THE UNIVERSITY OF ARIZONA

College of Agriculture and Life Sciences
Extension Publications

The Extension Publications collections in the UA Campus Repository are comprised of both current and historical agricultural extension documents from the College of Agriculture and Life Sciences at the University of Arizona.

This item is archived to preserve the historical record. This item may contain outdated information and is not intended to be used as current best practice.

Current extension publications can be found in both the UA Campus Repository, and on the CALS Publications website, http://cals.arizona.edu/pubs/

If you have questions about any materials from the College of Agriculture and Life Sciences collections, please contact CALS Publications by sending an email to: pubs@cals.arizona.edu

Extension Circular No. 80 October, 1933

University of Arizona
COLLEGE OF AGRICULTURE
AGRICULTURAL EXTENSION SERVICE

FERTILIZERS FOR ARIZONA SOILS

by

W. T. McGeorge

Published by
University of Arizona
Tucson, Arizona

University of Arizona

COLLEGE OF AGRICULTURE

AGRICULTURAL EXTENSION SERVICE

P. H. ROSS, Director

Cooperative Extension Work in Agriculture and Home Economics, the University of Arizona College of Agriculture and the United States Department of Agriculture cooperating. Distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914.

CONTENTS

FERTILIZERS FOR ARIZONA SOILS

By

W. T. McGeorge
Agricultural Chemist
Arizona Agricultural Experiment Station

INTRODUCTION

This bulletin has been prepared in order to acquaint the farmer with the different fertilizer materials, the practice of fertilization, and the soil investigations being conducted at the Arizona Agricultural Experiment Station which are directly related to the fertilization of Arizona soils. When a farmer buys fertilizer he does so with the intention of increasing the yield or quality of his crop to such an extent that not only the cost of the fertilizer will be returned but also a profit. The dominant question then is whether the time is ripe for the Arizona farmer to turn his thoughts toward commercial fertilizer.

A most instructive discussion, which has some bearing upon this, is given in the last report of the Secretary of the National Fertilizer Association. To quote from this report—

> "Taking the Eastern half of the United States as a whole there was a decrease of 32,000,000 acres between 1919 and 1929 in the acreage of all crops harvested. During the same period the acreage of all crops harvested in the Western half of the country increased about 33,000,000 acres. From this it appears that there was an actual shift of between 30,000,000 and 31,000,000 acre production from the East to the West during this decade. Harvested acreage of all crops in the East decreased 20 percent."

Thus there has been an amazing shift from fertilizer-using to non-fertilizer-using lands, and during this time there has been an actual increase in harvested crops. To quote further—

> "Over 75 percent of commercial fertilizer is used by four crops, cotton, corn, wheat, and potatoes. 16,238,000 acres of corn and wheat have moved from fertilizer-using to non-fertilizer-using territory and for cotton there has been an increase of 7,150,000 acres in non-fertilizer-using territory."

Soil exhaustion and the vital role of fertilizers in the agriculture of the South and East is common knowledge to us all. The above quotations are food for speculation on how long the natural reserves of the new non-fertilizer-using lands of the West will supply the crops requirements. Already the beet growers of Colorado and Nebraska have become heavy users of phosphates, and Utah beet growers are following suit, while consumption of fertilizer in the Pacific Coast States is increasing rapidly.

Evidence certainly indicates that the time is near for the Arizona farmer to acquaint himself with developments in crop fertilization, and the following is offered with this thought in mind.

COMMERCIAL FERTILIZERS

For many centuries it has been known that various waste materials when added to soils will tend to improve their productivity. The manner in which they react toward plants was not discovered until about a century ago when it was found that plants extracted mineral materials from the soil and that these stimulated growth just as the foods consumed by animals. Today it is well known that crop yields will eventually become unsatisfactory unless some systematic plan of fertilization or soil maintenance is adopted.

It is a comparatively simple matter to make chemical analyses of plants and to determine just what materials the crop has removed from the soil, and then to decide which of them become exhausted most rapidly. Following this procedure it was found that nitrogen, potassium, and phosphate seemed to be needed most of all, and from this discovery the commercial fertilizer industry grew. Its history is divided into three important epochs: first, the organic period in which only animal manures and plant refuse were utilized; second, the mineral period in which nitrogen, potash, and phosphate (natural) minerals gained a footing; and finally, the third or present "synthetic" period in which manufactured products are gradually displacing most of the mineral and organic materials.

The three outstanding discoveries on which the present fertilizer industry is based were the invention of a process for manufacturing superphosphate which occurred about 1840, the discovery of the potash-salt mines at Strassfurt, Germany, about 1860, and the discovery of the nitrate deposits of Chile about 1830.

Of these three products the manufacture of superphosphate is of greatest interest because it marks the first step in commercial processes for increasing the availability of mineral materials before adding them to the soil. Both bone and mineral phosphate-rock are very insoluble forms of phosphate, and the discovery that by treating them with sulphuric acid they were converted into more efficient fertilizers immediately placed the industry on a sound footing. Superphosphate is today the most important manufactured product of the fertilizer industry.

