percent K_2O) has been used at annual rates ranging from 50 to 100 pounds, usually half ahead of wheat and half ahead of corn.

These systems have involved a step-by-step build-up from no treatment to somewhat complex combinations. Long used and modified to some extent by the cropping system employed, they have tended to establish different levels of productivity, the limits of which are determined by the nature of the soils. Crop yields reveal the effects of the soil treatments and thus furnish an index to the needs of the various kinds of soil.

Recent modifications on several of the fields supply data on fertilizers and methods of application not used in the original systems of treatment. The various productivity levels established by the original treatments provided a wide range of conditions under which these supplementary tests have been made.

Soil Conditions on Test Fields

The soils on which the experiment fields are located may be classified in 10 of the 16 Illinois soil groups as follows.[1] The year in which the field was established is indicated in parentheses.

I. Very dark, moderately heavy soils with moderately permeable subsoils: *Aledo,* Mercer county (1910).

II. Very dark heavy soils with moderately permeable subsoils, carbonates shallow: *Hartsburg,* Logan county (1911); *Minonk,* Woodford county (1910).

III. Dark soils with moderately permeable subsoils: *Kewanee,* Henry county (1915).

IV. Moderately dark soils with moderately permeable subsoils: *Dixon,* Lee county (1910); *Mt. Morris,* Ogle county (1910).

V. Moderately dark soils with grayish cast, slowly permeable subsoils: *Carlinville,* Macoupin county (1910); *Carthage,* Hancock county (1911); *Clayton,* Adams county (1911); *Lebanon,* St. Clair county (1910).

VI. Dark soils with slowly permeable subsoils, carbonates shallow: *Joliet,* Will county (1914).

VII. Gray, strongly leached soils with very slowly permeable subsoils: (**A**) Slick spots infrequent—*Ewing,* Franklin county (1910); *Oblong,* Crawford county (1912); *Toledo,* Cumberland county (1913). (**B**) Slick spots frequent—*Newton,* Jasper county (1912).

X. Yellowish gray, strongly leached soils with slowly permeable subsoils: (**A**) Slick spots infrequent—*Enfield,* White county (1912); *Raleigh,* Saline county (1910). (**B**) Slick spots frequent—*Sparta,* Randolph county (1916).

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[1]Classifications prepared by R. S. SMITH, Chief in Soil Physics and Soil Survey.

XIV. Light-brown sands and loamy sand with slight subsoil development: *Oquawka,* Henderson county (1915).

XVI. Yellow soils with slowly to moderately permeable subsoils: *Elizabethtown,* Hardin county (1917).

Cropping Methods Used

Most of the experiment fields were designed for four-year crop rotations. On many of them the crop sequence has been corn, oats, legume hay, and wheat, with a seeding of biennial white sweet clover for use as a green manure. On a few fields other sequences were used, but for most fields a regular biennial or perennial deep-rooted legume occupied the land one year in every four. Each field was so arranged that each crop in the rotation was grown every year, thus providing continuous annual yields of wheat and associated crops.

WHAT LONG-TIME EXPERIMENTS SHOW

Inherent Differences in Soil Productivity

No carefully supervised tests are needed to prove that soils differ inherently in their capacity to produce crops. Those differences have long been observed. Tests are necessary, however, to show the extent of the differences.

The long-time average yields of wheat from the untreated land in these tests ranged from 1 bushel to nearly 30 bushels an acre. Even tho adapted varieties were used in well-designed systems of cropping, the yields on the light-colored soils averaged less than 6 bushels an acre, ranging from 1 bushel to 8 bushels. Untreated dark-colored soils averaged 22 bushels an acre, the range being from 17 to nearly 30 bushels. The untreated land on one sandy field averaged less than 9 bushels, but in seasons of favorable moisture almost 20 bushels an acre were obtained (*data not shown*).

Thus soils low in productivity often fail to return much more than the equivalent of the seed used, while highly productive soils, even without soil treatment, may return seed 20 to 30 fold when conditions are favorable.

Altho differences in yields that accompanied differences in soils were narrowed considerably by soil treatment, there were no treatments that completely overcame the fundamental soil differences. The highest yields continued to come from those fields that gave the highest yields without any treatment (Fig. 2).

TABLE 2.—ACRE-INCREASES IN WHEAT YIELDS RESULTING FROM SOIL TREATMENTS ON ILLINOIS EXPERIMENT FIELDS
(Long-time average ending in 1942)

Field	County	Number of crops	Livestock systems: Yield on untreated land	Livestock systems: Increases from— M	ML	MLrP	Grain systems: Yield on untreated land	Grain systems: Increases from— R	RL	RLrP	RLrPK
			bu.	bu.	bu.	bu.	bu.	bu.	bu.	bu.	bu.
Minonk	Woodford	19[a]-28	29.9	3.3	1.6	3.1	26.9	3.2	1.0	3.6	3.6
Aledo	Mercer	20[a]-28	27.5	5.0	7.2	8.3	26.8	2.1	6.6	8.7	9.3
Kewanee	Henry	23	26.5	5.2	8.0	12.5	27.6	2.3	5.8	10.8	11.0
Hartsburg	Logan	21[a]-29	24.1	4.5	9.8	11.2	25.9	4.0	2.1	5.9	6.0
Dixon	Lee	27	22.6	7.2	10.8	12.4	23.2	2.9	7.3	10.5	11.6
Lebanon	St. Clair	37[b]	21.6	8.1	8.9	9.9	22.4	1.0	6.6	7.4	8.0
Mt. Morris	Ogle	28	21.7	5.0	10.0	11.0	20.0	1.5	8.1	11.4	12.4
Carthage	Hancock	27	20.4	4.5	8.8	10.0	20.6	1.6	7.5	9.0	12.1
Joliet	Will	25	18.9	4.0	6.3	12.3	19.1	.7	1.2	11.5	14.8
Carlinville	Macoupin	27	17.1	6.6	12.9	14.0	19.5	−.1	6.9	10.5	11.5
Clayton	Adams	27[a]-28	18.0	5.7	9.0	11.3	18.2	3.3	7.6	10.2	12.3
Oquawka	Henderson	28	8.9	3.7	9.5	10.2	10.4	.6	5.5	5.6	6.6
Oblong	Crawford	28	8.4	4.8	14.7	19.2	8.4	2.4	10.8	16.7	19.4
Toledo	Cumberland	25	8.0	5.9	15.9	17.1	8.2	.8	11.8	15.2	21.7
Enfield	White	25	6.2	3.9	17.6	20.9	7.1	1.1	11.1	16.0	20.5
Raleigh	Saline	25	5.4	3.9	16.3	18.8	6.7	1.2	10.1	14.2	20.0
Sparta	Randolph	22	6.0	3.5	17.4	20.5	4.8	.4	14.6	16.9	18.4
Elizabethtown	Hardin	31[b]	4.1	4.2	12.0	17.5	4.1	.2	6.5	16.0	17.8
Ewing	Franklin	26	3.6	4.1	21.9	24.2	3.3	.2	15.7	19.7	28.3
Newton	Jasper	31	.9	2.3	15.2	20.4	2.0	0	8.6	14.5	20.4

[a]Wheat in livestock systems was discontinued prior to 1942. [b]Two crops of wheat were included in several rotations.

The continued use of soil treatments, however, has made the naturally low-producing soils of southern Illinois almost as good producers of wheat as the dark-colored soils of the corn belt (Fig. 3).

Effectiveness of Soil Treatment

With few exceptions, the systems of soil treatment used in these experiments raised the yields of wheat on every field (Table 2). The relative effectiveness of the different systems varied greatly, however, with the types of soils to which they were applied. In general the increases were largest on the less-productive soils, where the more complete treatments were needed. Under treatment, these soils tended to give yields approaching those of the more highly productive untreated dark-colored soils.

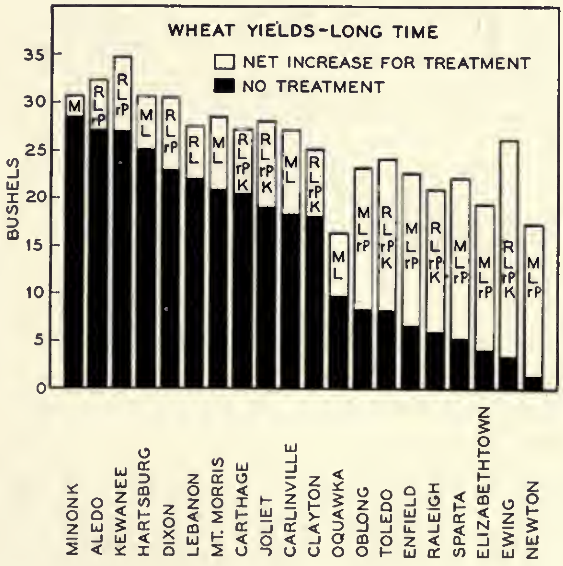


Fig. 2.—Long-time wheat yields, showing net increases for most effective treatments. This graph is based on averages ending in 1942. The untreated soils vary widely in their ability to produce wheat. Net response to treatment tends to be largest on the less productive soils.

Both livestock (*manure*) and grain (*residues*) systems brought good results. On some fields the livestock systems were most effective; on others the grain systems had the advantage. On the whole there was little difference in the responses to these two types of systems.

