OKLAHOMA
AGRICULTURAL AND MECHANICAL COLLEGE
AGRICULTURAL EXPERIMENT STATION
C. P. BLACKWELL, Director
STILLWATER, OKLAHOMA

Easily Soluble Phosphorus in Oklahoma Soils

HORACE J. HARPER
PROFESSOR OF SOILS

Experiment Station Bulletin No. 205 September, 1932

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EASILY SOLUBLE PHOSPHORUS IN OKLAHOMA SOILS

HORACE J. HARPER

Phosphorus deficiency in Oklahoma soils is an important agricultural problem, because phosphorus is an essential element for the growth of plants. When phosphorus is not preesnt in the soil in a form which can be absorbed by plant roots, a maximum production of crops cannot be secured. Plant growth is not usually restricted by a lack of available plant food during the first few years after virgin soils are brought into cultivation; however, when crops are continually removed from the land and phosphorus is not returned to the soil either in the form of organic manures or mineral fertilizers, a gradual decline in crop yield will occur. Although the reduction in the yield of certain crops produced in Oklahoma (See Fig. 1) may be due to other factors besides a decrease in the fertility of the soil, a lack of available plant food is probably one of the most important factors which has been responsible for this decline, since better adapted varieties of crops and better tools for cultivating the soil have been developed during the period in which a gradual decrease in crop yields has occurred.

Preliminary studies on the total phosphorus content in Oklahoma soils indicated that phosphorus might be a limiting factor in crop production, since the total amount of phosphorus in the average Oklahoma soil was only about one-half as great as that which occurs in the average corn belt soil in Iowa and Illinois. After a careful study it was found that total phosphorus was not as good an indication of phosphorus deficiency in a soil as easily soluble phosphorus. Further study also revealed that some knowledge concerning the amount of easily soluble phosphorus in a soil is important in order to make recommendations in regard to the use of phosphorus fertilizers in a system of permanent soil fertility. Consequently, in order to obtain information concerning the location of phosphorus deficient soils in Oklahoma, a large number of soil samples were collected and analyzed.

Experimental Study

The first indication of phosphorus deficiency in Oklahoma soils was secured as a result of field experiments in which phosphate fertilizers were applied to different crops in order to determine their effect on crop yield. Field experiments are an accurate method by which phosphorus deficiency in soils can be determined when favorable weather conditions prevail; however, because of the fact that many different soil types occur in the average community, general recommendations for a large area cannot be made from the results secured in a single field test conducted on one type of soil. Also the same type of soil occurring in different fields may not contain the same amount of available plant food because of good or poor farm management. Since many variations in soil type occur in the same and in different communities, it was necessary to use some other method in addition to a limited number of field experiments in order to secure more accurate information concerning the phosphorus needs of the many different types of soil which occur in Oklahoma.

Analyses of soils on which no fertilizer studies have been conducted can not be used to determine phosphorus deficiency, although very poor soils and very good soils can be detected by this method. However, when these analyses are correlated with soils to which phosphorus fertilizers have been applied and the effect on crop yield determined, fairly accurate recommendations can be made in regard to soil treatment. When samples of soil were treated with a dilute acid solution, it was found that soils which respond to phosphorus fertilization contain smaller amounts of easily soluble phosphorus than soils which do not respond to phosphorus fertilization.

Although the total amount of phosphorus in different soils may be about equal, the total phosphorus content of a soil is not always correlated with response from phosphorus fertilization, because the form in which the phos-

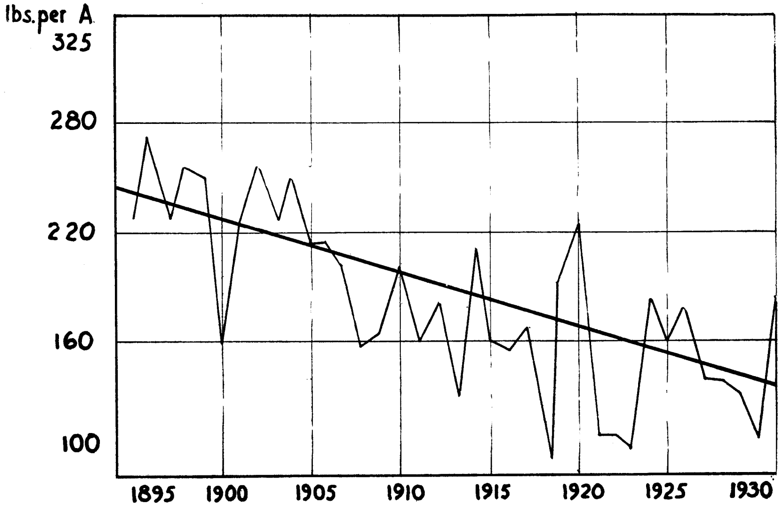

Fig. 1—Annual production of cotton lint per acre in Oklahoma, 1895-1931. Note the gradual decline in the average yield.

phorus is present in the soil varies. Frequently large amounts of total phosphorus may be present in a soil, but it is present in an insoluble form and cannot be absorbed rapidly by plant roots; consequently the total phosphorus content of soil is of little importance except as it gives some indication of the potential supply of phosphorus which may eventually be used by plants after it has been changed to an available form.

Method of Soil Analysis

The samples of soil which were secured for this study were analyzed in the laboratory by the following method:

Ten grams of soil were placed in a 500 cc. Erlenmeyer flask containing 100 cc. of fifth normal sulphuric acid. The flask was shaken every 5 minutes for 20 minutes. The soil suspension was filtered and 5 cc. of the clear filtrate was diluted to 95 cc. with distilled water. Two cc. of a solution containing 2½ per cent of ammonium molybdate and 37½ per cent of sulphuric acid were added and the solution was mixed thoroughly and allowed to stand one minute. Then three or four drops of a stannous chloride solution, made by dissolving one-half gram of pure tin in 10 cc. of arsenic-free hydrochloric acid and diluting to 50 cc. with distilled water, were added and the solution mixed again. The presence of inorganic phosphorus was detected by the formation of a blue color in the solution. The amount of phosphorus extracted from a soil by the dilute acid was determined by comparing the soil solution with a series of tubes containing known amounts of phosphorus which were treated with the same amount of reagents and in the same manner as recommended for the soil filtrate. Smaller or larger aliquots were taken from the soil filtrate if a comparison could not be made with 5 cc.

Basis for Correlating Phosphorus Deficiency in Soil With Laboratory Analyses

Soil samples secured from more than 100 different places in Oklahoma and from other states where fertilizer tests have been conducted were studied in the laboratory by the method which has just been described. The results of the analytical data were correlated with the effect produced when phosphate fertilizers were applied to the crops which were grown on the different soils. In some cases no response was secured from phosphate fertilization, while in other soils the response was classified as slight, medium, or large. Where the easily soluble phosphorus content in the soil was very low, frequently more than twice as large a crop would be produced on the fertilized plots as compared with adjacent areas which were not fertilized. The phosphorus removed from each sample of soil by extraction with dilute acid was calculated in pounds per 2,000,000 pounds of soil, which is the average weight of an acre of surface soil about six or seven inches deep.

The major portion of the root system of field crops which are planted and mature in one season develops in the surface layers of soil from zero to seven inches deep; consequently the amount of easily soluble phosphorus present in that portion of soil is most important from the standpoint of the successful production of the average crop. Subsoil phosphorus is important in case of crops producing a tap-root, such as alfalfa and sweet clover. Information concerning the easily soluble phosphorus in subsoils will be found in a later paragraph.