There eventually comes a time when every farmer, in a given district or area, must resort to the use of commercial fertilizer if good crops are to be produced continuously. Until about 30 years ago, soil exhaustion was not considered a serious problem. Exhausted lands were simply abandoned for more fertile virgin lands. But the era of pioneering is ended and now every farmer must take stock of the food capacity and life of his soil, and inevitably he must put back into the soil the plant food which is removed by his crops.

The list of materials used in compounding commercial fertilizers is so great that it is often confusing to select the most satisfactory ones. All have a certain but limited value. They are most effective when applied under rather definite soil conditions or according to plant preferences. A material which yields a profit on one man's land may be entirely unsuited to his neighbor's.

Fertilizer language. The fertilizer trade has adopted a number of terms which are in common usage but not entirely understood by the farmer. Nitrogen is sometimes designated by the symbol N and other times as the symbol NH_3. The latter is three parts hydrogen and one part nitrogen and known as ammonia. Either form may appear on the label of the bag. Phosphorus is expressed by the symbol P but is usually marked on the bag as P_2O_5 (phosphoric acid). Potassium with the symbol K (from the Latin word kalium), usually spoken of as potash (K_2O), and printed on the bags as K_2O, is the third important constituent of fertilizers. There is no valid reason for using the terms phosphoric acid and potash rather than phosphorus and potassium, but common usage for many years makes a change difficult.

The amounts of each of these ingredients in fertilizers varies over wide limits and the fertilizer formula is usually simplified by expression in numbers. For example a "3-8-10 fertilizer," in practically all States, means 3% nitrogen (N), 8% phosphoric acid (P_2O_5) and 10% potash (K_2O). An effort is being made to have this numerical method of expression uniform in all states and with very few exceptions this has been accomplished.

PHOSPHATE MATERIALS

Bone. Bone has been used as phosphate fertilizer for a longer period than any other substance. At one time it represented practically the only source of phosphate but this is now of minor importance. "Spent" bone black from sugar refineries is also useful.

Basic Slag. The iron ores of Europe yield a slag which contains quite a large amount of phosphate and under the name of basic slag is extensively used in Europe as a phosphate fertilizer. It finds little or no use in the United States.

Phosphate Rock. Raw phosphate rock, the natural mineral form of phosphate, occurs in large quantities in the United States and is extensively used in the raw form as a fertilizer after having been finely ground.

Superphosphate. On treating raw phosphate rock with sulphuric acid a product known as superphosphate is obtained. It contains about 17% phosphoric acid in a much more available form than in the raw mineral state.

Double superphosphate. This material is also sometimes called triple or treble superphosphate. It is manufactured by treating the mineral phosphate rock with liquid phosphoric acid instead of sulphuric acid as in ordinary superphosphate. It contains 40% water soluble phosphoric acid (P_2O_5), and is finding extensive use.

Ammonium phosphate. Since the invention of methods for artificially fixing the gaseous nitrogen of the air, the cost of ammonia has been very greatly reduced and is being offered to the farmer as ammonium phosphate. This is made by mixing liquid phosphoric acid and ammonia. The material is marketed under the trade name "Ammo-Phos" and may be obtained in a form which contains 46% phosphoric acid (P_2O_5), all of which is soluble in water. This high solubility makes the product a very popular one.

Several less important sources of phosphate include guano, tankage and ammoniated superphosphate. The latter should not be confused with "Ammo-Phos" as it contains only a small percentage of ammonia which ordinary superphosphate will absorb when exposed to ammonia gas.

POTASH MATERIALS

Before the discovery of potash-salt mines, wood ashes were the principal source of potash for fertilizer, but this finds little use at the present time. Potash salts are similar in appearance to common salt and are quickly available to the crop. The two principal salts are the chloride, sometimes called muriate, and the sulphate. They contain from 10% to 60% potash (K_2O), according to how well the crude materials have been refined. About five-sixths of the potash fertilizer used in the United States is imported from Europe, but large quantities are now being supplied from the salt brines of Searles Lake in California and a newly discovered mine near Carlsbad, N. M. Potash salts are all very readily soluble in water but are fixed or absorbed by soils and thus prevented from serious loss in the drainage water.

NITROGEN MATERIALS

Organic materials. The supply of materials carrying organic nitrogen is extremely limited and is now largely used in stock feeds. It includes tankage, dried blood, cottonseed meal, fish scrap, and a number of similar materials. Such waste products as hoof meal, leather, hair and feathers, although high in nitrogen, are not of any value unless chemically processed before applying to the soil. Nitrogen in organic forms is more costly than in mineral forms.

Nitrate of soda. This is a salt which occurs in vast quantities in the rainless desert of Chile and up until a few years ago was the main source of nitrogen for fertilizers. It is completely soluble in water and immediately available to crops.

Ammonia salts. In the manufacture of coke from coal large quantities of ammonia are given off in the gases and can be very easily recovered. For many years, this ammonia has been used for the manufacture of ammonium sulphate for fertilizer. It is a very satisfactory form of nitrogen for plants. Most crops cannot use ammonia directly. It must be changed to nitrate before the plants can absorb it. This change is brought about very rapidly in soils by soil bacteria.

Ammonium salts are now being manufactured from the nitrogen of the air. Air contains about 80% nitrogen. The methods used in extracting nitrogen from the air are so efficient that the cost of ammonium salts has dropped to a point that makes them a strong competitor of nitrate of soda.