TABLE 3.—ACRE-INCREASES IN WHEAT YIELDS RESULTING FROM USE OF INDIVIDUAL FERTILIZER MATERIALS ON ILLINOIS EXPERIMENT FIELDS
(Long-time average ending in 1942)

Field	County	Number of crops	Livestock systems: Yield on untreated land	Livestock systems: Increases from— M	L	rP	Grain systems: Yield on untreated land	Grain systems: Increases from— R	L	rP	K
			bu.	bu.	bu.	bu.	bu.	bu.	bu.	bu.	bu.
Minonk	Woodford	19[a]-28	29.9	3.3	−1.7	−.2	26.9	3.2	−2.2	.4	0
Aledo	Mercer	20[a]-28	27.5	5.0	2.2	1.1	26.8	2.1	4.5	2.1	.6
Kewanee	Henry	23	26.5	5.2	2.8	4.5	27.6	2.3	3.5	5.0	.2
Hartsburg	Logan	21[a]-29	24.1	4.5	5.3	1.4	25.9	4.0	−1.9	1.9	.1
Dixon	Lee	27	22.6	7.2	3.6	1.6	23.2	2.9	4.4	3.2	1.1
Lebanon	St. Clair	37[b]	21.6	8.1	.8	1.0	22.4	1.0	5.6	.8	.6
Mt. Morris	Ogle	28	21.7	5.0	5.0	1.0	20.0	1.5	6.6	3.3	1.0
Carthage	Hancock	27	20.4	4.5	4.3	1.2	20.6	1.6	5.9	1.5	3.1
Joliet	Will	25	18.9	4.0	2.3	6.0	19.1	.7	.5	10.3	3.3
Carlinville	Macoupin	27	17.1	6.6	6.3	1.1	19.5	−.1	6.9	3.6	1.0
Clayton	Adams	27[a]-28	18.0	5.7	3.3	2.3	18.2	3.3	4.3	2.6	2.1
Oquawka	Henderson	28	8.9	3.7	5.8	.7	10.4	.6	4.9	.1	1.0
Oblong	Crawford	28	8.4	4.8	9.8	4.5	8.4	2.4	8.4	5.9	2.7
Toledo	Cumberland	25	8.0	5.9	10.0	1.2	8.2	.8	11.0	3.4	6.5
Enfield	White	25	6.2	3.9	13.7	3.3	7.1	1.1	10.0	4.9	4.5
Raleigh	Saline	25	5.4	3.9	12.4	2.5	6.7	1.2	8.9	4.1	5.8
Sparta	Randolph	22	6.0	3.5	13.9	3.1	4.8	.4	14.2	2.3	1.5
Elizabethtown	Hardin	31[b]	4.1	4.2	7.8	5.5	4.1	.2	6.3	9.5	1.8
Ewing	Franklin	26	3.6	4.1	17.8	2.3	3.3	.2	15.5	4.0	8.6
Newton	Jasper	31	.9	2.3	12.9	5.2	2.0	0	8.6	5.9	5.9

[a]Wheat in livestock systems was discontinued prior to 1942. [b]Two crops of wheat were included in several rotations.

Part Played by Each Treatment Material

Since the systems of soil treatment used in these experiments involve a step-by-step build-up, it is possible to determine the separate effects of each material used. The data on this point are given in Table 3.

Most materials, it should be kept in mind, were used in association with other materials. If they had been used alone, larger or smaller effects might have been obtained. When two materials possess overlapping functions, either used alone would tend to have a greater effect than either used with the other. On the other hand, any material used alone would tend to be less effective on a soil deficient in another material than it would be where all plant nutrients were adequately supplied.

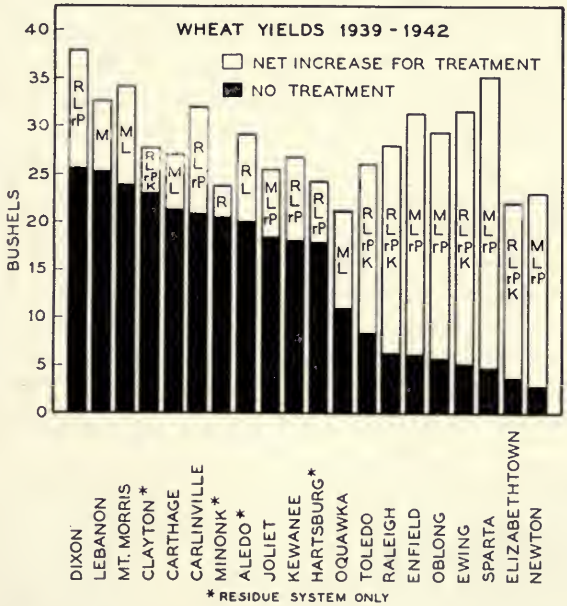


Fig. 3.—Wheat yields during last rotation, showing net increases for most effective treatments. Good soil treatment has gradually raised the yields on the light-colored soils of southern Illinois until the best of them have reached almost the level of the dark-colored soils.

It is evident that the treatment materials used in these experiments increased the wheat yields on most fields. There is, however, considerable variation in their behavior under different soil conditions.

Manure and crop residues. The chief sources of nitrogen and organic matter used in these experiments were animal manure (M) and crop residues (R). Being by-products of the farm, they can be returned to the soil with little or no cash expense. The quantities that can be returned, however, depend on the productiveness of the soil.

Manure, in general, gave greater increases than crop residues. The manure supplied not only nitrogenous organic matter but also readily usable mineral nutrients and, perhaps, other constituents as well. Crop residues varied a great deal in both quantity and quality. On the less productive soils the legumes usually failed where the land was unlimed; the returned residues consisted chiefly, therefore, of small amounts of stover and straws. On the more productive soils, however, the unlimed land usually produced good stands of legume crops, and their roots and stubble provided considerable quantities of effective residues.

Altho the manure system gave fairly substantial increases in yield on all experiment fields, it tended to be more effective on the dark-colored soils. The tendency toward smaller increases on the less productive soils was due in part, no doubt, to the smaller amounts of manure applied. The residues system also was more effective on the dark-colored soils, chiefly because the dark-colored soils produced better stands of legumes and green manure crops and therefore supplied more residues to be returned to the soil. The amounts of non-

Rock phosphate: yield 27 bushels   No treatment: yield 16 bushels

Fig. 4.—How wheat responds to rock phosphate. Broadcasted at the rate of 1,000 to 1,500 pounds an acre, rock phosphate has substantially increased wheat yields on many soils. The plots shown above are on the University South Farm at Urbana.

legume residues returned to the less productive soils were so meager that they had little effect in increasing the yields of wheat.

Limestone. When applied as a supplement to either manure or crop residues, limestone (L) was the most important aid in increasing the yields of wheat (Table 3). In general the response to limestone increased with declining soil productivity. The tendency, however, was toward better results with the residues systems on the dark-colored soils and with the manure systems on the light-colored soils. Field observations and legume-hay yields (*data not shown*) suggest that the major influence of limestone was due to the larger accumulation of organic matter which resulted from better stands and better growth of legume crops. Soils capable of growing legumes satisfactorily without limestone gave little or no increase in yields of nonlegume crops as a result of liming.

Phosphates. In these experiments, rock phosphate (rP) applied as a supplement to the manure-limestone and residues-limestone treatments increased the wheat yields on most fields, but the increases were more variable than those which were due to limestone (Table 3). Rock phosphate was, in general, more effective in the residues systems than in the manure systems. Altho there was a tendency toward larger responses on soils of low productivity, some highly productive soils gave rather good increases while some soils of low productivity gave rather poor yield increases (Fig. 4).

Superphosphate was not used in the original treatment systems, but changes were made in 1923 on a number of experiment fields in order to permit its use. Since it possesses chemical characteristics different from those of rock phosphate, experiments were made to determine whether its effects in the treatment system would be different from the effects of rock phosphate. On some fields superphosphate was broadcasted before wheat seeding at the rate of about 300 pounds an acre while on others it was drilled with the wheat at the rate of around 200 pounds.

Results are now available for periods ranging from 13 to 19 years. Data for this carrier, applied with and without limestone in the residues systems of farming, together with comparable data for rock phosphate, are shown in Table 4.

Both carriers tended to give greater increases on soils of declining productivity, but this relationship was not entirely consistent. For example, on the Hartsburg field, located on rather productive soil, both carriers caused greater increases than on some other fields located on less productive soils. At Hartsburg the effects of superphosphate were

TABLE 4.—AVERAGE ACRE-YIELDS OF WHEAT AND INCREASES FROM ROCK PHOSPHATE AND SUPERPHOSPHATE APPLIED WITH AND WITHOUT LIMESTONE[a]

Field	Number of crops	Without limestone			With limestone		
		Yield without phosphate	Increases from—		Yield without phosphate	Increases from—	
			Rock phosphate	Superphosphate		Rock phosphate	Superphosphate
		bu.	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*
Hartsburg	18	28.7	5.4	3.5	26.8	5.2	8.6
Aledo	19	28.3	3.5	2.5	34.3	3.0	2.1
Dixon	19	27.4	4.2	3.4	32.8	3.0	3.0
Lebanon	14	26.6	3.1	5.9	31.1	.7	3.4
Carthage	13	23.9	6.1	6.7	27.4	2.5	4.8
Toledo	19	9.7	9.9	6.7	20.3	4.6	5.1
Raleigh	17	7.4	11.2	7.7	15.2	9.6	10.9
Ewing[b]	14	5.6	...	7.0	24.8	6.8	8.9

[a]The phosphates were applied to the wheat and corn crops grown in four-year rotations. At the Carthage, Ewing, and Lebanon fields the phosphates were drilled with the wheat and hill-dropped for the corn. The average acre-rates of application on the annual basis were 90 pounds of superphosphate and 140 pounds of rock phosphate. At the other fields broadcast applications were made. The average annual acre-rate was 150 pounds of superphosphate, 300 pounds of rock phosphate without limestone and 400 pounds with limestone. Crop residues were plowed under on all plots. [b]Potassium deficiencies were corrected. No rock phosphate was used on unlimed land, and on limed land the rock phosphate was residual since 1924.

especially striking. Recently established experiments on the Minonk field, which belongs to the same soil group, gave similar results.

The data in Table 4 indicate in general that both rock phosphate and superphosphate increased the yields of wheat on soils of different productivity levels. Without limestone, rock phosphate gave slightly larger increases than superphosphate; with limestone, this relationship was reversed. Usually, however, the highest total yields were obtained on the limed land.