Data on the correlation between the response of different crops to fertilization and the amount of easily soluble phosphorus extracted from soil by dilute sulphuric acid are given in Table I. Crops do not usually give a profitable response from an application of phosphate fertilizers when planted on soils which contain more easily soluble phosphorus than indicated in the table. Soils which contain less easily soluble phosphorus than the amount indicated for each particular crop respond to phosphorus fertilization when phosphorus is the first limiting factor in crop production or when other limiting factors for plant growth in addition to phosphorus are supplied.

In some instances the problem of fertilization may be more closely related to the value of the crop produced than to the soil. When crops are grown which return a high income per acre, frequently large amounts of plant food are added in order to hasten the maturity of the crop, which is important from the standpoint of securing a better market for the product. Under such conditions a big excess of plant food may be applied regardless

Table I—Relation Between Easily Soluble Phosphorus in Soil and Response of Crops to Phosphorus Fertilization

Crop	Easily Soluble Phosphorus in Pounds Per Acre Above Which Phosphorus Fertilization Is Usually Not Profitable.
Alfalfa	40 to 50
Cotton	30 to 40
Oats	30 to 40
Wheat	30 to 40
Sweet Clover	30 to 40
Corn	20 to 30
Soybeans	20 to 30
Cowpeas	15 to 25
Grain Sorghums	15 to 20

of the fertility in the soil. If time of maturity is not a limiting factor in relation to the income received from the crop, then the data presented in Table I are applicable.

A study of the above table will indicate that there is a marked variation in the ability of different crops to secure phosphorus from the mineral compounds which are present in the soil. This difference may be due to the fact that certain crops need more phosphorus than other crops in order to develop normally. Also there is a difference in the length of the growing season for different plants and this factor may limit the growth of some crops because of the fact that the rate of solution of phosphorus in the soil may be too slow to permit a maximum growth of that particular crop. In general the legume crops are stronger feeders for soil phosphorus than the non-legumes. However, the alfalfa plant and the grain sorghums are exceptions to this statement.

Alfalfa can be considered a poor feeder on the insoluble phosphorus in the soil, although the crop requires a large amount of phosphorus in a short period of time in order to produce the large yields of forage which are frequently produced by this crop if soil and climatic conditions are favorable. Alfalfa will give a marked response to phosphorus fertilization on many soils where no response is secured from fertilizer applied to other crops such as cotton, wheat, and cowpeas. The grain sorghums do not respond to phosphorus fertilization on most soils and these crops may be considered as strong feeders on the insoluble phosphorus compounds in the soil; although the phosphorus content of this group of plants is relatively low as compared with the legumes. Also the apparent lack of response from fertilizers applied to grain sorghums may be partially due to the length of the growing season and to the very extensive root system which is developed by these crops.

Garden crops were not included in this study; however, they require a large amount of readily available plant food in order to produce large yields. Soils which contain high or very high amounts of easily soluble phosphorus will produce a good growth of garden crops without phosphorus fertilization. Liberal applications of farm manure increase the easily soluble phosphorus in the soil; consequently on garden soils where several applications of farm manure have been applied, the easily soluble phosphorus in those soils will be high. Phosphorus is not usually a limiting factor in crop production under such conditions unless the soil is very basic in reaction.

The organic phosphorus content of the soil may be an interfering factor in correlating crop response with the easily soluble phosphorus content of soils because of the fact that considerable amount of the organic phosphorus may be slowly changed to the inorganic form as a result of the decomposition of organic matter in the soil by bacterial action. Phosphorus which is liberated when organic matter decays is available for crop use, but the method of analysis which was used in this investigation to determine the easily soluble phosphorus content of soil does not measure organic phosphorus. Consequently soils which are high in organic matter but rather low in easily soluble phosphorus frequently do not give as much response to phosphorus fertilization as compared with fertilizer tests conducted on soils in which the organic matter content is relatively low. Soils which are low in organic matter content are frequently deficient in available nitrogen; consequently some means of supplying both nitrogen and phosphorus is essential in order to secure maximum crop yields on many soils. In some instances soil acidity may also be a limiting factor in crop production and as a result crops like sweet clover or alfalfa cannot be grown even when phosphorus fertilizers are applied. An application of finely ground limestone to strongly acid soils should be made if many garden crops and field crops like alfalfa, sweet clover, and barley are to be grown successfully.

In the interpretation of the results of analytical data, many factors must be considered in order to get a clear picture of conditions as they exist in the field in order that accurate recommendations can be made. Many soils are deficient in phosphorus but the addition of a phosphorus fertilizer will not make them productive. Successful crop production may require, in addition to phosphorus fertilization, a liberal application of limestone, fertilization with potash, and the addition of a large amount of organic matter. In some instances the physical condition of the soil is unfavorable for the absorption of rainfall and the development of plant roots and this factor may limit the growth of plants. All soils which are low in phosphorus will not give the same response to phosphorus fertilization; consequently recommendations on the use of phosphate fertilizers on the basis of the analysis of the easily soluble phosphorus content of the soil may be inaccurate unless other soil conditions are also considered.

Easily Soluble Phosphorus in Oklahoma Soils by Counties

Over 6000 samples of surface soil have been analyzed for easily soluble phosphorus by the method which was described in a previous paragraph. About one-half of these samples were collected by members of the experiment station staff and extension division. The other half were secured by farmers and were sent to the experiment station for analysis. These samples were classified into five different groups, depending upon the amount of easily soluble phosphorus present in them. The different groups and the amount of easily soluble phosphorus present in pounds per acre of surface soil six and two-thirds inches deep are given in Table II.

Table II—Easily soluble phosphorus content of soils grouped according to correlations made between crop response to fertilization and soil analyses

Group	Crop Response to Phosphorus Fertilization	Easily Soluble Phosphorus	Pounds Per Acre 6 2-3 Inches Deep
1	None	Very High	100 or more
2	Unprofitable	High	50-99
3	Profitable for Weak Feeders	Medium	30-49
4	Profitable for Most Crops	Low	14-29
5	Profitable for All Crops	Very Low	0-13

The results of the analyses of surface soils for easily soluble phosphorus are presented in Table III. Although the data cannot represent accurately the soil conditions which occur on any particular farm, they do furnish information in regard to the easily soluble phosphorus content of different areas. One criticism, which is true in many instances has been that samples of soil which have been sent to the laboratory for analyses have been taken from the poorest part of the farm. Although poor soils may be selected in many instances for analyses, it is quite certain that the limiting factor in crop production is not always phosphorus. It may be a lack of nitrogen and organic matter, or possibly in many cases soil acidity is responsible for the poor growth of crops. Consequently if a large number of poor samples of soil were secured from one county, the different factors which are responsible for the poor growth of crops would tend to offset each other, since it is not true that poor soils are always low phosphate soils. Where only a few samples of soil are secured from a county, some error may occur if the percentage of phosphorus deficiency is calculated, since the samples secured may not be an accurate index of the soil conditions as they exist in that area. In many counties where only a few samples were secured the majority of the samples were carefully taken by members of the experiment station staff; consequently the possibility of inaccurate results has been reduced to a minimum in most cases.