Cyanamid. This material is sometimes known as lime nitrogen and is a combination of lime and nitrogen from the air. It finds considerable use on acid or lime deficient soils, but is a somewhat less available form than ammonium sulphate or nitrate of soda.

Lime nitrate. Many farmers object to the use of nitrate of soda because of the sodium in it. Nitrate is now available in the form of lime nitrate which obviates this objection. This substance is immediately available to the crop and has the added value of improving the soil texture. The principal objection to its use is that it absorbs water very quickly from the air and is therefore difficult to handle.

Other nitrogen materials include potash nitrate, and commercial (synthetic) urea which is a very available form of organic nitrogen. Urea is the nitrogenous constituent of animal manure.

The composition of some of the important materials used as fertilizers or in the manufacture of mixed fertilizers is shown in the following table.

TABLE I. Composition of some important fertilized materials.

	Nitrogen %N	Phos. Acid $\%P_2O_5$	Potash $\%K_2O$
Bone	1.6-4	20-25	0
Superphosphate	0	14-20	0
Double superphosphate	0	40-50	0
Muriate of potash	0	0	50-60
Sulphate of potash	0	0	48-50
Sulphate of ammonia	20-21	0	0
Nitrate of soda	15-16	0	0
Nitrate of lime	15-16	0	0
Nitrate of ammonia	33-35	0	0
Cyanamid	20-25	0	0
Urea	46	0	0
Cottonseed meal	5-7	2-3	1.5-2
Dried blood	9-14	0	0
Tankage	5-10	3-14	0
Ammo-Phos	11-16	20-46	0

THE FERTILIZER INDUSTRY

The world's consumption of fertilizer, according to late figures, is approximately 45,000,000 tons, of which the United States consumes 20% and is the second largest consumer. Germany is the largest consumer while France is third. It is of interest that China and India, the two most thickly populated countries of the globe, use practically no commercial fertilizer. Of the 45,000,000 tons of fertilizer used, about one-half is phosphate, namely 17,000,000 tons superphosphate and 6,000,000 tons of bone and basic slag. Nitrogen comes second with about 10,000,000 tons, and potash third with 6,000,000 tons. In dollars and cents, the world spends approximately $600,000,000 per year for fertilizer.

Of the 8,000,000 tons of fertilizer used in the United States nearly 6,000,000 tons are used by the farmers of the thirteen Southern States, while slightly less than 200,000 tons are used by the eleven Western States, and most of this is in California, Washington and Oregon.

Some additional statistics, from the *Yearbook of the American Fertilizer Industry,* concerning Arizona, show that on a basis of 636,000 acres of cropped land our fertilizer consumption is 3 pounds per acre. Assuming the value of our farm products as $40,000,000, it is shown that Arizona's fertilizer expenditure is 81 cents per $1,000 of crop value. Inevitably this will increase and the soil investigations at the University of Arizona are being conducted with a view toward getting the greatest possible returns from commercial fertilization.

DETERMINING THE FERTILIZER REQUIREMENTS OF SOILS

Soil analysis. It is a relatively simple matter to analyse a soil and find out exactly how much nitrogen, potash and phosphate it contains, so naturally this was the first method used by chemists in attempting to estimate the fertilizer needs of a soil. It was not long before they found that advice based on such analyses was faulty. This was due to the fact that plants did not have the strong acids to use which the chemist was using on soils in his laboratory, and thus an attempt was made to determine the weak acids present in plants and to imitate the plants by using these. This procedure was more satisfactory and in many sections of the world agricultural chemists are using these very weak acids to estimate the fertilizer requirements of soils. On some soils and with some crops the method is very reliable, but in many cases it is not. It is least successful with high-lime soils such as we have in Arizona.

The latest development in chemical methods is that of field kits by means of which anyone, after a little experience, can make tests in the field for nitrate, potash, phosphate and lime requirements of soils. These kits are finding extensive application in many farming districts but cannot be used for all soil types. No chemical method is universally applicable to all types of soil, and so the chemist must confine his recommendations to suggestions rather than definite statements.

Analyses of plants. Another method of estimating fertilizer requirement, which has been extensively used by field men, is to determine the yield per acre of a crop and then analyse a sample of the crop to determine the actual amount of plant food which the crop has removed from the soil. While this is a laborious process, it is a sound policy to follow for it is based on the theory that a farmer should put back into the soil that which is removed in the crop, thus avoiding soil exhaustion. Crops have greatly different feeding properties and plant food requirements which are affected by climatic conditions. So while the analysis of the crop is of great value it still lacks exactness for making a definite fertilizer recommendation of more than local value.

Plant symptoms. Plants have a language and, to the farmer who is a close observer, the behavior of a crop will often disclose much regarding its needs. An excess or deficiency of nitrogen, potash, phosphate, lime, etc., will usually affect crops by manifestations which are readily recognizable. Actual cases are known to the writer where fertilizer applications are based largely upon crop behavior and appearance; in other words, by learning the language of the crop. Such a system is highly commendable because it develops a keen sense of observation in the farmer and makes him an effective thinker. Symptoms differ for different crops so the method requires much close study.