These experiments show that the usefulness of phosphate may be affected by the presence or absence of other treatment materials. These other materials may add to the phosphorus-supplying power of the soil, or they may overlap the functions of the phosphates. In either event the phosphate would tend to be less effective than if used alone. On the other hand, if another nutrient element, such as potassium, was as deficient as phosphorus, the applied phosphate would be subject to handicaps.

There is evidence that systems which include manure, crop residues, and limestone do increase the phosphorus-supplying powers of some soils. Chemical analyses (*data not shown*) of experiment-field soils show that the amount of available phosphorus in the surface soil of a number of fields has increased. This increase may be due (1) to the return of soil-derived phosphorus in applied animal manure; (2) to the use of subsoil phosphorus by deep-rooted legumes and the accumulation of this phosphorus in the surface soil when the legumes are plowed under; and (3) to the influence of limestone in maintaining soil phosphorus in more usable forms. Altho these relationships can not all continue indefinitely, they may be of considerable temporary importance.

Overlapping functions of limestone and phosphate. Limestone and phosphate may also possess overlapping functions. Both contain calcium, an important element in plant nutrition. If the calcium in phosphate serves any useful purpose, the total yield increases resulting from separate applications of limestone and phosphate should be greater than the increases from the two when both are applied on the same soil. An experiment established on the Aledo field in 1916 provides data for such comparisons (Table 5).

TABLE 5.—VALUE OF CROP INCREASES[a] PER ACRE PER YEAR WHEN LIMESTONE AND PHOSPHATE WERE APPLIED TO SEPARATE PLOTS AND WHEN APPLIED TO THE SAME PLOTS
(Aledo field, 1916-1940)

Phosphorus carriers[b] and amount applied per acre per year	Limestone and phosphate applied to separate plots			Limestone and phosphate applied to the same plot	Overlapping effects[d]
	Limestone[c]	Phosphate	Total		
Value of increases during period of phosphate applications, 1916-1931					
Bone (130 pounds)	$2.44	$5.01	$7.45	$6.44	$1.01
Super (223 pounds)	2.59	4.40	6.99	5.94	1.05
Rock (467 pounds)	2.83	4.11	6.94	5.00	1.94
Slag (188 pounds)	3.10	5.31	8.41	6.67	1.74
Value of increases during period of residual phosphate effects, 1932-1942					
Bone (130 pounds)	$2.35	$1.82	$4.17	$4.34	−$ .17
Super (223 pounds)	3.31	2.86	6.17	4.01	2.16
Rock (467 pounds)	3.67	2.71	6.38	5.15	1.23
Slag (188 pounds)	3.11	3.26	6.37	4.73	1.64

[a]With corn at 50 cents a bushel, oats at 30 cents, wheat at $1, hay at $10 a ton. [b]Until last application in 1931. [c]Six tons an acre; none applied since 1918. [d]Difference between Columns 3 and 4.

Four carriers of phosphorus were applied with and without limestone. Limestone was also used with and without the phosphates. The yields show overlapping effects in every instance with the exception of bone phosphate in the last period. Such data may be interpreted as measuring the depressing effects of limestone on phosphates and of phosphates on limestone. It is interesting to note that during the period in which the phosphates were applied, the phosphates alone produced better increases than limestone alone, but in the subsequent period this relationship was reversed. This behavior tends to support the implications discussed above.

Response to phosphate reduced by potash deficiencies. Especially on the less productive soils, a deficiency of potash may prevent phosphate applications from having their full effect on crop yields. If this is true, increases from phosphate should be greater when applied in addition to residues, limestone, and potash (RLK) than when applied with only residues and limestone (RL), as in the original systems of treatment. To permit further study of these relationships, some changes were made on the Ewing field in 1929. No new applications of rock phosphate were made, but superphosphate was introduced for comparison with rock phosphate. The data thru 1942 are recorded in Table 6.

The residual rock phosphate, on the whole, gave better yield increases after the potash deficiency was corrected than before. Superphosphate applied in addition to potash was less effective than the rock phosphate in the earlier years, but has been more effective during recent years. These results emphasize the need for correcting *all* deficiencies which affect crop yields.

Another question is raised by a study of these data. Since potash deficiencies affect the usefulness of the phosphates, will not phosphorus

TABLE 6.—INCREASES IN WHEAT YIELDS SHOWING HOW UNCORRECTED POTASSIUM DEFICIENCY REDUCED EFFECTIVENESS OF PHOSPHATIC FERTILIZERS AND HOW UNCORRECTED PHOSPHATE DEFICIENCY REDUCED EFFECTIVENESS OF POTASH FERTILIZERS, 1929-1942
(Ewing field: data are in terms of four-year mowing averages[a])

Year	Yields from crop residues and limestone (RL)	Increases from phosphates[b]			Increases from potash	
		Potash deficiency	No potash deficiency			
		Rock phosphate (RLrP/ RL)	Rock phosphate (RLrPK/ RLK)	Super-phosphate (RLKsP/ RLK)	Phosphate deficiency (RLK/RL)	No phosphate deficiency (RLrPK/ RLrP)
	bu.	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*
1929	20.3	3.4	8.4	5.0	4.0	9.0
1930	17.7	1.2	5.1	4.1	3.8	7.7
1931	23.5	3.0	5.9	2.9	3.9	6.8
1932	23.9	3.3	4.7	2.4	6.1	7.5
1933	22.3	5.3	3.3	2.1	8.4	6.4
1934	24.1	7.1	5.1	6.0	8.3	6.3
1935	17.2	6.4	4.5	7.1	8.2	6.3
1936	14.4	7.3	7.8	11.6	6.0	6.5
1937	14.4	5.8	9.9	15.1	4.4	8.5
1938	12.3	4.5	8.2	11.8	5.3	9.0
1939	15.8	6.3	10.0	13.4	4.9	8.6
1940	20.0	5.7	7.7	10.1	5.1	7.1
1941	23.3	5.0	6.5	9.0	4.6	6.1
1942	23.0	5.3	8.1	11.4	2.9	5.7
Average[c]	19.5	5.0	6.8	8.9	5.3	7.1

[a]Full four-year averages were not attained until 1932. [b]Rock phosphate was last applied in 1924; superphosphate was first applied in 1929, at rates of 200 pounds drilled at wheat seeding and 200 pounds at corn planting. [c]Based on annual acre-yields.

deficiencies affect the usefulness of potash? The Ewing experiments throw some light on this point (Table 6). With few exceptions potash gave better increases where the soils did not lack phosphorus. The difficulty of assigning definite values to any one treatment is apparent from these data.

Detailed study of the Ewing wheat yields indicates that there is a need for both phosphate and potash on this field. These materials gave similar increases earlier, but those due to superphosphate are now tending to become somewhat larger than those due to rock phosphate or potash. Similar studies of corn (*data not shown*) reveal large increases that can be credited to potash and comparatively small increases that can be credited to phosphates.

Special studies with phosphates. Tests to compare the effectiveness of different kinds of phosphates and different rates of application of rock phosphate were begun at the Joliet and Kewanee fields in 1927. The soils were unlimed, slightly acid, and moderately productive for their respective soil groups.

Wheat and legume hay were grown in a two-year rotation on small replicated plots. Rock phosphate (Table 7) was broadcasted ahead of the wheat drill, half of the total amount being put on in 1927 and the remainder in 1929. Different phosphate carriers were broadcasted before each wheat crop. At the time the experiment was begun, the acre-cost of each treatment was about $3.50.

TABLE 7.—AVERAGE ACRE-YIELDS OF WHEAT WHERE ROCK PHOSPHATE AND OTHER PHOSPHATE CARRIERS WERE BROADCASTED
(Joliet and Kewanee fields, 1928-1939. Rotation: wheat and red clover or alfalfa)

Treatment	Joliet 6 crops	Kewanee 5 crops
Yields with rock phosphate applied at different rates[a]		
	bu.	*bu.*
No rock phosphate	18.6	25.9
500 pounds an acre	19.4	28.5
1,000 pounds an acre	23.0	32.3
2,000 pounds an acre	24.3	34.7
4,000 pounds an acre	24.9	34.4
Yields with different phosphate carriers[b]		
No phosphate carrier	16.2	23.2
Rock phosphate (400 pounds)	20.1	32.3
Bone meal (110 pounds)	22.1	32.4
Superphosphate, 20-percent (250 pounds)	23.0	31.6
Superphosphate, 45-percent (110 pounds)	24.3	31.9

[a]Half of the total amount was applied ahead of the 1928 crop and half of the 1930 crop. [b]Applied for each wheat crop.

The behavior of wheat with rock phosphate was similar at the two fields. The second ton of rock phosphate caused no increase in yield over that of the first ton. The yields were a little larger where a 2,000-pound application was made than where a 1,000-pound application was made.

At Kewanee the four phosphate carriers gave almost identical results, the wheat increases averaging 8.8 bushels an acre, with a range of only .8 bushel between the lowest and the highest increase. At Joliet rock phosphate and treble superphosphate increased yields 3.9 and 8.1 bushels respectively. The effects of the bone meal and of the 20-percent superphosphate were midway between these extremes.