Soils which are classified as high or very high in easily soluble phosphorus do not usually give a profitable response from phosphorus fertilization, and in most cases no difference in yield will be secured when fertilized and unfertilized plots are harvested. Soils which contain only a medium amount of easily soluble phosphorus respond to fertilization when crops which have a low feeding power for phosphorus are grown. Samples of soil which are low or very low in easily soluble phosphorus respond to phosphorus fertilization when practically all crops are planted, provided other essential elements or soil conditions are not limiting factors in plant development.

A study of the results of the analyses which are recorded in Table III indicates that the major portion of the soils in the eastern half of Oklahoma are deficient in easily soluble phosphorus. From the standpoint of a profitable system of agriculture it is evident that a marked increase in the use of phosphorus fertilizers will be necessary in that area in order that many individual farmers and the communities in which they are located can be more prosperous. Fig. 2 shows the percentage of soils which contain less than 50 pounds of easily soluble phosphorus per acre in the surface soil, classified according to the county from which they were received. That portion which is shaded represents counties in which 50 per cent or more of all soils analyzed were deficient in easily soluble phosphorus. In some instances the number of samples of soil secured from certain counties may be too low to use in calculating exact information concerning phosphorus deficiency, but frequently the adjacent counties located in the same soil area can be used to give a clue or furnish additional proof of the condition which prevails in that region.

Although the major portion of the field experiments which have been conducted in Oklahoma have been located in the eastern half of the state, experiments which have been conducted in western Oklahoma have seldom given any response to applications of phosphorus fertilizers. This fact agrees quite accurately with the data presented in Fig. 2, which show that the major portion of western Oklahoma soils are high in easily soluble phosphorus. Phosphorus deficiency in western Oklahoma usually occurs in areas of light sandy soil, although not all sandy soils are deficient in this important plant food. The fine textured soils in this area are usually high or very high in easily soluble phosphorus.

In eastern Oklahoma the phosphorus deficiency is not associated with differences in soil texture but is more closely related to upland and bottom land soils. The major portion of the bottom land soils in eastern Oklahoma are not deficient in phosphorus because of the fact that these soils have been derived from the erosion of surface soil occuring at higher elevations. Under virgin conditions, the surface layer of soil which is affected by sheet erosion is high in organic matter. When this organic matter is deposited along with the mineral portion of the soil on the flood plains of streams, the organic matter gradually decays and the phosphorus which it contains is changed from an organic to an inorganic form which is readily available for plants. Some of the black waxy soils in eastern Oklahoma which have been formed from the weathering of limestone rock are not deficient in easily soluble phosphorus; although many of the dark colored prairie soils derived from sandstone and shale are very deficient in this particular plant food.

In some instances a high percentage of the soil samples secured from certain areas have been taken from bottomland soils. This is especially true in case of Muskogee county where many samples of soil have been taken along the Arkansas River in order to determine if phosphorus fer-

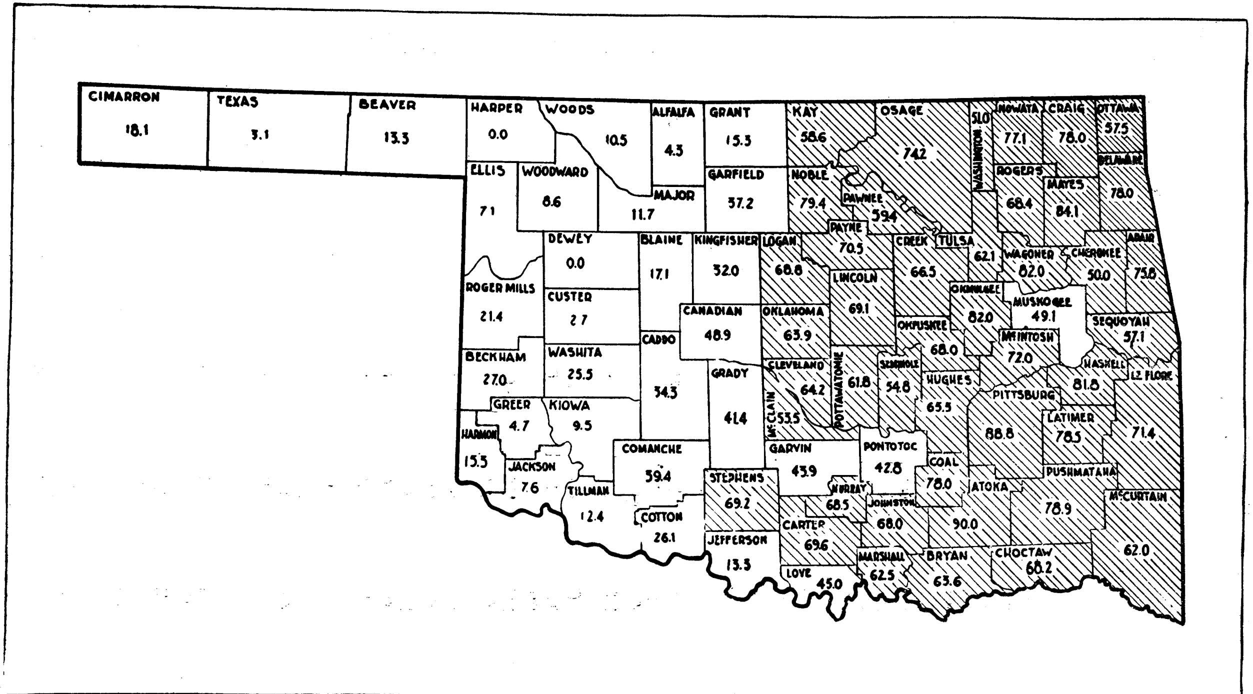

Fig. 2—Oklahoma map showing percentage of soils tested which are medium to low in easily soluble phosphorus. Shaded portion includes all counties in which the deficiency is greater than 50 per cent.

Table III—Studies on the easily soluble phosphorus in Oklahoma soils, by counties

County	Easily Soluble Phosphorus and Number of Samples in Each Group					Total Number of Samples Analyzed
	Very High	High	Medium	Low	Very Low	
Adair	1	6	8	3	11	29
Alfalfa	32	12	2	0	0	46
Atoka	0	2	0	11	7	20
Beaver	11	2	2	0	0	15
Beckham	13	22	6	3	4	48
Blaine	15	14	5	1	0	35
Bryan	3	9	2	11	8	33
Caddo	34	75	15	23	19	166
Canadian	40	112	67	61	13	298
Carter	18	39	18	39	74	188
Cherokee	0	2	0	0	2	4
Choctaw	7	6	6	7	15	41
Cimarron	7	2	2	0	0	11
Cleveland	3	7	8	9	1	28
Coal	7	4	3	15	21	50
Comanche	6	17	4	8	3	38
Cotton	12	44	10	12	6	84
Craig	2	7	5	17	10	41
Creek	42	103	61	116	112	434
Custer	21	15	0	1	0	37
Delaware	6	45	34	49	98	232
Dewey	16	9	0	0	0	25
Ellis	20	6	2	0	0	28
Garfield	27	77	15	19	7	145
Garvin	13	10	3	7	8	41
Grady	37	38	9	26	18	128
Grant	40	26	4	8	0	78
Greer	28	12	2	0	0	42
Harmon	10	1	0	1	1	13
Harper	7	2	0	0	0	9
Haskell	3	5	8	17	11	44
Hughes	8	22	9	29	19	87
Jackson	41	19	3	1	1	65
Jefferson	8	5	0	2	0	15
Johnston	2	6	2	10	5	25
Kay	15	35	29	28	14	121
Kingfisher	12	24	5	6	6	53
Kiowa	25	32	2	4	0	63
Latimer	0	3	1	6	4	14
LeFlore	13	1	8	15	12	49
Lincoln	19	42	23	39	75	198
Logan	6	28	18	35	22	109
Love	4	7	4	4	1	20
Major	21	9	1	3	0	34
Marshall	0	6	2	4	4	16