Pot tests. The farmers of Germany, who are the heaviest users of fertilizer in the world, base their fertilizer applications largely on pot tests. A small amount of soil is taken from the field, placed in pots and tested with different kinds and amounts of fertilizer. The idea of *asking the plant* by means of a pot test is based on sound principles, and if the soil is representative and is placed in the pots in such a manner as to represent true field conditions a very accurate interpretation can be made from such tests.

Field plot trials. Field plot experiments are usually considered the final answer in a fertilizer test but are quite expensive because of the number of repetitions which are necessary. They are often carried continuously as a part of a cropping system so that a grower may have a continuous check on the performance of his soil.

So, in answer to the question of determining the fertilizer needs of a soil, it may be said that an exact answer is difficult to obtain, but with the several methods just described a very close approximation can usually be made.

THE AMOUNT OF FERTILIZER TO APPLY

This is governed both by the limit of profit and the limit of tolerance of the crop. Some of the questions which arise in this connection are: Where is the peak of application at which maximum yield can be obtained without injury to the crop? What is the maximum than can be applied without loss? What amount of fertilizer will yield the highest profit per acre, or what amount will supply the crop and still maintain soil fertility?

These questions can be answered only by field experiments. It is possible for a plant to absorb more food from the soil than it needs for normal growth. This is usually referred to as luxury consumption. If the amount absorbed exceeds a certain limit, which varies for different crops, the quality or quantity of the crop may be reduced. In fact, injury from over-fertilization is not uncommon. It rarely happens with phosphates as this form of plant food is rapidily fixed by the soil and thus removed from the soil solution. On the other hand, since this is less true for potash and not true at all for nitrate, injury from over-fertilization is usually from one or both of the latter mentioned foods.

If a soil is deficient in any plant food material, there will be a progressive increase in yield of crop with increase in amount of fertilizer used. This increase in yield is quite rapid at first and the profit great up to a certain point. Beyond this point the increase in yield will be too low to pay for the extra amount of fertilizer required and will not therefore represent a profit. Beyond the range of unprofitable increase in yield, additional amounts of fertilizer will reduce yields. The amount of fertilizer to apply is indeed an important question.

In the case of nitrates, over-fertilization will usually mean a loss of nitrate in the drainage as this material is readily leached from soils. This may happen to a slight extent with potash but not at all with phosphate.

HOW FERTILIZERS INFLUENCE CROPS

The main purpose in the use of fertilizer, and usually the first thing desired, is an increase in yield of crop. But this is only half the story. Quality of crop is just as important as quantity, and often more desirable. So in fertilizing one should not sacrifice quality for quantity. The effect, then, of the various fertilizer materials on crops is of interest.

Nitrogen. Nitrogen is needed by the plant to produce vegetative growth. When a plant is suffering from nitrogen starvation it is usually stunted in growth and the leaves have a yellowish-green color in contrast to the dark green color of a well nourished plant. Trees suffering from nitrogen starvation will shed their leaves early and the lateral buds may die. On the other hand, if the plant is getting too much nitrogen there may be too great a vegetative growth in comparison to fruiting, and the maturity of the crop will be delayed. Then, again, if plants receive too much nitrogen the leaves tend to become soft and thus an easy prey to insects and many plant diseases. The intelligent use of nitrogen fertilizer is therefore necessary to influence the maturity, quality, and insect or disease resistance, as well as to increase yields.

Phosphate. Different plants vary in their sensitiveness to phosphate starvation. On the whole, evidence of this is shown by a stunted growth accompanied by little or no change in color of leaves. Phosphate greatly stimulates the development of both lateral and fibrous roots. It is most effective in heavy clay soils where root growth is restricted by the mechanical condition of the soil. Sandy soils less often require phosphates than clay soils.

Root crops, such as beets and turnips, demand a large amount of phosphate and make poor growth where phosphate is deficient. Leaf crops, such as lettuce and cabbage, develop firmness when amply supplied with phosphate. In the grains phosphate induces tillering and heavy seed production. One important property of phosphate is to hasten the maturity of crops. Phosphate also greatly stimulates the activities of soil bacteria which are very essential in fertile soils. If phosphate is deficient there is often serious competition between the soil bacteria and plants for this essential food material.

Phosphate is a bone builder in animals and phosphate starvation of crops may therefore be far reaching. By phosphate fertilization the phosphate content of forage crops can be increased. Phosphate-deficient feeds lead to deficiency diseases in animals, and such a deficiency even in range grasses is often shown by animals, in pasture, devouring bones. The animal instinct may sometimes be used in detecting phosphate deficiencies.

Potassium (potash). Potassium seems to be related in some mysterious manner with the operations of the tiny factory in the leaf which manufactures sugar. A deficiency of potassium therefore often shows itself by a reduction in the sugar content of the plant. A balance between potash and nitrogen seems to be essential as neither gives its full effect without the other being present in proper amounts. In most plants potash starvation is shown by a premature death or drying of the leaves. This is often referred to as marginal firing as the leaves begin to die or dry at the outer edges and it works inward. Potash imparts a resistance in plants to many diseases. In England, for example, wheat is less attacked by rust when fertilized with potash and tomatoes are less attacked by streak disease. Potash starved plants often fail to reach maturity. Potash is most abundant in the leaves and when an old leaf begins to dry up the potash will be moved to the newer leaves where it is used again.