A detailed study of the effect of different phosphates when used with light and with heavy limestone applications has been made at Carlinville. A two-year rotation of corn and wheat, with a sweet-clover green-manure catch crop, was used. The corn was cut before wheat seeding. In this rather exhausting rotation the yields have been low on those plots where sweet clover and the phosphates have been omitted (Table 8). On the area receiving only 1½ tons of limestone an acre, the rock phosphate, superphosphate, and concentrated superphosphate have increased the wheat yields an average of 8.6 bushels an acre, little difference being shown among the three carriers. When used with 5 tons of limestone to the acre, the two superphosphates have given almost equal returns, averaging 10.7 bushels an acre,

TABLE 8.—INCREASES IN WHEAT YIELDS, SHOWING EFFECT OF ROCK PHOSPHATE AND SUPERPHOSPHATE WHEN USED WITH LIGHT AND WITH HEAVY LIMESTONE APPLICATIONS

(Carlinville field. Rotation: corn, wheat (sweet clover). Phosphates broadcasted)

Treatment	Average annual acre rate of application	Wheat yield 8-crop average	Increases due to— Phosphate	Heavy liming	Sweet-clover catch crop
Light liming (1½ tons an acre)					
	lb.	*bu.*	*bu.*	*bu.*	*bu.*
None	...	11.5	...	...	−.7
Rock phosphate	333	19.8	8.3	...	...
Superphosphate, 20-percent	167	20.4	8.9	...	...
Superphosphate, 45-percent	83	20.1	8.6	...	...
None (no sweet clover)	...	12.2	...	...	...
Heavy liming (5 tons an acre)					
None	...	19.2	....	7.7	6.5
Rock phosphate	333	25.5	6.3	5.7	...
Superphosphate, 20-percent	167	29.0	9.8	8.6	...
Superphosphate, 45-percent	83	30.7	11.5	10.6	...
None (no sweet clover)	...	12.7	....	.5	...

whereas rock phosphate gave only 6.1 bushels. In the four-year rotation at Carlinville the long-time average response of wheat to the rock-phosphate treatment in the grain-farming system was only 3.6 bushels an acre (Table 3). This and a number of other experiments indicate that winter wheat is much more responsive to phosphate when grown after a summer crop, such as corn or soybeans, than when grown after a spring grain. The frequency of wheat in the rotation may also be significant in this comparison: wheat in the first mentioned rotation occurs every second year; in the latter rotation, only every fourth year.

That organic matter is important in wheat production is again emphasized by the data from the Carlinville experiment (Table 8). On one plot at each limestone level, sweet clover was not seeded. Where the liming was light (1½ tons an acre), this omission caused little change because there was not enough limestone to produce a good growth of sweet clover. On the area which received 5 tons of limestone to the acre, the omission of the sweet-clover catch crop reduced the average wheat yield 6.5 bushels an acre. The average yield of the four plots where sweet-clover was seeded was 8.1 bushels higher on the heavily limed area than on the area receiving only a light liming.

Potash. On the permanent experiment fields carriers of potassium (K) were applied as a supplement to the residues, limestone, rock-phosphate treatment.

Potassium, thus used, increased the wheat yields on most fields (Table 3). The need for potash increased generally with declining soil productivity. The increases during recent years (*data not shown*) have become much larger than those of the long-time average. It is also of interest to note that corn and legume crops are much more sensitive to potash deficiencies than is wheat. For a thoro understanding of these data, the disadvantages caused by other nutrient deficiencies should be kept in mind (see page 188).

Effect of Long-Continued Treatment

Thruout the thirty-year period the treated land in these tests has yielded substantially more wheat than the untreated land. This is one clear and outstanding fact to be derived from these long-time experiments. There are other considerations, however, which are of vital economic importance in the evaluation of soils and systems of soil improvement. These are the quickness of the response produced and the yield limits attainable. Light on these questions is supplied by Figs. 5, 6, and 7, which show yield trends for two systems of treat-

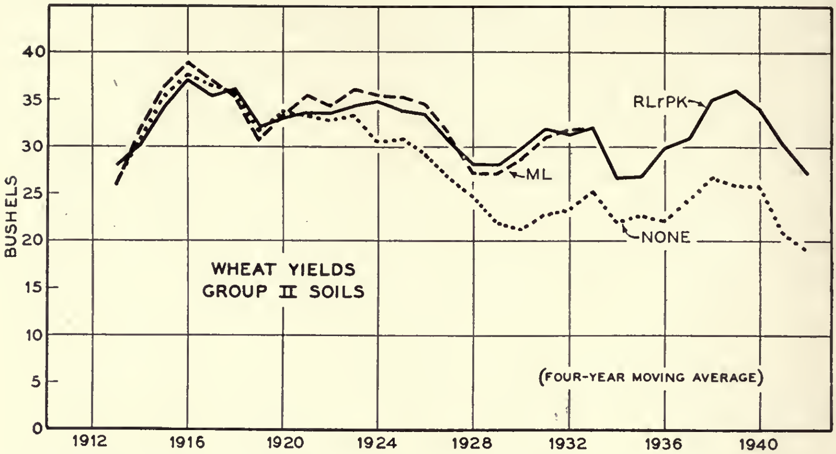


Fig. 5.—Trend of wheat yields on very dark heavy soils, treated and untreated. These soils, with moderately permeable subsoils and shallow carbonates, are represented by the Hartsburg and Minonk fields. Wheat does well on these soils if a good rotation is practiced. The use of minerals, however, is necessary in order to prevent a gradual decline in production.

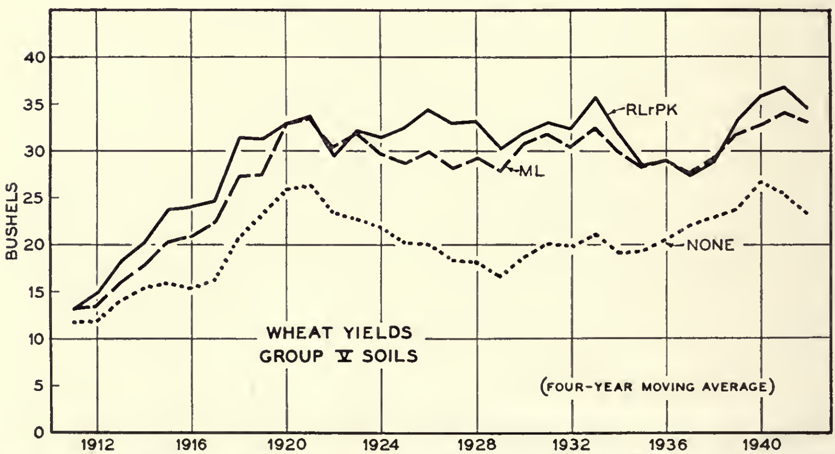


Fig. 6.—Trend of wheat yields on moderately dark soils, treated and untreated. The soils of this group, which have a grayish cast and slowly permeable subsoils, are represented by the Carlinville, Carthage, Clayton, and Lebanon fields. These soils are good producers of wheat. High yields can be maintained with soil treatment and a good rotation. The use of manure and limestone (ML, livestock system) was about as effective as residues, limestone, phosphorus, and potash (RLrPK, grain system).

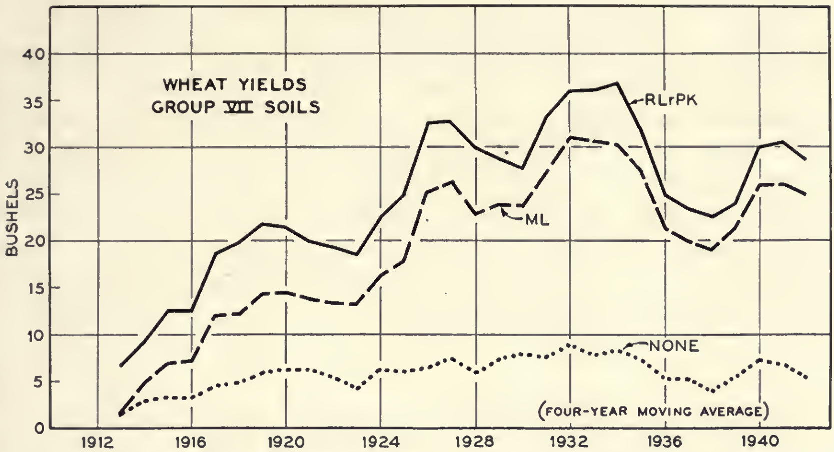


Fig. 7.—Trend of wheat yields on gray, strongly leached soils, treated and untreated. These soils, with slowly permeable subsoils, are represented by the Newton, Oblong, and Toledo fields. Untreated soils of this group are very low in organic matter and are poor producers of wheat. With soil treatment, yields increased gradually until 1934, when they reached 36.6 bushels.

ment (ML and RLrPK) for thirty years on ten experiment fields located on three different groups of soils.

The highly productive soils in Group II (Fig. 5) show a rapid upward trend in wheat yields during the first four years regardless of treatment—a trend probably due to an improved cropping system. For the first twelve years there was little difference between treatment and no treatment, but since that time the yields have been declining faster on the untreated land. During recent years differences in yields have been substantially in favor of the treatment systems, but the treatments have not, on the whole, raised yields—they have merely prevented declines such as have taken place on the untreated land.

On the moderately productive soils in Group V (Fig. 6) wheat yields increased gradually during the first eleven years on both the treated and the untreated land. The increases on the treated land during this time were more rapid than in later years, the yields changing from around 13 bushels to more than 33 bushels an acre. During recent years the yields on the treated soils have been fairly uniform, tending to range between 30 and 35 bushels. Thruout almost the entire time the residues systems have been a little more productive than the manure systems. The yields on the untreated land declined gradually following the first increases but have been slowly rising again.

The wheat yields on the light-colored soils of Group VII were low when these experiments were begun (Fig. 7). Crop rotation without soil treatment had little effect in bettering them. With treatment, however, there was a fairly consistent upward trend until the drouth period beginning in 1935, when yields declined sharply. During recent years recovery is in evidence. Yields have risen as high as 35 bushels an acre on the treated land, being somewhat higher in the residues systems than in the manure systems. There was no evidence that the highest levels had been obtained during the predrouth period, but whether yields will continue upward following recovery from the drouth remains to be seen.

EFFECT OF DIRECT FERTILIZER APPLICATION

The cumulative effects of long-continued treatments have just been described. The treatment materials were used with crop rotation, and their influences on wheat yields seem to be due largely to their effect on organic matter replenishment and the general productivity level of the soil.

Fertilizer materials applied directly for winter wheat also have been studied in many tests. The relative importance of certain nutrient elements—nitrogen, phosphorus, and potassium—and the most appropriate time, method, and amount of their application have been considered. Several different commercial carriers of nitrogen and phosphorus have been compared, and also a number of experimental phosphates.