Table III—(continued)

County	Easily Soluble Phosphorus and Number of Samples in Each Group: Very High	High	Medium	Low	Very Low	Total Number of Samples Analyzed
Mayes	0	10	10	22	21	63
McClain	4	9	3	8	4	28
McCurtain	4	15	14	11	6	50
McIntosh	4	22	15	21	31	93
Murray	2	9	6	10	8	35
Muskogee	11	19	3	16	10	59
Noble	5	33	35	56	56	185
Nowata	13	19	25	46	37	140
Okfuskee	16	23	19	29	35	122
Oklahoma	51	106	71	76	131	435
Okmulgee	4	19	20	35	50	128
Osage	6	19	11	23	38	97
Ottawa	3	14	4	6	13	40
Pawnee	10	37	14	29	26	116
Payne	23	81	64	105	80	353
Pittsburg	2	8	21	24	35	90
Pontotoc	6	14	2	4	9	35
Pottawatomie	6	15	6	18	10	55
Pushmataha	0	4	3	4	8	19
Roger Mills	5	6	3	0	0	14
Rogers	4	19	11	23	16	73
Seminole	2	12	3	6	8	31
Sequoyah	4	5	1	6	5	21
Stephens	1	15	9	12	15	52
Texas	20	11	1	0	0	32
Tillman	12	30	5	0	1	48
Tulsa	48	61	31	70	78	288
Wagoner	6	8	7	23	34	78
Washington	3	17	8	3	10	41
Washita	17	18	9	3	0	47
Woods	11	6	2	0	0	19
Woodward	12	9	2	0	0	23
Totals - -	970	1663	846	1339	1392	
GRAND TOTAL - - - - - - -						6210

tilizers are needed in order to increase the production of Irish potatoes and alfalfa. Very few samples of soil have been secured from the upland in this county as compared with other counties in the Eastern Prairie area, and the upland samples which have been analyzed are usually very low in easily soluble phosphorus. The total area of bottom land soils is much smaller than the total area of upland soils; consequently when an equal number of samples come from the two different locations, the percentage distribution of the easily soluble phosphorus in the county may be considerably distorted. The same condition occurred in McCurtain county where only a small percentage of the total area in the county is in cultivated crops and a considerable part of the cultivated land is alluvial soil. The soils along the Red

River are high in easily soluble phosphorus and several samples of soil were secured from this area.

There are some instances, however, in the eastern part of Oklahoma where the alluvial soils are not high in easily soluble phosphorus. This is especially true in regions where the phosphorus content of the upland soil surrounding the area is very low. Although alluvial soils do not usually respond to phosphorus fertilization, tests should be made to determine their phosphorus content because a lack of available phosphorus may be the limiting factor in crop production.

The problem of phosphorus deficiency in the western part of Oklahoma may be more acute than the present experimental evidence would indicate, because of a lack of information on the effect of high alkalinity on the absorption of phosphorus by plants. However, western Oklahoma soils have a marked advantage over eastern Oklahoma soils because of the higher content of easily soluble phosphorus in the subsurface layers. Also most of the phosphorus deficiency in western Oklahoma soils can be classified as medium, while in eastern Oklahoma a high percentage of phosphorus deficient soils are classified as low and very low in easily soluble phosphorus.

Easily Soluble Phosphorus in Subsurface Soils

The factors which are important in the process of soil formation in regions of high rainfall are quite different from those which are active in an arid country. As a result of the leaching effect of water, much of the phosphorus in both the surface and subsurface soils in eastern Oklahoma has been changed from an easily soluble to a difficultly soluble form; consequently if an examination is made of a major portion of the typical soil profiles occurring in eastern Oklahoma, results very similar to the analyses from profiles secured in Haskell and Nowata counties, which are presented in Table IV, will be obtained. Where soil erosion has removed a considerable portion of the surface soil in areas where the easily soluble phosphorus content of the subsurface soil is much lower than in the surface horizon, the easily soluble phosphorus content of the soil which remains will be considerably lower than that which was present in the virgin soil before the erosion occurred. This is one very important reason why soil erosion should be reduced to a minimum on certain types of soil.

Table IV—A Comparison of Easily Soluble Phosphorus in Typical Soil Profiles in Eastern and Western Oklahoma

Sample No.	Depth of Sample in inches	Location of Profile*			
		Garfield County	Greer County	Haskell County	Nowata County
1	0- 6	88	300	20	16
2	7-12	60	220	14	6
3	13-18	72	200	4	3
4	19-24	84	200	4	2
5	25-30	88	220	4	6
6	31-36	88	200	8	12
7	37-42	96	180	4	28
8	43-48	96	280	--	40

*Data are in pounds of easily soluble phosphorus per 2,000,000 pounds of soil.

In western Oklahoma the subsoils have not been leached appreciably by gravitational water occurring from excessive rainfall and as a result the subsoil phosphorus is still in a form which can be secured rather easily by growing plants. Analyses of two soil profiles secured from Garfield and Greer counties are given in Table IV. These analyses do not mean that all