There is no evidence as yet that Arizona soils are in need of potash fertilizers. We know of no cases where it has given any response in the field and in pot tests at the Experiment Station it has shown no response. Arizona soils are on the whole well supplied with potash.

THE KIND OF FERTILIZER TO USE

In the early days of the fertilizer industry a commercial fertilizer was often largely sand or some other inert filler material. Many mixed fertilizers contained not more than 5% actual plant food and the rest was filler on which the farmer paid the freight. Thanks to progress, fertilizer laws, and the education of the farmer, those days are past and the market is now stocked with materials which represent true values. There is no reason why a buyer should not have a full knowledge of what he is buying. Thus even in a state such as Arizona which has no fertilizer law, the farmer is fairly well protected from fraud if he sticks to standard label products or other materials which are sold on a basis of guaranteed analysis. However, there are still many frauds on the market and a farmer is safe only if he has an analysis made when he is in doubt. The Arizona Experiment Station makes analyses of such materials, without charge, for farmers of this State.

The choice of materials depends upon several things of which the principal ones are kind of crop, nature of soil, climate, and the location of the consumer with respect to freight traffic.

In Arizona materials should be selected which give the farmer the most plant food in the least bulk, otherwise freight charges devour the profits before the fertilizer is in the ground. There are many materials which satisfy this requirement, chiefly nitrate of potash, ammonium nitrate, ammonium phosphate, double superphosphate, and the potash salts; these are practically 100% plant food. The present tendency all over the country is toward concentrated fertilizers and some states are refusing to license fertilizers below a certain minimum of plant food content.

There is only one danger in the use of concentrated materials. Some of them are injurious if in direct contact with the seed. So in using them care must be exercised to place the fertilizer an inch or more from the seed.

On the fertilizer bags one often sees phosphate labeled as *percent available.* Available does not always mean soluble in water and this should be understood by farmers who desire water-soluble materials. In the East or Mid-West this differentiation would not be very important. Their soil and climatic conditions are vastly different from those of Arizona. So-called available phosphates are practically as efficient as water-soluble phosphates in other sections of the United States, but this is not true for Arizona soils.

A large percentage of crop troubles are related in some way to improper nourishment. The writer has taken plants suffering from root rot, in fact on the verge of death, transplanted them, roots and all, to other soils known to be fertile, and in a very short time they have developed into strong, healthy plants. Fungus diseases of leaves have been controlled by reducing the amount of nitrogen in the fertilizer. In Colorado and Nebraska a serious sugar beet disease is being controlled by phosphate fertilization. During the World War, when it was difficult to get potash, the cotton crop of the South suffered more from plant diseases than in any other period of its history.

This does not mean that all plant diseases can be controlled by a properly balanced fertilizer, but illustrates that many plant diseases are destructive because the absence or presence of some factor predisposes the plant to disease. Malnutrition will make plants susceptible to disease quicker than any other condition we know.

Our soils, like all arid soils, are low in nitrogen. But alfalfa, being a crop which can obtain nitrogen from the air and one which is used in rotation in this State, will furnish much of the nitrogen needed by other crops in the rotation. If nitrogen should still be needed such materials as ammonium sulphate, nitrate of lime, ammonium phosphate or urea are admirably suited to Arizona soil types.

The two principal forms of phosphate which are suited to Arizona soils are double superphosphate and ammonium phosphate. The latter, which has the trade name "Ammo-Phos," is preferable because it gives better penetration and because the additional growth which is produced by phosphate creates a demand for extra nitrogen and this is supplied by the nitrogen present in this "Ammo-Phos." Phosphate is extensively used in conjunction with animal manures, and it is possible that the inclusion of this with the present practice of manuring in this State might enhance the value of both these materials.

THE BEST WAY TO APPLY FERTILIZER

When chemists demonstrated that the soils which were being profitably fertilized already contained far more total plant food materials than were added in the fertilizer it threw a different light upon fertilization. As a result there have been many types of machines invented for the application of fertilizers in the most favorable location with respect to the seed or the roots of crops. These machines greatly lower the cost of application and increase profits by making the application more efficient.

Many experiments have been conducted demonstrating the value of proper placement of fertilizer. The Joint Committee of Fertilizer Application of the National Fertilizer Association is making every effort to encourage experiments along this line. At present they are devoting most of their efforts to cotton and corn as these two crops consume more than one-half the fertilizer tonnage of the United States. In an average of data obtained from experiments repeated in sixteen different states, 500 pounds of 4-10-6 fertilizer applied broadcast gave an average increase of 8.2 bushels of corn per acre, while placing the fertilizer in the hill at the amount of 125 pounds per acre gave an increase of 15.7 bushels per acre. Similar results were obtained with cotton in experiments in South Carolina. Likewise with wheat as shown by experiments in Kansas. In the latter case the average increase from broadcasting the fertilizer was 9.03 bushels per acre, while the average increase where the fertilizer was applied in the row with the seed was 16.4 bushels per acre, using the same amount of fertilizer in each case. There is no question but that it will pay to determine the most efficient way to apply fertilizer. The writer has seen increased yields merely from dusting seed with phosphate before it is planted. Phosphate is the only fertilizer which can safely be placed in contact with seed.