Effect of Materials Applied Alone and in Combination

Tests were made during the years 1931-1939 to compare certain individual fertilizer materials—ammonium sulfate (N), muriate of potash (K), rock phosphate (rP), and superphosphate (sP)—broadcasted for winter wheat. Each material was used alone, and the phosphates were used also in combination with nitrogen and potassium. The tests were made cooperatively on farmers' fields which had been limed. Average results from 13 trials on seven dark-colored soils and 6 trials on three light-colored soils are reported (Table 9). The nitrogen (N) applications were broadcasted in the spring, ammonium sulfate being used at the rate of 100 pounds an acre in most tests. Just before wheat seeding, the other fertilizers were broadcasted on the prepared seedbed. Potassium was supplied in muriate of potash applied at the rate of 100 pounds an acre. Rock phosphate was applied at rates

TABLE 9.—INCREASES IN WHEAT YIELDS RESULTING FROM USE OF AMMONIUM SULFATE (N), POTASSIUM CHLORIDE (K), ROCK PHOSPHATE (rP), AND SUPERPHOSPHATE (sP) ON DARK-COLORED AND LIGHT-COLORED SOILS
(Broadcasted on limed land, 1931-1939)

Fertilizer	Dark-colored soils, average of 13 crops on 7 fields	Light-colored soils, average of 6 crops on 3 fields	Fertilizer	Dark-colored soils, average of 13 crops on 7 fields	Light-colored soils, average of 6 crops on 3 fields
	bu.	*bu.*		*bu.*	*bu.*
N	5.6	.8	rP	3.4	4.4
N over K	4.4	3.9	rP over N	2.2	.2
N over rP	5.4	0	rP over K	4.7	.8
N over sP	6.3	0	rP over NK	3.3	3.3
N over rPK	3.0	6.4	Average increase from rP	3.4	2.2
N over sPK	4.2	3.9			
Average increase from N	4.8	2.5	sP	5.5	9.5
			sP over N	6.2	7.5
K	2.6	.3	sP over K	6.2	8.5
K over N	2.4	3.4	sP over NK	6.0	8.5
K over P	3.9	0	Average increase from sP	6.0	8.5
K over sP	3.3	0			
K over rPN	1.5	6.5			
K over sPN	1.2	4.4	Average yield without fertilizer	25.6	18.1
Average increase from K	2.5	2.4			

varying from 400 to 800 pounds an acre; superphosphate rates varied from 200 to 350 pounds an acre.

Previous liming and the use of legumes had made the soils moderately productive. Where no fertilizers were applied, the average wheat yields on the dark-colored and the light-colored soils were 25.6 and 18.1 bushels respectively.

Superphosphate was the most effective of these fertilizers, giving an average acre-return of 6 bushels on the dark-colored soils and 8.5 bushels on the light-colored soils. Potash used in addition to nitrogen and phosphate was quite effective on the light-colored soils. Nitrogen applied in the spring consistently increased yields on the dark-colored soils, the increases averaging 4.8 bushels an acre. On the light-colored soils, it caused an average increase of 4.7 bushels an acre when used with potash but failed to give consistent increases when potash was omitted.

Effect of Nitrogen Fertilizers Top-Dressed

Nitrogen deficiencies affect winter wheat in spring more than at any other time. When severe, the plants become pale green or yellow.

Most of the nitrogen for Illinois crops is supplied by the use of legumes in crop rotations and by the return of animal manure to the soil, but under some conditions the use of additional nitrogen from commercial sources has been found practical.

TABLE 10.—WHEAT INCREASES DUE TO TOP DRESSINGS OF AMMONIUM SULFATE AT DIFFERENT DATES AND FOLLOWING DIFFERENT CROPS

(Grundy silty clay loam, Greene county, 1931. Ammonium sulfate applied at rate of 100 pounds an acre to land previously limed and phosphated)

Time of application	Wheat after wheat		Wheat after oats		Wheat after four corn crops		Average increase
	Total yield	Increase	Total yield	Increase	Total yield	Increase	
	bu.	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*
None applied............	37.0	...	34.0	...	25.4	...	...
Late fall (October 29).....	39.0	2.0	38.0	4.0	35.0	9.6	5.2
Early spring (March 18)...	41.1	4.1	41.3	7.3	42.0	16.6	9.3
Late spring (April 22).....	38.5	1.5	37.4	3.4	28.1	2.7	2.5
Average increase........	....	2.5	....	4.9	....	9.6	...

The efficiency of nitrogen-carrying fertilizers for winter wheat depends principally on (1) the productivity of the soil, (2) previous crops, (3) time of application, and (4) weather conditions in April and May. Tests with ammonium sulfate on productive dark-colored soil in Greene county (Table 10) have supplied information regarding the effect of the first three of these conditions, and numerous other field experiments show similar results. Wheat following four consecutive corn crops made considerably larger responses to this nitrogen fertilizer than were made by wheat after wheat or wheat after oats. Without ammonium sulfate, however, the wheat after corn produced considerably less than wheat after grain; and the early spring application brought yields up to approximately the same level on each of the three rotations. Best returns from ammonium sulfate have usually been obtained from applications made about the time spring growth becomes active. In the Greene county test, applications made March 18 were considerably more effective than those of either April 22 or October 29.

In seasons favorable to wheat growth nitrogen applications have frequently failed to give crop increases on soils of moderate or high productivity. Instead they have sometimes caused lodging (see page 205), which has resulted not only in reduced yield but also in a lower quality of grain. Damage to the clover seeded in the wheat may also result from lodging.

On the more productive soils clover stands have sometimes been greatly reduced by nitrate applications even where wheat growth was not excessive. Poor inoculation on high nitrate soils suggests that an excessive supply of nitrates may interfere with normal activity of the nodule bacteria.

TABLE 11.—INCREASES IN WHEAT YIELDS DUE TO DIFFERENT CARRIERS OF NITROGEN TOP-DRESSED ON WHEAT ON PREVIOUSLY UNTREATED SOILS LOW IN NITRATES

Nitrogen carrier and amount applied per acre	County, soil type, and date of application			
	1934		1939	
	Crawford: O'Neill sandy loam, March 20	Crawford: O'Neill sandy loam, April 25	Montgomery: Harrison silt loam, May 2	Washington: Cisne silt loam, May 2
	Increases due to treatment			
	bu.	*bu.*	*bu.*	*bu.*
Ammonium sulfate (100 pounds)....	5.4	−1.0	2.4	6.0
Calcium cyanamide (100 pounds)...	8.8	2.7	5.9	...
Sodium nitrate (135 pounds).......	9.5	5.8	11.4	7.7
	Yields without treatment			
No treatment......................	16.0	16.0	13.1	11.0

Effect of Different Nitrogen Carriers

Tests of different carriers of nitrogen applied in the spring have shown sodium nitrate to be slightly more effective than either ammonium sulfate or calcium cyanamide.

Crop increases resulting from several different soil conditions are reported in Table 11. Application rates were adjusted so that each carrier supplied 20 pounds of the element nitrogen per acre.

The chemical nature of sodium nitrate makes it more quickly effective than either ammonium sulfate or calcium cyanamide, and the sharp reduction in response that followed delayed applications of these latter materials suggests that they should be applied somewhat earlier than the most effective top-dressing date for sodium nitrate.

A series of tests using ammonium sulfate or sodium nitrate to supply 20 pounds of nitrogen an acre on limed land in the spring was made during the seasons 1931 to 1938. The tests included 22 wheat crops grown on 10 different farms having a wide range of soil types. All the soils were in a fairly high state of productivity. Wheat yields were increased an average of 4 bushels an acre by the use of these nitrogen carriers.

Effect of Mixed Fertilizers Applied Directly

Mixed fertilizers are prepared by combining available plant nutrients in simple mixtures. Compounds of any two or all three of the nutrient elements nitrogen, phosphorus, and potassium may be included.

The proportion of each ingredient is designated by a numerical system. Nitrogen is reported directly as percent of nitrogen, phosphorus as percent of phosphorus pentoxide (P_2O_5), commonly called phosphoric acid, and potassium as percent of potash (K_2O). The portions of the three ingredients are reported in the order just mentioned. Thus a 2-12-6 fertilizer mixture contains 2 percent of nitrogen, 12 percent of phosphoric acid, and 6 percent of potash.

The relative effectiveness of the three different ingredients in fertilizer mixtures when drilled with wheat was studied in field tests made during the seasons 1935 to 1937. Each year three previously untreated fields were selected. The fertilizers were especially mixed, the amount of one ingredient being progressively increased without changing the percentages of the other two (Table 12).

The single-element carriers were also included in most of the tests. All materials and mixtures were drilled with the seed wheat at the acre rate of 200 pounds.

Superphosphate, whether used alone or in any combination, gave good results in all these tests. Apparently the amount of phosphorus supplied by a 200-pound application of 2-12-6 was enough when drilled with the seed to remove the deficiency for the wheat crop (Fig. 8).