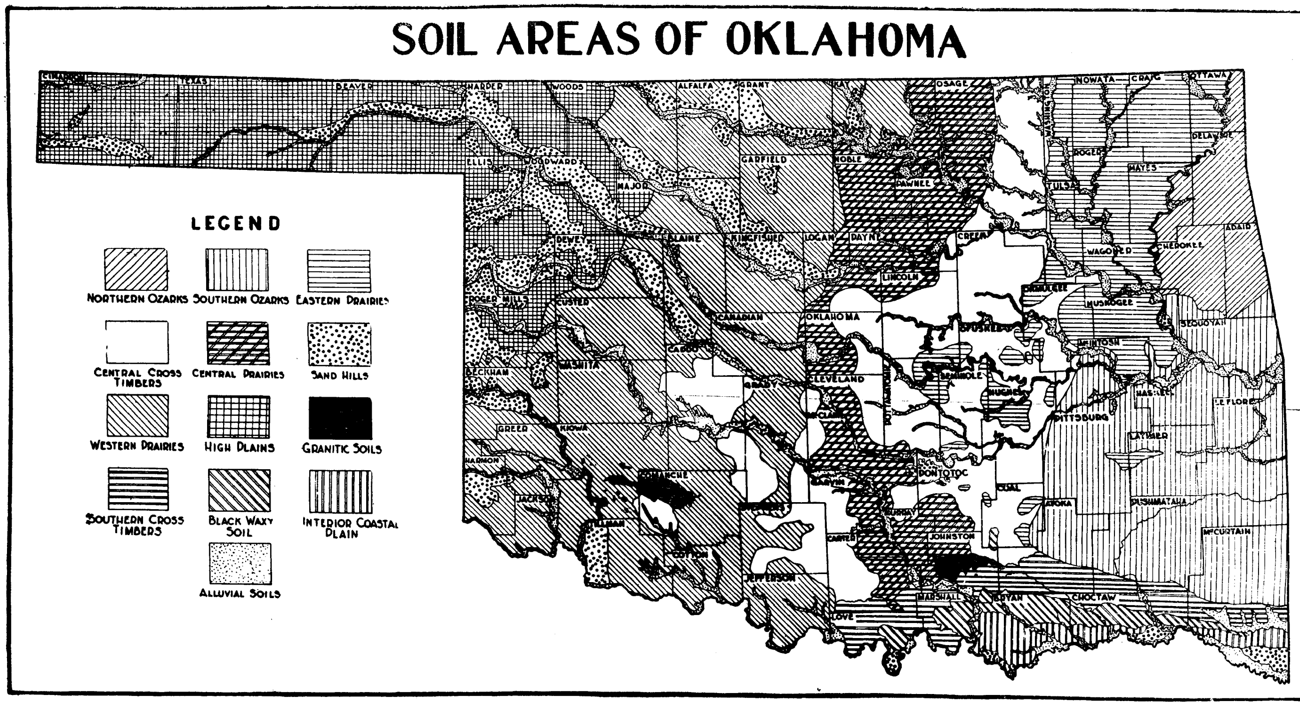

Fig. 3—Soil area map of Oklahoma showing major soil differences which have developed as a result of the combined influence of rainfall and natural vegetation (forest and prairie) on the parent materials from which the soils were formed.

western Oklahoma soils are uniformly high in easily soluble phosphorus but that the content of easily soluble phosphorus in the subsurface layers of soil does not decrease appreciably as compared with the amount of easily soluble phosphorus present in the surface soil.

In some instances the phosphorus content of the rocks from which the soil is derived plays a very important part in determining the amount of phosphorus which may be present in the soil. There are many areas in Oklahoma where the soils have not been leached by excessive rainfall during the present geological period, yet the phosphorus content of these soils is very low. This condition is present not only in soils derived from sandstone but also in case of soils derived from shale and from limestone. A map showing the different soil areas in Oklahoma which have been developed as a result of the combined influence of climatic conditions and natural forest or prairie vegetation on the parent materials from which the soils were derived is shown in Fig. 3.

A low content of easily soluble phosphorus is frequently associated with acid soil, although it is not always true that acid soils are low in easily soluble phosphorus. Since medium to strongly acid soils are usually rather low in easily soluble phosphorus, it might be assumed that soils which are not acid are high in easily soluble phosphorus. However, lack of acidity in soil cannot be correlated with a high content of easily soluble phosphorus since there are many non-acid soils in Oklahoma which contain a very small amount of both total and easily soluble phosphorus.

In order to determine the relation between the easily soluble phosphorus in surface and subsurface soils in different parts of Oklahoma over 1400 samples of surface and subsurface soils were collected and analyzed. The results of these analyses classified according to districts and the total number of soil samples secured from each county are shown in Table V. The average amount of easily soluble phosphorus which occurred in the different soils secured from each district and classified according to the data given in Table II is presented in Table VI. A graphic presentation of these data is shown in Fig. 4. A careful study of Fig. 4 will show that the surface soils are usually higher in easily soluble phosphorus than the subsurface soils. In every instance the percentage of subsurface soils which are very low in easily soluble phosphorus is much higher than the percentage of surface soils which occur in that group. This difference is due to the influence of vegetation on the process of soil formation. Grass roots penetrate the soil to a depth of several feet depending upon the kind of grass and soil conditions. Some of the phosphorus in the lower layers of soil is absorbed by the grass roots and is transferred to the leaves and stems of the plants. When the leaves and stems decay or are burned the phosphorus remains on top of the ground and is gradually mixed with the surface layer of soil due to the action of insects, worms, and rain. When soils were covered with forest under natural conditions the same condition prevailed, since the leaves fall to the surface of the ground and gradually decay and return to the surface soil the phosphorus which may have been asborbed by roots which penetrated many feet into the earth.

Table V—Geographical distribution of counties and number of samples of surface and subsurface soils secured from each county in Oklahoma

Northeast Counties		North Central Counties		Northwest Counties	
County	No. of Surface and Subsurface Samples	County	No. of Surface and Subsurface Samples	County	No. of Surface and Subsurface Samples
Adair	18	Creek	38	Alfalfa	1
Cherokee	2	Kay	24	Beaver	8
Craig	12	Lincoln	38	Blaine	18
Deleware	145	Logan	13	Canadian	13
Mayes	31	Noble	52	Cimarron	8
Muskogee	7	Okfuskee	15	Custer	19
Nowata	26	Oklahoma	72	Dewey	13
Okmulgee	26	Osage	12	Ellis	14
Ottawa	11	Pawnee	40	Garfield	33
Rogers	6	Payne	112	Grant	9
Tulsa	82			Harper	0
Wagoner	21			Kingfisher	8
Washington	10			Major	12
				Roger Mills	6
				Texas	12
				Woods	6
				Woodward	2
TOTAL	397		416		182
Southeast Counties		**South Central Counties**		**Southwest Counties**	
Atoka	14	Carter	31	Beckham	5
Bryan	2	Cleveland	11	Caddo	67
Choctaw	13	Coal	21	Comanche	3
Haskell	2	Garvin	3	Cotton	4
Latimer	14	Hughes	4	Grady	30
LeFlore	16	Johnston	14	Greer	11
McCurtain	0	Love	16	Harmon	10
McIntosh	17	Marshall	8	Jackson	6
Pittsburg	44	McClain	0	Jefferson	5
Pushmataha	0	Murray	27	Kiowa	29
Sequoyah	4	Pontotoc	1	Stephens	5
		Pottawatomie	8	Tillman	18
		Seminole	3	Washita	0
TOTAL	127		147		192

Table No. VI—Data on the easily soluble phosphorus content of surface and subsurface soils secured from different sections of Oklahoma

Easily Soluble Phosphorus	SURFACE			SUBSURFACE			SURFACE			SUBSURFACE		
	No. Samp.	Ave. Phos. in P.P.M.*	Per Cent	No. Samp.	Ave. Phos. in P.P.M.*	Per Cent	No. Samp.	Ave. Phos. in P.P.M.*	Per Cent	No. Samp.	Ave. Phos. in P.P.M.*	Per Cent
	Northwest Oklahoma						**Southwest Oklahoma**					
Very High	109	124.8	59.8	88	120.7	48.3	92	117.8	47.6	75	105.9	38.8
High	25	37.3	13.7	31	40.3	17.0	51	37.8	26.4	42	38.3	21.7
Medium	23	20.3	12.6	11	19.6	6.0	18	20.8	9.3	20	20.4	10.3
Low	10	10.9	10.4	15	10.1	8.2	19	10.3	9.8	22	10.0	11.3
Very Low	6	3.6	3.2	37	3.1	20.3	13	4.3	6.7	34	1.6	17.6
Total No. of Samples	182			182			193			193		
	North Central Oklahoma						**South Central Oklahoma**					
Very high	56	122.8	13.4	31	137.2	7.4	21	124.1	14.2	13	133.8	8.8
High	55	36.2	13.2	26	36.1	6.2	18	32.1	12.2	7	35.0	4.7
Medium	70	19.3	16.8	45	19.7	10.8	20	19.1	13.6	6	18.5	4.1
Low	126	10.7	30.2	63	9.6	15.1	44	10.0	29.9	19	10.7	12.9
Very Low	109	3.5	26.2	251	2.1	60.3	44	3.2	29.9	102	1.8	69.3
Total No. of Samples	416			416			147			147		
	Northeast Oklahoma						**Southeast Oklahoma**					
Very high	63	100.8	15.8	33	104.5	8.3	6	157.0	4.7	6	173.3	4.7
High	37	38.5	9.3	35	39.0	8.8	6	36.6	4.7	3	32.6	2.3
Medium	61	19.5	15.3	28	19.2	7.0	12	20.1	9.4	2	21.0	1.5
Low	104	10.0	26.2	58	9.5	14.6	38	9.8	29.9	22	9.4	17.3
Very Low	132	4.4	33.2	243	2.7	61.2	65	2.5	51.1	94	2.0	74.0
Total No. of Samples	397			397			127			127		

*Parts per million.