The method of applying soluble fertilizers in irrigation water has been in use on the sugar plantations of Hawaii for many years and is becoming increasingly popular in California. Arizona soils contain a fairly good supply of mineral phosphates. They are not in a water-soluble form but in a form which is almost impossible for the crop to absorb. Therefore, we should use water-soluble phosphates in small individual applications, otherwise it may be lost in the soil by going over (reverting) to the same form as that already present, which is insoluble and not available. An acre-foot of average soil contains only 10 to 15 pounds of soluble phosphate in the soil solution at any one time. This is only 5 pounds per 1,000,000 pounds of soil. While it hardly seems believable that crops can subsist on this small amount, it has been definitely proven that a soil can produce a maximum crop on this *provided the amount is constantly maintained in the soil moisture.* Therefore there is no occasion for adding large amounts at a time if small amounts can be added in each application of irrigation water.

How would this practice be affected by soil type? Let us select a gravelly soil such as exists in the Camel Back district of the Salt River Valley or the sandy types on the Yuma Mesa. These soils possess very little clay and cannot hold much plant food in reserve, as this is almost entirely a property of the clay particles in soils. It would therefore be an excellent plan to dissolve a small amount of plant food in every irrigation, or less often if desired, for crops on such soils. Obviously, they are getting plenty of water so it is entirely possible that growth would be aided by such a practice. As for the heavier soils, let us cite some experiments with citrus in California. It was shown there that if ammonium phosphate is applied in small doses in the irrigation water, and the soil not disturbed between applications, a penetration of phosphate to 30 or 40 inches was obtained by five irrigations. This is due to the fact that each application tends to push the previous one to greater depths if the soil has not been disturbed in the meantime.

PHOSPHATE FERTILIZERS FOR ARIZONA SOILS

The Soil Chemistry Laboratory at the Arizona Experiment Station has devoted considerable time in past years to the study of phosphates in Arizona soils. Many of the developments during this study are of great practical value and give new ideas about the use of phosphate fertilizers in the highly alkaline calcareous soils of this State. In brief, this work has shown that many soils will give response to phosphate fertilization. It may not always be shown by greater yields but produces a crop of much superior quality.

There are unlimited supplies of raw mineral phosphate in the United States. In many sections of the country the ground raw mineral is used effectively as a fertilizer, but the greatest consumption is of manufactured phosphates. In these manufactured products it is the aim to improve the availability of the phosphate. The raw material is of no value whatever for our soils.

There are a number of things to be considered in determining which of the manufactured products are best suited to our soil. First, the amount of phosphate already present. As already stated Arizona soils are quite well supplied. Second, in what form is this phosphate and why can it not be used by crops? Phosphate exists in Arizona soils in the same form as in bones or in teeth, and the plant cannot use it because the soils contain so much lime that it interferes, under our conditions, with the feeding processes of the roots and with the solubility of the phosphate.

It thus stands to reason that such materials as bone or ground phosphate rock should not be used on Arizona soils as there is plenty of that form already present. The next possibility is superphosphate. While superphosphate is a vast improvement in effectiveness over phosphate rock, it still contains appreciable amounts of phosphate in a form which is insoluble in water and therefore not readily available in high-lime soils such as ours.

The latest improvement in phosphate manufacture is a product highly soluble in water. In addition, it contains larger amounts of phosphoric acid per ton than any other form of superphosphate and there is therefore a great saving in freight. This material is known as double superphosphate and contains 40% water soluble phosphate with only 6% water insoluble phosphate. This, then, is an excellent form to use on Arizona soils.

In some of our work it has been found that when phosphate fertilizer is applied to a soil there will be a much better yield of crop if a small amount of nitrogen is also added. The reason for this is that the better growth from phosphate creates a demand for more nitrogen than is present in the soil. Therefore, the full value of phosphate may be lost unless there is plenty of available nitrogen present in the soil. This suggests the use of a still more soluble and more concentrated phosphate known as "Ammo-Phos." This product contains 46% water-soluble phosphoric acid and 11% nitrogen. It is the most efficient form for use on our soils.

ORGANIC MANURES AS FERTILIZER

As far back as historical records go animal manures have been used by farmers for enriching soils. With the application of such materials as wood ashes, bones and later the so-called commercial fertilizers, the possibility of a substitute for animal manures began to grow in men's minds, but it is still recognized that the substitution is not complete in spite of the great value of commercial fertilizers. Fertilizer materials are sold on the basis of the amount of nitrogen, potash and phosphates which they contain. This does not apply to manure, for in reality manure is of greater value, due to its organic matter, than a chemical analysis would indicate. There is a more or less mysterious crop response to manure which commercial fertilizers have never been able to duplicate.

Manure may be defined as partly decomposed vegetable or animal matter. The composition of manure depends in large part upon the organic materials which have undergone decomposition. Contrary to general opinion it is not necessary for vegetable matter to pass through the animal to produce manure. If alfalfa hay is ground up rather coarsely, moistened and allowed to stand in a warm place it will decompose in a few weeks into a manurial stage. This final product cannot be distinguished from the products of the stable and has the same beneficial effects upon growing plants as stable manure.