In these and many other tests the use of nitrogen in fertilizers has increased yields only slightly. Ordinarily under Illinois conditions this nutrient is best supplied by the use of inoculated legumes in the

TABLE 12.—YIELDS OF WINTER WHEAT WHERE FERTILIZER MIXTURES WERE DRILLED WITH THE SEED

Fertilizer drilled at rate of 200 pounds an acre	Average by years[a]			Average on different soils		
	1935	1936	1937	Light-colored soils	Moderately dark soils	Dark soils
	bu.	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*
None	14.1	16.6	27.2	13.6	17.8	26.4
0-12-6	24.2	26.3	39.2	21.6	35.0	33.1
2-12-6	24.2	31.6	37.5	24.5	30.2	38.6
4-12-6	23.4	29.3	39.0	24.7	30.0	37.1
8-12-6	19.6	34.9	39.0	23.3	32.0	38.3
8-12-0	....	34.2	36.2	....	29.2	....
12-0-0	....	21.4	29.3	....	22.2	....
None	14.8	17.2	26.3	15.1	18.1	25.1
2-0-6	16.1	20.3	29.2	16.9	21.8	27.0
2-6-6	25.0	31.5	39.4	32.1	30.3	33.3
2-12-6	26.0	31.6	38.7	24.6	32.6	39.2
2-18-6	25.0	30.2	36.4	23.0	30.9	37.8
0-24-6	....	30.9	37.1	....	32.7	....
0-24-0	....	27.6	36.5	....	30.2	38.7
None	17.3	17.2	22.1	13.7	15.7	27.1
2-12-0	22.3	30.8	34.1	25.5	28.4	33.2
2-12-6	21.3	31.6	37.2	23.0	31.8	35.3
2-12-12	28.7	33.9	36.1	27.6	32.0	39.1
2-12-18	29.2	36.9	37.0	29.0	33.0	41.1
0-6-24	....	27.1	33.5	....	30.7	....
0-0-24	....	25.0	23.3	....	22.3	....

[a]Tests each year were made on three previously unfertilized fields.

rotation. Commercial nitrogen, if used for winter wheat, is usually most effective when applied as a top-dressing in the spring (see page 197).

Most of the gray-colored soils of southern Illinois are sufficiently low in available potassium to justify including it in fertilizer mixtures for wheat because of its effect on succeeding crops as well as its effect on the wheat.

Fig. 8.—Mixed fertilizers and superphosphate are usually most effective when drilled with the seed. The plot at the left shows the effect of a 2-12-6 fertilizer drilled for wheat. The plot at the right had superphosphate. Taken near Savoy in Champaign county, this picture shows typical spring-growth response to phosphate fertilizers on phosphorus-deficient soils.

Tests Using Experimental Phosphates

During recent years the U. S. Department of Agriculture has done considerable research in the preparation of phosphate fertilizers, some of which have been used in field tests with winter wheat. Altho the new materials are not on the market at present, the results of the tests are of interest.

TABLE 13.—AVERAGE ACRE-YIELDS OF WHEAT ON PLOTS FERTILIZED WITH COMMERCIAL SUPERPHOSPHATE AND ON PLOTS FERTILIZED WITH EXPERIMENTAL PHOSPHATES

Treatment	Available phosphoric acid (P_2O_5)	Approximate acre-rate drilled	Average acre-yields each year				Average for four years	
			1937 5 trials	1938 2 trials	1939 5 trials	1940 5 trials	Yield	Increase
	perct.	*lb.*	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*	*bu.*
None	..	...	17.3	34.4	27.6	24.1	25.9	...
Superphosphate	20	150	28.2	40.6	30.8	36.4	34.0	8.1
Fused rock phosphate	26	125	26.9	40.7	32.5	33.4	33.4	7.5
Monocalcium phosphate	51	75	29.8	38.4	31.6	35.8	33.9	8.0
Metacalcium phosphate	63	60	29.5	44.2	33.6	35.4	35.7	9.8

Comparisons show these phosphates to be about as effective as 20-percent superphosphate when drilled for wheat in amounts which supply equal quantities of available phosphorus (Table 13). The concentrated materials, however, have the advantage of being more conveniently sacked and shipped, and it now seems that their place in commercial use will be determined largely by their cost and by the supply of equipment with which to apply them satisfactorily.

Effects of Productivity Levels on Usefulness of Fertilizers

There are different opinions as to the place of readily available fertilizers in a soil-improvement program. Should such fertilizers be used at the beginning of such a program, or should they be used as the last step after the cropping system, well balanced with deep-rooted legumes, has been established? The soil-experiment fields provide excellent opportunities for answering questions of this kind because, as a result of various treatments, a wide range of productivity levels has been developed. Plots on several of the fields are now being utilized for this purpose. Results with wheat on dark-colored soils of medium pro-

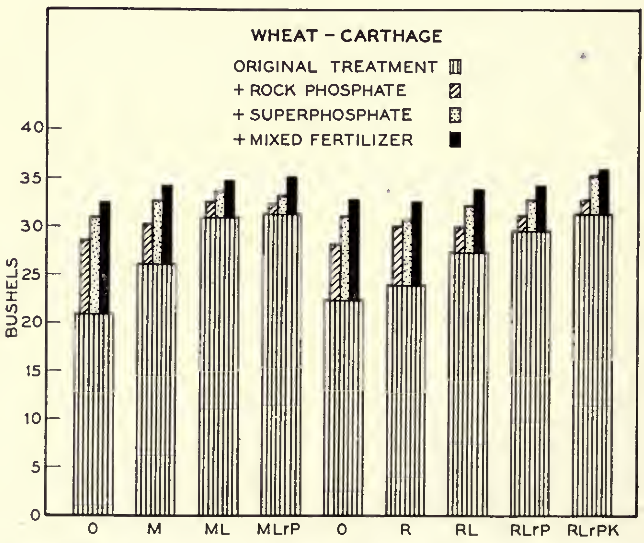


Fig. 9.—Wheat yields on the Carthage field, with original and with supplementary treatments, 1930-1942. On the untreated plots (0) of this moderately productive land, wheat has responded markedly to phosphates and mixed fertilizers drilled at seeding time. The effect of such supplementary treatments has been much reduced, however, wherever any of the basal systems of treatment have been used.

ductivity at Carthage and on light-colored soils of low productivity at Ewing are of interest.

The use of supplementary fertilizers was begun in 1929, about twenty years after the original treatments were established. At both fields the plots were subdivided in order to maintain on some plots the original treatments and on others to allow for drilling fertilizers with wheat and corn at planting time as a supplement to each of the original treatments. At Carthage 400 pounds of rock phosphate, 200 pounds of 20-percent superphosphate, and 200 pounds of 2-12-6 were drilled with the wheat at seeding time. At Ewing the supplementary treatments consisted of 100 pounds of muriate of potash and the same quantity of potash combined with 200 pounds of 20-percent superphosphate. At Ewing during recent years these fertilizers have been drilled into the soil a few days ahead of wheat seeding to avoid delaying germination. The effects of these practices are shown graphically in Figs. 9 and 10.

Both the original and the supplementary treatments increased wheat yields on the two fields.

At Carthage the effect of the supplementary treatments was rather

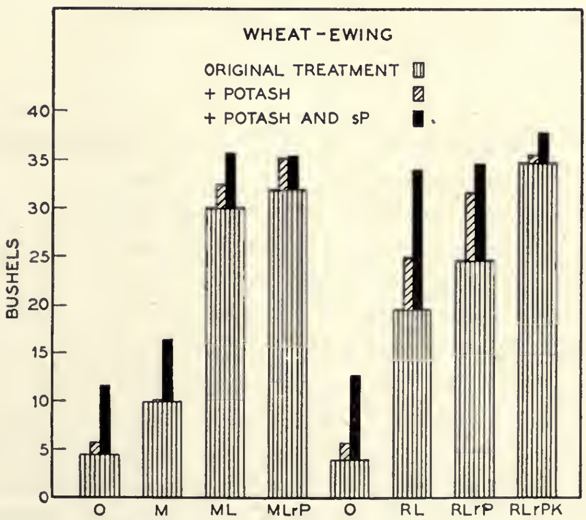


Fig. 10.—Wheat yields on the Ewing field, with original and with supplementary treatments, 1929-1942. This field is representative of the gray soils of southern Illinois which, without the help of lime and legumes, are too low in organic matter and nitrogen to produce satisfactory wheat yields or satisfactory yields of any other crops. Fertilizers used at seeding time cannot overcome the basic deficiencies of these soils.

large on the untreated land but decreased with the increasing productivity which was brought about by the long-continued basal treatments. The supplementary treatments brought yields to almost as high a level on the previously untreated plots as they were on the plots which had received treatment for many years. The thirteen-year average shows superphosphate to have been slightly more effective than rock phosphate and less effective than the 2-12-6 fertilizer. In recent years, however, the effects of rock phosphate (*data not shown*) have approached those of superphosphate and with some treatments have surpassed them.

Supplementary treatment on unlimed land at Ewing approximately doubled the yield of wheat, but even with this increase the yield was still too low for efficient production. On limed land where long continued treatment had supplied the necessary phosphorus and potassium, the supplementary treatment had little effect; but where either phosphorus or potassium was lacking, the treatments gave large increases.

Thus where productivity levels are not too low, fertilizers applied directly for wheat may be helpful in attaining satisfactory yields. But on soils which are as depleted of nutrients as those of the untreated plots at Ewing and which have other conditions as unfavorable, such fertilizers are of little value until organic matter has been replenished by the use of manure, crop residues, and limestone.

BEST METHODS OF APPLYING FERTILIZERS

From the many experiments which have been made to compare the efficiency of different methods of fertilizing wheat, a number of guiding principles have been fairly well established.

1. **Nitrogen-carrying fertilizers** are most effective when broadcasted in the early spring.

2. **Rock phosphate** should be thoroly mixed with the surface soil, and is most effective when used with legumes in a good rotation. Acre-applications of 1,000 to 1,500 pounds made at intervals of eight to twelve years have been satisfactory and on phosphorus-deficient soils have been followed by good wheat responses. Excessive liming should be avoided if rock phosphate is used, because a slightly acid soil reaction is necessary for greatest returns from rock phosphate. Numerous tests using small amounts of rock phosphate drilled for wheat have shown drilling to be somewhat less effective than broadcasting the larger amounts mentioned above.

3. **Superphosphate** in small amounts drilled near the seed will satisfy the needs of a single crop since most of the phosphorus in superphosphate is quickly available to wheat plants. The phosphorus requirements of other crops in the rotation, however, must be satisfied, and this often can be most conveniently done by a single larger treatment at wheat-seeding time. As larger applications are made, the need for drilling becomes less imperative; in fact where large amounts of superphosphate are used, drilling sometimes causes delays in germination, but this method does have the advantage of timeliness, convenience, and uniformity of distribution. Since winter-wheat plants seem to require an abundance of phosphorus during their early growth, drilling superphosphate near the seed is the best method of applying it. When applied in the spring, superphosphate treatments for winter wheat on phosphorus-deficient soils show only slight increases.