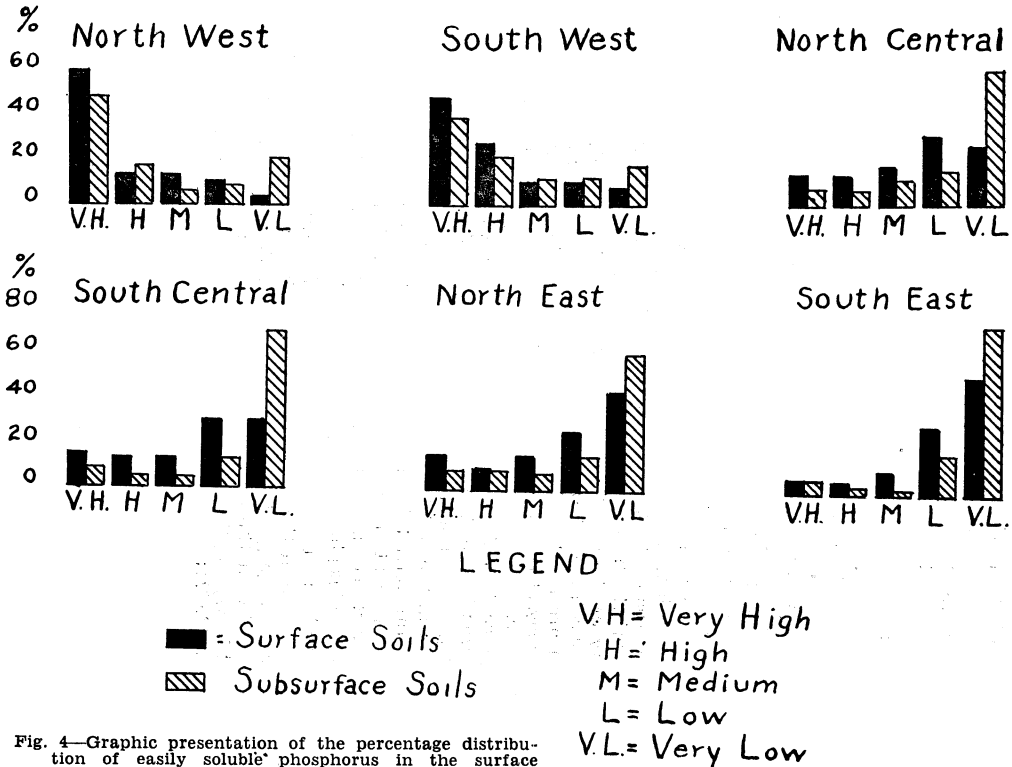

Fig. 4—Graphic presentation of the percentage distribution of easily soluble* phosphorus in the surface and subsurface soils in various sections of Oklahoma.

The surface layer of soil is not only higher than the subsurface soil in easily soluble phosphorus but it is also higher in organic matter and total nitrogen. The conservation of natural resources is an important problem and any method or methods which will reduce the losses of surface soil should be put into practice by every farmer and landowner in the state.

Effect of the Addition of Organic Matter on the Easily Soluble Phosphorus Content of Soil and Response to Fertilization

When crops are planted on soils which because of their marginal nature have not been farmed for several years, much better yields will be secured for one or two seasons if climatic conditions are favorable than were secured before the field was abandoned. An accumulation of available nitrogen in the soil as a result of nitrogen fixation by soil organisms and the growth and decay of vegetation is partly responsible for the improvement in crop growth; however, an increase in the availability of all of the important plant foods including easily soluble phosphorus will also occur when vegetation is allowed to grow and decay and crops are not removed from the soil. It has been found that sweet clover will increase the easily soluble phosphorus content of a soil if all of the organic matter produced by the growth of that crop is returned to the soil. This plant can secure phosphorus from the subsurface soil and transfer it to the stems and leaves of the plant. If the stems and leaves are returned to the soil, an increase in the easily soluble phosphorus content of the surface soil occurs from the liberation of the phosphorus which was chemically combined with the organic matter. Also the decay of the sweet clover in the soil will gradually change some of the insoluble soil phosphates into a more readily available form, especially in soils which are not too acid. Cowpeas, which do not have such a deep root system as sweet clover, are able to extract phosphorus from the insoluble phosphorus compounds in the soil. When the cowpea plant decays, the phosphorus present in the organic mater is left in a more readily available form than it was before it was taken up by the roots of the cowpea plant. Consequently plowing under legume crops will increase the availability of the phosphorus in the soil to crops which follow as a result of some phosphorus being transferred from the subsurface to the surface layers of the soil and also as a result of changes in the form and distribution of the phosphorus in the soil because of the strong feeding power of the legume crop for the insoluble phosphorus compounds present.

The application of large amounts of farm manure to soils will also produce an increase in the easily soluble phosphorus content of soil. Consequently the average garden soil is not usually deficient in easily soluble phosphorus. Data on the easily soluble phosphorus content of soils which have received heavy applications of farm manure over a long period of time are given in Table VII.

Table VII—Data on the effect of applications of farm manure on the easily soluble phosphorus content of soil

Source	Plot No.	Easily Soluble Phosphorus in parts per Million		Rate of Manure Application in Tons Per Acre Per Year
		Manured Plot	Unmanured Plot	
Oklahoma Agr. Exp. Sta.	Field "0" Plot 3	34	--	3
	Field "0" Plot 8	--	14	None
New Jersey Agr. Exp. Sta.	18A	360	--	16
	7A	--	28	None

Although crops are harvested from these plots each year and no commercial fertilizer has been applied, the easily soluble phosphorus content of the manured soil has gradually increased. This effect may be due to phosphorus added in the manure or it may be due to the effect of the solvent action and possible changes in the mineral phosphate in the soil due to the decomposition of the organic matter in the manure.

Crops for Phosphorus Deficient Soils

A very important factor which should not be neglected in planning a rotation system is the variation which occurs in the feeding power of plants. During periods when agricultural prices are relatively low and much of the land is marginal in nature, farmers are not in a position to purchase large quantities of fertilizer; consequently an individual should know something about the relative ability of a plant to secure insoluble plant food in order to reduce the possibility of crop failure to a minimum. Many farmers frequently make the statement that certain crops are "hard" on land. This is especially true when a crop which has a strong feeding power is grown and all of the grain and most of the forage is removed from the soil. Good examples of this condition are wheat following soybeans and small grain following kafir, especially on soil which is relatively low in available plant food. Kafir does not have a harmful effect on crop growth when it is planted on a good soil except as it may reduce the moisture content of the subsoil to a point where a lack of moisture may be a limiting factor in the yield of the succeeding crop, especially during seasons of low rainfall. On poor soils, the grain sorghums reduce the amount of the nitrogen which is available for the following crop unless a considerable period elapses between the time the grain sorghum crop is plowed under and the subsequent crop is planted. Cotton and legume crops are the best crops to use in a rotation following grain sorghums.