Many attempts have been made to artificially manufacture manure. An excellent example is known as "adco." It is prepared by adding "adco" powder to a compost of any non-woody organic material such as straw, wetting and allowing the whole to decompose. It is extensively used in England where the process originated

The value of manure depends in large part upon the food of the animal. A cow fed upon cotton seed meal alone will produce manure worth $15 or $20 per ton, dry weight, while the manure from a cow fed upon straw is almost worthless in so far as the amount of plant food present is concerned. These facts should be kept in mind when purchasing manure. There is no entirely satisfactory way of determining the manurial value of organic matter except by crop tests. A determination of nitrogen is about the best criterion. The three tests most essential are its nitrogen content, the amount of water it contains, and the amount of sand or soil which may be present. Usually manure can be bought intelligently on this basis. It is very important to know whether sand or soil has been added to increase the weight if manure is purchased by the ton. In Arizona the manure from sheep, goats, and cattle on the range is usually of good quality because of the large number of leguminous plants in the forage. Arizona has a greater variety of wild legumes than any other section of the United States. A leguminous plant is very rich in nitrogen and will decompose readily.

Manure quickly depreciates in value unless it is stored where it will not be leached by rains. Also, nitrogen is often lost as ammonia during decomposition, unless some means is provided for absorbing it. This can be accomplished by mixing superphosphate into the manure pile.

The following table gives an approximate composition of most of the animal manures.

	Percent Water	Percent Nitrogen N		Percent Phosphate P_2O_5		Percent Potash K_2O	
		A	B	A	B	A	B
Sheep	59.52	0.77	1.90	0.39	0.97	0.59	1.46
Hogs	74.13	0.84	3.26	0.39	1.49	0.32	1.24
Cattle	75.25	0.43	1.73	0.29	1.16	0.44	1.78
Horse	48.69	0.49	0.96	0.26	0.50	0.48	0.94
Chicken	56.00	1.50	3.40	1.40	3.19	0.85	1.94

A—percent on wet basis B—percent on dry basis

While the value of manure is everywhere recognized, it probably has its greatest value in the arid districts in the Southwestern United States. As an aid in the reclamation of alkali soils it has no equal. Manure requires a great deal of moisture for decomposition. Therefore, under arid conditions it should be plowed in deeply so that it will remain sufficiently moist for the bacteria to act upon it.

The outstanding experiments demonstrating the value of manure are probably those of the Rothamsted Experiment Station in England. These have been conducted continuously for over eighty years and have compared commercial fertilizers with barnyard manure. For the first few years the commercial fertilizers led in yields but were soon surpassed by animal manure, applied in fairly large amounts, and except for these first few years the manure plots have been consistently in the lead. Also, the crop has suffered less from seasonal factors, the soil has held moisture better, has maintained better tilth, and has stimulated better root growth. There seems to be no question but that animal manures add something to the soil which is of vital importance and lacking in commercial fertilizers.

Among the explanations of this difference which have been suggested is that manures contain vitamins or vitamin-like substances and that plants require these in their nutrition, just as do animals. The Soil Laboratory at the Arizona Experiment Station has devoted some time to studying this point because of the fact that citrus is very insistent in its demand for organic matter in its scheme of nutrition. This unknown but important constituent of manure is formed during the decomposition of organic matter, for undecomposed manure is sometimes actually toxic. Likewise green manures are toxic in the fresh state and beneficial only after partial decomposition.

This active constituent of manure is soluble in water. But if all mineral plant food is removed from the black water extract of manure the black solution still stimulates plant growth just as well as ever. A small amount of this poured around a yellow sickly citrus seedling will change it into a healthy green plant in a very short time.

The value of manure in the reclamation of alkali soils is of special interest in Arizona. The puddled condition of black alkali soils and the existence of slick spots are the most serious troubles which the Southwestern farmer must combat, and manure is his best ally not only in overcoming these conditions but in maintaining tilth and preventing the recurrence of alkali. The fundamental system by which alkali soils can be reclaimed or kept in good tilth is by means of carbonic acid gas (carbon dioxide), derived either from the air or through the decomposition of organic matter. Decomposing manure supplies large quantities of this gas to soils, and this in turn neutralizes black alkali to form sodium bicarbonate. This tends to promote good drainage and permeability, a prime requisite in the cropping of arid soils.

Still another important property of manure was discovered in our phosphate studies. One reason phosphates are so insoluble in our calcareous soils is because carbonic acid is deficient or completely absent. On applying manure to these soils, carbonic acid is generated and the solubility of phosphate in the soil is greatly increased.

ALKALI AS RELATED TO FERTILIZATION

The existence of alkali is definitely traceable to climatic conditions. Alkali soils rarely occur in humid climates. It is a natural result of too light a rainfall to leach out and remove the mineral salts. Therefore, it will always be a problem in arid regions, but one which can be overcome with reasonable care and effort.

We still use the classification "white alkali" and "black alkali." The first refers to the presence of excessive amounts of such salts as common salt (sodium chloride), Glauber's salt (sodium sulphate), and sometimes soluble salts of calcium or magnesium. These soils are often neutral soils and fairly easy to reclaim if plenty of water is available. This type might well be referred to as saline soils so as not to confuse them with the black alkali types. Black alkali soils are those which contain enough sodium hydrate (lye) to dissolve organic matter and render the soil solution black. They are always the least fertile and the hardest to reclaim. For those who are interested, the writer advises the reading of Bulletin 123 of the Arizona Experiment Station, *Alkali Soil Studies and Methods of Reclamation,* by P. S. Burgess, which may be secured at the county agents' offices or from the mailing bureau at the University.