4. **Potassium**, where needed for winter wheat, is most beneficial when applied at seeding time. It may be broadcasted on the prepared seedbed or included in a fertilizer mixture. Drilling potash with the seed, either alone or in large quantities in a mixture, is likely to interfere with germination, especially if the seedbed is dry. Altho acre-applications as large as 150 to 200 pounds of 0-20-20 have been drilled without damaging effect, larger amounts are likely to reduce stands.

Most of the potassium tests reported in the preceding pages were made with muriate of potash, this being the carrier most commonly used now in Illinois.

5. **Mixed fertilizers** have given greatest returns when applied with a fertilizer attachment on a wheat drill, as suggested for superphosphate. There are now on the market granular fertilizers which can be drilled successfully from the wheat hopper of an ordinary grain drill if a fertilizer attachment is not available. This is a makeshift method which requires a second trip over the field, but it gives good results. Finely powdered fertilizers, however, cannot be applied satisfactorily from the wheat hopper.

RELATION OF SOIL TREATMENTS TO OTHER YIELD FACTORS

Insect Damage Reduced by Fertilization

Fertilization of soil offers some protection against at least two of the major insect enemies of wheat—the chinch bug and the Hessian fly. It is well known that chinch bugs prefer thin wheat. If they can find feeding places elsewhere, they will avoid the rank growth of fertile wheat fields. Hessian fly injury is prevented to a large extent by delaying seeding until after the relatively "fly-free date." Occasionally, even if this precaution is taken, weather conditions are such that damage by the spring brood of Hessian fly may be quite serious. In such seasons losses on soils well supplied with phosphorus have been low.

TABLE 14.—RESPONSE OF WHEAT INFESTED WITH HESSIAN FLY TO DIFFERENT FERTILIZERS, 1939

Fertilizer	Acre-rate drilled	Acre yield	Test weight	Fallen[a] straw	Hay yield[b]
	lb.	*bu.*	*lb.*	*perct.*	*tons*
None	...	21.3	54.5	18.0	1.69
Rock phosphate (broadcasted)	1,000	32.3	57.5	5.7	2.47
Superphosphate, 20 percent	150	39.4	57.5	.3	2.17
None	...	23.4	56.0	8.3	1.34
0-20-20	150	46.2	57.0	1.3	2.14
Calcined phosphate	125	47.0	56.5	.7	2.63
None	...	27.7	56.0	9.0	1.57
Fused phosphate	125	48.5	57.5	.3	2.46
Metaphosphate	60	47.4	57.0	2.3	2.10
None	...	26.1	55.0	17.7	1.69
Average of untreated plots		24.6	55.4	13.2	1.57
Average of treated plots		43.5	57.2	1.8	2.33

[a]Courtesy of J. H. Bigger, Illinois State Natural History Survey. [b]Clover-timothy mixture.

The response of wheat to phosphate fertilization on phosphorus-deficient soils is usually good and is quite certain to be large during Hessian fly seasons. In such seasons yields are usually low as well as of poor quality unless the soil is well supplied with available phosphorus. The results given in Table 14 and the contrast shown in Fig. 11 illustrate this point. The plots were located on Catlin silt loam in Champaign county. The fertilizers were drilled with the wheat in the fall of 1938. The average yields on the treated plots were almost double those on the untreated plots: 43.5 bushels compared with 24.6 bushels. The high percentage of fallen straw on the untreated plots is a common symptom of Hessian fly injury.

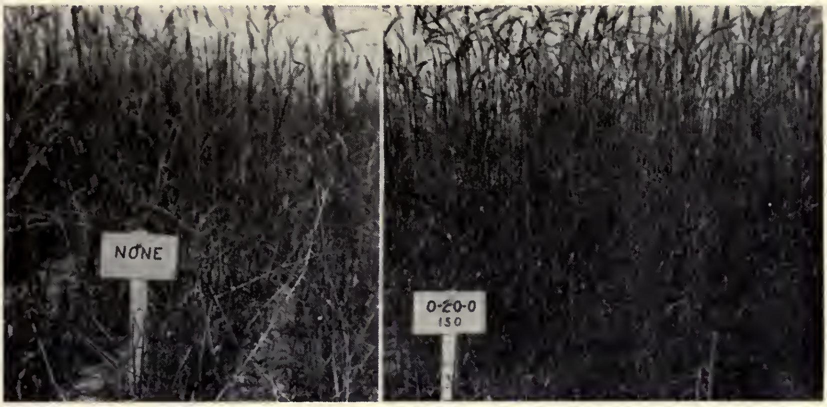


Fig. 11.—Well-nourished wheat (right) is less susceptible to Hessian fly injury. This pest of wheat is usually well controlled by delaying seeding until the recommended date. Sometimes, however, weather conditions encourage serious infestation by the spring brood even tho the seeding rule is followed. Phosphate fertilization has greatly reduced losses from this cause. (Data for above plots are given in Table 14.)

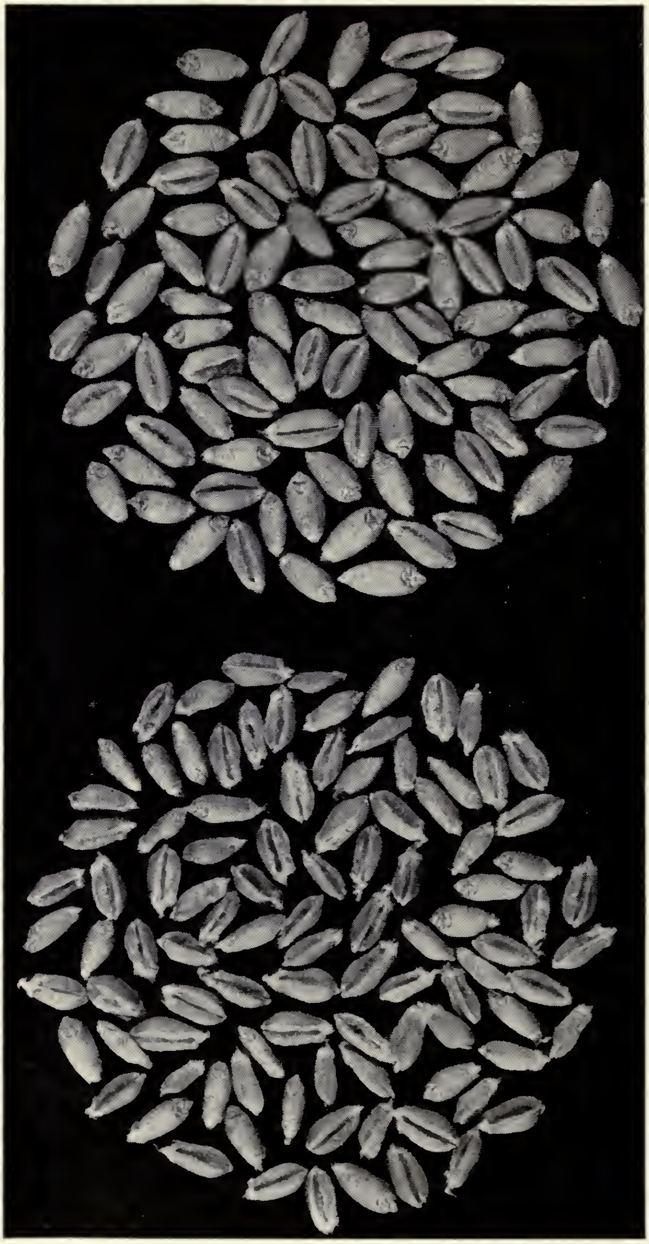
Effect on Wheat Lodging and on Clover Stands

Wheat often makes rapid and heavy growth on fertile soils, sometimes becoming so rank that it falls to the ground before maturing. This condition, commonly called *lodging,* makes harvesting difficult and frequently reduces the yield and quality of the grain.

Lodging is usually associated with high nitrate supplies in the soil. Therefore, to prevent it, efforts have been made to balance these high nitrate supplies by adding phosphate and potash fertilizers. Most of these efforts, however, have been unsuccessful, and it seems best to combat wheat lodging by using varieties that have stiff straw[1] and by so placing wheat in the rotation that it will come at a time when soil nitrates are not excessively high.

Ordinarily a legume or hay mixture seeded in wheat will be benefited by the residual effect of phosphate and mixed fertilizers used for wheat (Table 14). However, the heavy growth which results from the use of fertilizers sometimes causes severe shading and other injury to the clover seeding and may possibly be the direct cause of failure. Losses of this kind occur only on soils of relatively high fertility. Where wheat lodging and excessive growth of straw are a

[1]For latest recommendations see Circular 563 of this Station, "Winter Wheat Varieties in Illinois," 1943.