Grain sorghums and cotton are two of the last crops which are planted upon land before it is abandoned; consequently two of the best crops to grow on relatively poor soils are grain sorghums and cotton. In order to keep up the nitrogen content of the soil, cowpeas should be utilized since this crop is also a very strong feeder for the insoluble plant foods in the soil. If alfalfa, wheat, or corn is included in a kafir, cotton, cowpea rotation, the results secured on poor soil will be unsatisfactory because of the fact that alfalfa, wheat, and corn are not able to compete with such crops as cotton, kafir, and cowpeas from the standpoint of their ability to secure insoluble plant foods such as phosphorus from the soil minerals. Hairy vetch is another legume which will make a fair growth on soils which do not contain a good supply of easily soluble phosphorus although it does respond to phosphorus fertilization. This crop offers many possibilities from the standpoint of soil improvement at a low cost per acre, since it will continue to produce a crop year after year under favorable climatic conditions if each crop is allowed to mature seed. This is especially important from the standpoint of building up the nitrogen and organic matter content of abandoned land.

Early Growth and Maturity as Affected by Easily Soluble Phosphorus in Soils

Phosphorus is very important in the process of cell division; consequently plants which have been fertilized with phosphorus, especially when grown on soils which are deficient in this particular plant food, develop much more rapidly than unfertilized plants grown on the same soil. This is due partially to a more rapid extension of the root system and as a result larger quantities of plant food are absorbed, which in turn increases the number and size of the leaves and stems which appear above the surface of the ground. When legume crops are being grown, phosphorus fertilization increases the fixation of nitrogen when the roots of these plants are well inoculated because the addition of the fertilizer increases the total yield of the crop. Consequently the addition of phosphorus to legume crops grown on phosphorus deficient soils is an important factor in increasing the nitrogen and organic matter content of the soil when legume crops are being grown for soil improvement.

SUMMARY

A study of the easily soluble phosphorus content of Oklahoma soils was made in order to secure information concerning the relation between phosphorus deficiency in soils and crop production.

Over 6,200 surface soils and more than 1400 subsurface soils were collected and analyzed for easily soluble phosphorus by extraction with fifth normal sulfuric acid. The samples were classified by counties and were divided into five groups as follows: Very low, low, medium, high, and very high in easily soluble phosphorus.

The easily soluble phosphorus content of soils secured from many different fertilizer experiments located in Oklahoma and in other states was correlated with crop response obtained from phosphorus fertilization and the data were used as a basis for classifying the samples of soil secured from different counties in Oklahoma.

More than 50 per cent of the soils in eastern Oklahoma contain less than 50 pounds of easily soluble phosphorus per acre and in many communities a profitable agricultural industry cannot be developed without the liberal use of this important plant food.

Although many soils in western Oklahoma were classified as deficient in the easily soluble phosphorus, most of those soils were only medium deficient; while a very high percentage of the phosphorus deficiency in eastern Oklahoma was classified as low and very low in easily soluble phosphorus.

Bottom land soils are higher in easily soluble phosphorus than the adjacent upland soils in most cases and usually do not respond to phosphorus fertilization; although there are some areas in Oklahoma where bottom land soils have been derived from the rapid erosion of phosphorus deficient soils from the adjacent uplands and are very low in easily soluble phosphorus. The easily soluble phosphorus content of bottom land soils along the larger streams in eastern Oklahoma which orginate in regions of low rainfall are usually high in easily soluble phosphorus.

In some soils a high content of organic phosphorus may affect the response secured from phosphate fertilizers applied to soils low in phosphorus soluble in dilute acid.

Subsurface soils are not as high in easily soluble phosphorus as surface soils. The difference between the easily soluble phosphorus content in the subsurface and surface soils in western Oklahoma is not as important from the standpoint of phosphorus availability and crop production as it is in

eastern Oklahoma. Many subsurface soils in eastern Oklahoma are extremely low in easily soluble phosphorus and the removal of the surface soil by erosion leaves a very infertile soil which has a very low capacity for crop production.

The easily soluble phosphorus content of the surface soil can be increased by turning under legumes and the addition of farm manure. Garden soils which have been heavily fertilized with farm manure are usually high in easily soluble phosphorus.

A study was made of the ability of different crops to obtain phosphorus from soils containing varying amounts of soluble phosphorus. With the exception of alfalfa the legumes commonly grown in Oklahoma are more vigorous feeders on the insoluble phosphorus compounds in the soil than crops like corn, wheat, oats, and barley. Grain sorghums can grow on soils very low in easily soluble phosphorus.

The early growth of crops is affected by the amount of easily soluble phosphorus in the soil because phosphorus is essential for cell division.

An appendix has been included which gives information concerning sources of phosphate fertilizers, a list of fertilizer distributors, and a discussion of the proper methods for fertilizer application. Recommendations have also been given for the fertilization of crops when grown on phosphorus deficient soils and a method has been suggested in order to secure accurate samples of soil for analysis.

APPENDIX

Sources of Phosphate Fertilizers

The use of fertilizer is relatively new in the major portion of Oklahoma; consequently in many communities fertilizer cannot be purchased because local dealers do not handle it. In order to secure small amounts of fertilizer for experimental use, it is frequently necessary for farmers to secure fertilizer from some other place. A list of fertilizer companies registered to sell fertilizer in Oklahoma for the season 1931-32 is given in Table VIII. Farmers or other individuals interested in the purchase of phosphate fertilizers can write to any of these companies and secure information in regard to their nearest local dealer. Most of these companies sell superphosphate and mixed fertilizers. Companies which do not sell superphosphate and mixed fertilizers are indicated and the fertilizer which they distribute is given in a footnote at the bottom of the table.

The cost of the same kind of fertilizer secured from different companies is approximately the same except for the possibility of differences in freight rates. Freight charges are usually paid by the company from which the fertilizer is ordered when fertilizer is shipped in carload lots.

The sale of phosphate fertilizer is regulated by law, and fertilizer samples are collected and analyzed by the Oklahoma State Board of Agriculture to determine whether the analysis of the fertilizer is the same as that which is printed on the fertilizer sack. In most cases fertilizers are manufactured by reliable companies and the amount of plant food specified on the fertilizer tag which is attached to each sack is frequently slightly less than the total amount actually present.