The fundamental causes of black alkali soils are the basic salts of sodium. These salts will inevitably accumulate in soils of arid regions unless preventive measures are taken. On the other hand they may develop after reclamation from the careless use of irrigation water.

One of the most noticeable effects of black alkali is that it interferes seriously with drainage. The soil *freezes up,* refuses to take water, and may become stagnant. Few crops can tolerate these conditions. The reason for this condition is that black alkali causes the clay particles of the soil to swell to many times their normal size and thus clog up the pores of the soil.

Another reason why alkali soils are infertile, as suggested by many, is that the alkali is toxic toward plants. Some discoveries regarding the fertilization of alkali soils have led us to place a limitation upon the application of this theory. We have found that most black alkali soils do not contain enough black alkali to actually poison plants. But it can interfere with the feeding activities of roots and stop the absorption of plant food even though it is not present in sufficient quantities as to be poisonous.

To illustrate, in selecting soils for phosphate experiments several black alkali soils were selected in the lot to be fertilized. It was found that the black alkali soils contained more water soluble phosphate than those which did not contain black alkali. Yet when phosphate was added to the black alkali soils and the soils planted to tomatoes, there was a remarkable increase in growth.

The conclusion is inevitable that black alkali soils require more phosphate than those which do not contain black alkali, because black alkali affects the fertility of the soil by injuring the tilth, swelling the clay particles to such compactness that root growth is impaired, and by stopping the absorption of the nitrate and phosphate plant foods, and thereby inducing plant starvation.

CARBONIC ACID AS AN AID TO FERTILIZATION

Few people realize the important part which carbonic acid, or carbon dioxide as it is often called, plays in the fertility of soils. This is the self same gas which is dispensed in the form of soda water at the drug store fountain. Without carbon dioxide in the soil the farmer would simply have to shut up shop. This applies more to the farmers of the arid Southwest where carbonic acid is just as important as irrigation water. Let us bring out a few points to illustrate.

First why does manure improve the texture and fertility of alkali soils? Because in decomposing it gives off carbonic acid which neutralizes black alkali and dissolves plant food from the insoluble forms stored in the soil. The effect upon texture can be shown by shaking a small amount of puddled clay with soda water. The cloudiness will completely disappear and the soil settle out in a crumby condition, where previously it was so finely divided it would not settle at all.

Why does gypsum help in the reclamation of alkali soils? Because as the result of the improvement in physical condition of the soil, air can enter and the carbon dioxide in the air and better root respiration makes for improved fertility. As a matter of fact every method which has had any value in the reclamation of alkali soils is in reality a means of getting carbon dioxide into the soil.

What are the sources of carbon dioxide or carbonic acid in soils? There are two. First, all organic materials decompose as soon as they become mixed with a damp soil. Unfortunately organic matter is scarce in arid regions. But plant roots breathe, that is, they take in oxygen and give off carbon dioxide and a healthy crop will give off great volumes of this gas. So the second source is the roots of the crop itself. This supply may be sufficient if the soil is in good tilth but never if the soil is puddled.

In addition to improving the tilth of a soil carbonic acid is the means by which the roots obtain their food from the soil. It acts when dissolved in water as a weak acid. It has been found that the infertility of alkali soils is due to the fact that plants cannot properly absorb plant food from such types in the absence of carbonic acid. The plants will die of starvation even though surrounded by plenty. If a plant is placed in water containing all the necessary plant food and a small amount of black alkali is also added to the water, though not enough to poison the plant, the plant will not absorb the nitrate or phosphate. But if the plant is allowed to remain in the water long enough the roots will give off sufficient carbonic acid to neutralize or do away with the black alkali, and from this point on the plant will absorb its food normally. This illustrates the means by which plants feed in alkali soils and the value of carbonic acid in this process. It is also the reason why many farmers in reclaiming alkali soils try to get an alkali resistant crop started as soon as possible.

A thorough knowledge of the possibilities of carbon dioxide is without doubt the key to the successful cropping of the arid soils of the Southwest.

SUMMARY

During the past decade there has been an extensive migration of agriculture from fertilizer-using to non-fertilizer-using lands.

Non-fertilizer-using lands will continue as such only as long as the virgin reserves of plant food are able to supply the needs

of the crop Beyond this their fertility can be maintained only by supplying the crop with commercial fertilizers and animal manures.

Nitrogen and phosphate exhaustion usually occur first. The former can be largely avoided by cultural methods, namely by using leguminous crops in the rotation and by encouraging the activities of nitrogen fixing bacteria in the soil. These have the property of removing nitrogen from the air and adding it to the supply in the soil.

Phosphate exhaustion can be corrected only by the use of commercial fertilizers. This is indicated by the fact that about one-half the commercial fertilizers now consumed are phosphate fertilizers. For Arizona soils, soluble phosphate fertilizers must be used because our soils are high in lime and always alkaline.

A combination of intelligent farming and fundamental research will steer Western agriculture away from the pitfalls which have brought many Eastern soils to their present stage of abandonment.