No treatment: yield 21.8 bushels, test weight 50.5 pounds — 0-20-20 drilled: yield 40.5 bushels, test weight 57.5 pounds

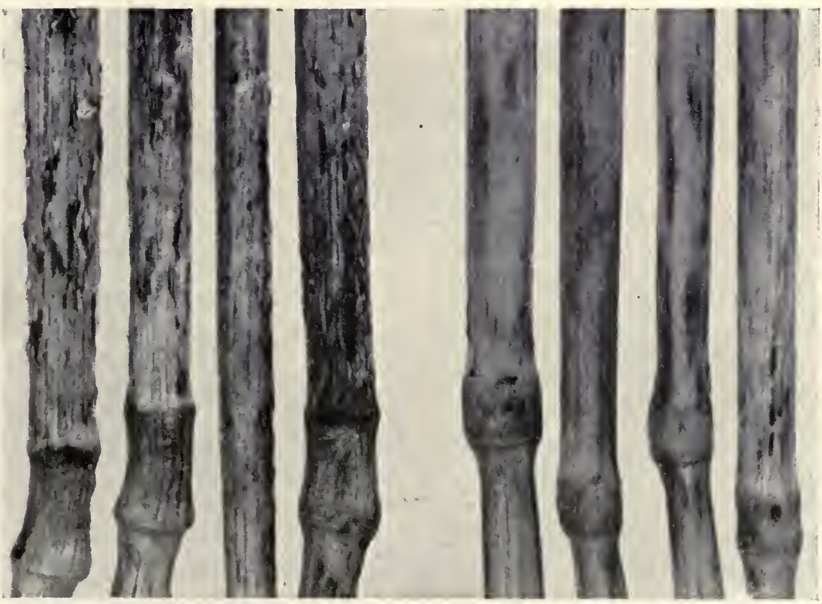
Fig. 12.—Wheat quality is often improved by soil treatment. Mineral deficiencies in the soil cause poor quality and low yield. The samples of Fulhio shown above were grown in 1940 on adjacent plots on deficient soil in Clinton county.

perennial problem, it may be best to change the present crop rotation or to pasture or clip spring growth.

Effect of Soil Treatment on Wheat Quality

Test weight per bushel is the most commonly used measure of quality for market wheat. During seasons of extreme damage from plant diseases, drouth, or insects the test weight is usually increased by soil treatment. The effect of soil treatment in reducing Hessian fly damage is illustrated in Table 14. In 1937 central Illinois wheat suffered an epidemic of stem rust which made some fields of grain almost worthless. On other fields fertilization greatly reduced the damage and improved the yield and quality, apparently because the treatments hastened maturity by making the plants less susceptible to infection when the disease struck.

In any season when there is danger of disease, drouth, or insect damage, early maturity is of considerable advantage (Figs. 12 and 13).



No treatment: yield 20.8 bushels, test weight 47 pounds

0-20-10: yield 43 bushels, test weight 56.5 pounds

Fig. 13.—Fertilized wheat is usually less damaged by disease. The earlier ripening of fertilized wheat is often a reason for its escaping disease injury. The wheat stems of Fulhio shown here were grown in Pike county in 1941.

Fertile Soil Provides Insurance Against Failures

Under Illinois conditions soil fertility helps to stabilize wheat yields from year to year. Mention of the protection which soil treatment gives against insect damage was made on page 204.

The value of a fertile soil in protecting the wheat crop against the combined effect of all hazards over a fifteen-year period on four fields —Aledo, Carlinville, Mt. Morris, and Oblong—varying widely in their productive capacity, is shown in Fig. 14. In this graph the frequency

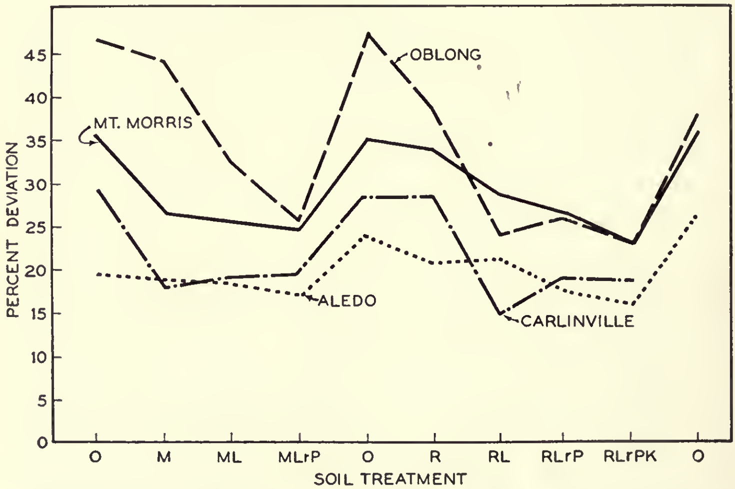


Fig. 14.—Extent to which wheat yields have deviated from the average under different soil treatments, fifteen-year average for four fields. Systematic soil treatment has tended to stabilize wheat yields. The smallest variations have occurred where treatments were most complete. The four fields selected for this analysis have varied widely in their productive capacity (Table 2).

with which crop failures have occurred is indicated by the extent to which yearly yields deviated from the average yield for the period, wide variation indicating frequent failures. At Aledo, for example, where the untreated soil is relatively fertile, the average yearly deviation was low and was not greatly affected by soil treatment. At Oblong, where the untreated soil is rather unproductive, yielding only about 9 bushels an acre during the fifteen-year period, yearly variations from the average were very wide, averaging 46.1 percent. But land that had been built up with crop residues, limestone, phosphate, and potash showed an average yearly deviation of only 22.7 percent from the average yield for the period, thus demonstrating the "insurance" value of soil treatment.

The frequency of low yields during the fifteen-year period is reported in Table 15 for each fertility level on these same fields, Aledo, Carlinville, Mt. Morris, and Oblong. Altho there is a definite tendency for the better soils to have fewer failures or near failures, it is also to be observed that the number of failures on the poorer soils was greatly reduced by appropriate soil treatments.

TABLE 15.—FREQUENCY OF LOW WHEAT YIELDS ON DIFFERENTLY TREATED PLOTS ON FOUR EXPERIMENT FIELDS, 1921-1935

Soil treatment	Number of times during 15 years that low yields (less than 60 percent of average) were secured			
	Aledo	Carlinville	Mt. Morris	Oblong
0	1	3	3	5
M	0	1	2	3
ML	1	1	1	3
MLrP	1	1	1	2
0	0	2	4	5
R	0	2	4	3
RL	0	0	2	1
RLrP	2	0	1	1
RLrPK	1	0	1	1

CONCLUSIONS: SUGGESTIONS TO WHEAT GROWERS

Satisfactory yields of winter wheat can be produced on most of the cropland of Illinois if adapted varieties[1] are grown and if suitable soil treatments are used. The following soil-management practices are of major importance in producing wheat efficiently.

Rotations are needed that will provide a moderate supply of nitrates and organic matter in the soil at seeding time. On soils of moderate or low productivity, wheat can be grown successfully after legume or sod crops; but on fertile soils it is better to have it follow a small grain crop. During favorable seasons, wheat may be seeded after soybeans or corn. Under most conditions, it is a satisfactory companion crop for legume seedings.

Liming of acid soil is necessary in order to get a good growth of

[1]See Bulletin 460 of this Station, "Winter Wheat Varieties for Illinois," 1939; and Circular 563, "Winter Wheat Varieties in Illinois," 1943.

soil-building legumes, without which the nonlegume crops, including wheat, cannot be produced efficiently.[1]

Phosphating of phosphorus-deficient soils is essential. The application of 1,000 to 1,500 pounds of rock phosphate an acre every eight to twelve years is recommended. If superphosphate or other carriers of this nutrient are used, they give best results when applied in small amounts for each responsive crop in the rotation. Best utilization of phosphorus from applied fertilizers or from minerals in the soil requires the regular growing of legumes and the maintenance of a good supply of organic matter.[2]

Drilling fertilizers that contain phosphorus or phosphorus and potash is effective where soils have low supplies of these nutrients. Standard grades, such as 20-percent superphosphate and 0-20-10, may be drilled at the rate of 100 to 150 pounds an acre at seeding time. If broadcasted, the rate should be increased to 200 to 250 pounds, and the fertilizer should be applied before seeding and mixed with the surface soil.

Potassium, where needed, may be supplied by broadcasting 100 to 250 pounds of muriate of potash per acre at seeding time; the best rate will depend on the degree of deficiency and the methods used to fertilize other crops in the rotation. Winter wheat will tolerate a greater potassium deficiency than will corn or legumes, but it is especially sensitive to a shortage of phosphorus during the early stages of its growth. If wheat is seeded after a late-maturing crop, such as soybeans, a temporary phosphorus deficiency may develop and justify drilling superphosphate or mixed fertilizers even on soils which are otherwise well supplied with available phosphorus.

Top-dressing wheat with a nitrogen-supplying fertilizer gives variable results, depending largely on weather conditions and the productivity of the soil. Early spring applications of 100 to 125 pounds of ammonium sulfate an acre, or the nitrogen equivalent supplied by other carriers, have given good returns on nitrogen-deficient soils. On fertile land, top-dressing with nitrate fertilizers is usually ineffective and may cause lodging. Under most Illinois conditions, however, nitrogen is best supplied by the systematic use of legumes in the rotation.

Phosphates and mixed fertilizers applied as top-dressings in the

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[1]Detailed discussion of this problem will be found in Bulletin 405 of this Station, "Response of Illinois Soils to Limestone," issued in 1934.

[2]The phosphate problem is discussed in detail in Bulletin 484 of this Station, "The Problem of Phosphate Fertilizers," issued in 1942.

spring are much less effective than when drilled at seeding time and are not advised unless needed for succeeding crops.

Wheat lodging often occurs on soils high in nitrates. The use of phosphorus and potash to balance this condition frequently causes greater lodging and seldom reduces it. Where lodging is a serious problem, stiff-strawed varieties should be grown. In extreme cases a change in the crop rotation or the use of spring pasturing or clipping may be practical.

Failures and near failures of winter wheat are less frequent when it is grown on fertile land. Under Illinois conditions the hazards from winterkilling and drouth and from insect and disease injury are materially reduced by good soil management.

WINTER WHEAT IS A RELIABLE widely-adapted cash crop for Illinois farmers. It fits easily into rotations, helps to distribute the farm labor load, reduces soil erosion, and provides a satisfactory companion crop for legume seedings.

Except for phosphorus, the nutrient requirements of winter wheat are only moderate. Where there is too little available phosphorus, yields are likely to be low and quality poor, and in unfavorable seasons complete failure of the crop is almost certain.

A good time to apply fertilizers is when the seedbed is being prepared or the seed being drilled. Any plan of treatment should recognize the needs of the other crops in the rotation.

Of all our common crops winter wheat is one of the most responsive to phosphate fertilizers.

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