Table VIII—Fertilizer Manufacturers Operating in Oklahoma

American Agricultural Chemical Co.	National Stock Yards	East St. Louis, Mo.
American Cyanamid Co.	535 Fifth Avenue	New York, N. Y.
Armour's Fertilizer Works		New Orleans, La. Nashville, Tenn. Houston, Texas
Arkansas Fertilizer Co.	Box 945	Little Rock, Ark.
Chilean Nitrate Sales Corp.*	120 Broadway	New York, N. Y.
Ford Motor Co.**		Dearborn, Mich.
Ft. Smith Cotton Oil Co.		Ft. Smith, Ark.
Gate City Fertilizer Co.	Box 945	Little Rock, Ark.
Hope Fertilizer Co.		Hope, Ark.
International Agri. Corp.		Texarkana, Ark.
Keefe-Le Stourgeon Co.		Arkansas City, Kans.
Meridian Fertilizer Factory		Shreveport, La.
Newhouse Chemical & supply Co		
N. V. Potash Export My., Inc.***		New York, N. Y.
Pate Bros. Fertilizer Works		Sulphur Springs, Tex.
Ruhm Phosphate & Chemical Co.****		Mt. Pleasant, Tenn.
Smith Agri. Chemical Co.		Columbus, Ohio
Swift & Company Fertilizer Works		St. Louis, Mo. Shreveport, La. National Stock Yards, Illinois
Synthetic Nitrogen Products Corp.		New York, N. Y.
Stumpp & Walter Co.		New York, N. Y.
Temple Cotton Oil Co.		N. Little Rock, Ark.
Tennessee Corporation		Lockland, Ohio
Thomson Phosphate Co.****		Chicago, Ill.
Virginia-Carolina Chemical Corp.		Shreveport, La. and Memphis, Tenn.
Wilson & Co.		Oklahoma City, Okla.

*Distribute nitrate of soda.
**Distribute ammonium sulfate.
***Distribute potash fertilizers.
****Distribute finely ground rock phosphate.

Fertilizer Distributors

The proper application of fertilizers in order to secure the most effective use of plant food in them is an important economical problem. The machinery for distribution is always absent in areas where commercial fertilizer has not been used, and frequently crops do not secure a maximum benefit from the use of fertilizer because it is not applied so the plant roots can come in contact with it. Fertilizers which are applied broadcast to row crops can not be utilized by the growing crop as effectively as fertilizers which are properly applied in the row near the seed at the time of planting. This is especially true in seasons of relatively low rainfall; and when the fertilizer has not been thoroughly mixed with the soil or when soils have a high capacity for the fixation of phosphorus in forms which are not available for plants. In fertilizing small grain, a grain drill with fertilizer attachment is the most satisfactory method of applying fertilizer to the soil.

Fertilizer can be applied with the seed in case of crops like oats and wheat and no injury will occur to the young plants when ordinary rates of application are used. When fertilizers are applied in the row to crops such as cotton or corn, the relative concentration of the fertilizer is increased appreciably as compared with small grain in which the rows are only seven or eight inches apart. If the fertilizer is applied so that some soil occurs between the fertilizer and the seed, no harmful effect on the germination of the seed and growth of the young plants will occur, unless the rate of fertilization exceeds four or five hundred pounds per acre and the fertilizer is high in soluble nitrogen and potash-salts. Fertilizers are most toxic to young plants during periods of low rainfall, and this effect is usually more pronounced on sandy soil. Superphosphate does not cause injury to the growth of plants, although it may retard germination when placed in contact with the seed if the amount of capillary moisture in the soil is low. Mixed fertilizers containing soluble nitrogen and potash salts are very toxic to young plants if applied so that they come in contact with the seed or in contact with the young plant just as the roots and stem begin to develop.

Fertilizer distributors can be secured which apply the fertilizer in the row so that it does not come in contact with the seed or any part of the young plant during the early stages of growth, and this factor should be considered in purchasing a fertilizer distributor. Whether the fertilizer should be applied before planting or at the time the crop is planted will depend upon several factors. Frequently the time available for planting is short, if weather conditions are not favorable, and the individual who applies the fertilizer and plants the seed in one operation is concentrating a large amount of work into a short period of time.

With the tendency toward the use of fertilizers containing a higher percentage of the different plant foods, such as treble superphosphate and the ammonium phosphates, and also considering the fact that the cost of production can be lowered if the fertilizer can be applied at the same time the crop is planted, the amount and cost of labor available and the type of the cropping system may be important factors in determining the method which should be used in applying the fertilizer to the soil.

Recommendations for the Fertilization of Crops

Although there are many problems in regard to the fertilization of different crops in various parts of Oklahoma which have not been studied, the following recommendations have been prepared from the experimental data which are available at the present time. The rate and method for the fertilization of crops grown on phosphorus deficient soils in Oklahoma are as follows:

Alfalfa: Broadcast annually 150 to 200 pounds of superphosphate on each acre about March 1 to March 15. If fertilizer is applied before the seed is planted, harrow or disc it into the soil. The fertilization of alfalfa with farm manure and superphosphate is also recommended. If the soil is acid, lime may be needed to neutralize the acidity. It should be applied and thoroughly worked into the soil before the alfalfa is seeded.

Corn: On soils which produce a good growth of stalks 100 to 150 pounds of superphosphate should be applied in the row at time of planting. In case of poor soils, eitther a complete fertilizer such as a 4-12-4 should be applied in the row at the rate of 300 pounds per acre or a legume rotation should be followed and superphosphate applied annually to the corn crop except in areas where cotton is fertilized heavily and is grown in a rotation with corn.

Cotton: Under average conditions 300 pounds of a 4-12-4 fertilizer applied in the row at time of planting will give good results. Where soils contain a good supply of available organic matter and produce on the average 1000 pounds of seed cotton per acre, the use of fertilizer in central and western Oklahoma cannot be recommended because of the frequent limiting effect of dry weather on crop production.

Sweet Clover: Apply 300 to 400 pounds of either rock phosphate or superphosphate and work the fertilizer into the soil at the time the sweet clover is planted. Apply lime if the soil is acid. If a combination grain drill with fertilizer distributor is available, smaller amounts of phosphate fertilizer can be applied at the same time the sweet clover seed is drilled into the soil.

Wheat: Nitrogen is an important limiting factor in wheat production and must be supplied in order to maintain or increase the yields of all crops except the legumes. On most soils which are considered wheat soils, 150 pounds of superphosphate drilled with the seed at time of planting will produce a marked increase in the growth and yield of wheat if the available nitrogen content of the soil is not a limiting factor in crop production.

Other crops such as oats, cowpeas, soybeans, and grain sorghums in most cases will be grown in rotation with alfalfa, corn, cotton, sweet clover, or wheat and will be able to secure some phosphorus from the residual effect of fertilizers applied to those crops.

Procedure Recommended in Order to Obtain Accurate Samples of Soil for Analysis

The results secured from a chemical analysis of a soil are of little value unless a soil sample is obtained which acurately represents the soil conditions as they exist in the field. The following method should be used in order to secure accurate samples of soil:

Divide the area or field into different soil types if any variation in the character of the soil occurs. Secure surface samples of soil from six or seven different places in each area and mix these samples together. The total amount of soil secured should be about one pint. No samples should be taken near a fence row or from any spot which appears to be poorer or better than the average for that particular type of soil.

Secure samples of subsurface soil in at least three different places in each soil area and mix them together. About one pint of subsurface soil should be secured. These samples should be taken about 12 to 15 inches deep. It is unnecessary to sample eroded areas since the analysis of the subsoil will be a good indication of conditions existing on the eroded land. Label all samples as follows: Surface No. 1, Subsurface No. 1; Surface No. 2, Subsurface No. 2; etc., so that they can easily be identified. The name of the person who secured the sample and the owner of the farm should also be attached to each sample. Samples can be analyzed for acidity and easily soluble phosphorus by county agents and Smith-Hughes teachers, or they can be sent to the Oklahoma A. and M. College, at Stillwater.