

THE PRODUCTIVE CAPACITY OF SEMIARID SOILS AND THE PRESENT EMERGENCY



Reclamation Experiment Station
Tucson, Arizona, U.S.A.

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FOREWORD

The "exploitation-of-new-land" program of the United States has just about reached its end. The American farmer must now give thought to repairing and rebuilding his soil just as he has always given attention to repairs on dwellings, fences, barns, and machinery. The European farmers were forced into such a program many years ago. Expenditures for soil repair or soil building should be treated as a form of insurance—namely, insurance on soil structure, soil fertility, and soil productivity. It can be accomplished by a carefully designed program of soil handling, and fortunately investments in soil repair are investments which are free from taxation.

In Arizona, soil rebuilding or repair calls for a program which takes into consideration several important factors or soil treatments: (1) the use of soil correctives for maintaining freedom from alkali and for reclaiming soils already injured by alkali; (2) the use of animal manures and organic farm waste—that is, returning to the soil as much as possible of the organic material which the soil itself has produced; (3) the use of soil analysis for developing a program of fertilization.

This bulletin has been prepared to meet the demand for information on how best to handle Arizona soils during the present emergency and how to keep them at maximum productivity.

THE PRODUCTIVE CAPACITY OF SEMIARID SOILS AND THE PRESENT EMERGENCY

BY W. T. McGEORGE

RECLAMATION OF ALKALI SOILS—STRUCTURAL ASPECTS

Introduction

The mechanical condition of a soil, commonly referred to as the structure of the soil, is an extremely important factor in soil productivity. This is especially true in irrigated agriculture and so in times of emergency or good prices, when the grower wants to get his soil at its peak of productivity, a thorough check on the structure of the soil is imperative. While it is true that a supply of available plant food, the proper organic level in the soil, and other factors are vitally associated with productivity, there can be no bumper crops without a favorable soil structure. In Arizona, soil structure has often been referred to as the greatest single growth-limiting factor. It is a fundamental principle of irrigated agriculture that the soil must take water, and soil structure is the primary condition governing this principle.

One of the necessary essentials of a structurally normal soil is its saturation or near saturation with calcium (lime), for calcium saturation imparts many desirable structural characters to any type of soil. This condition is obtained in acid soils by the practice of liming and in alkali soils by the use of gypsum and other similar acting alkali soil correctives. In irrigated agriculture the nature of the salts present in the irrigation water is important. With the wide variety of waters available for irrigation in Arizona a condition of calcium saturation, in soil, is rarely attained, and so salinity and alkalinity problems go hand in hand with soil structure problems.

This bulletin is prepared in response to many requests for information on the use of gypsum, sulphur, and organic matter as well as leaching in the reclamation of alkali soils, in the control of soil alkalinity or salinity, and therefore in controlling soil structure and reclaiming structurally deteriorated soils.

The two terms "soil texture" and "soil structure" are often confused. Soil texture refers to the size of the individual soil particles—that is, the percentage of fine, medium, and coarse particles which together are the soil. The terms "clay," "silt," "sand," and various combinations of these terms are used to express soil texture. Soil structure refers to the manner in which the different sized soil particles are gathered together. The word "structure" is used a great deal in Arizona when referring to the mechanical condition of the soil. It is necessary that structure provide a fair volume of space, between the particles, for air and water if the soil is to be productive. We refer to a tight soil structure as one in which the soil particles are packed together too closely for air

and water movement. On the other extreme there is the porous structure, then the hardpan structure, and many others. The ideal structure is one in which the finest soil particles are gathered together in crumbs of sufficient aggregation to permit an easy growth and movement of roots and the ready movement of air and water in the root zone. In irrigation agriculture this is a goal which is difficult to attain and once attained is difficult to maintain. There are two kinds of soil crumbs. The stable crumb is the one which is held together in both dry and wet soils. The unstable crumb holds only in dry soil but breaks down as soon as the soil is wet. In large part the stability of the crumb depends upon its chemical composition and thus upon the type of irrigation water used. All irrigation waters carry soluble salts in solution, and these salts react chemically with the minerals which compose the soil particles. The relation between salinity, alkalinity, and soil structure then is self-evident, and no discussion of alkali soils is complete without a discussion of soil structure.

The most serious structural condition and therefore the principal one to guard against is soil dispersion—namely, a swelling of the finely divided clay particles in the soil to form a sticky or plasticlike mass structure. Such a condition may be readily identified by working the wet soil in the palm of the hand. A dispersed condition may appear throughout the entire soil depth or may exist only in layers of varying thickness at any depth of soil. Of course the more clay the soil contains—that is, the heavier the soil—the more serious the condition may be. In most cases the cause of this dispersion can be traced to too much sodium salts in the irrigation water or in the soil solution. On the other hand it may develop from improper tillage methods. The soil absorbs water, salts, odors, and in fact a great deal of whatever it comes in contact with, and so from soft waters which are high in sodium it will absorb sodium in excess and from hard waters which contain an excess of calcium it will absorb an excess of this element. In some ways this absorptive property works for the benefit of the soil and crop, but in others it does not. Among the latter the absorption of sodium is probably the most undesirable. The absorption of sodium is so complete from soft water that the soil becomes sticky, hard to handle without puddling, and drainage is seriously impaired. Such a soil will break into large, hard clods when plowed and thus make an undesirable seedbed. On the other hand the absorption of calcium by the soil is highly beneficial, especially if a fair amount of organic matter is present. For this reason hard waters should be used for irrigation, and when hard water is not available the water should be made hard by adding calcium salts, for example gypsum.

In working with soil problems involving soil structure the plan of attack depends upon whether one is designing a program for maintaining a soil structure which is already satisfactory or whether it is a problem involving the reclamation of a badly deteriorated structure. There are several well-proved and estab-

lished programs of treatment, and it is the purpose of this part of the bulletin to present this information.

Alkali

Before presenting the methods for control or reclamation of soil structure an explanation of alkali will lead to a better understanding of the structural problems and the control methods which are useful. When soluble salts exist in soils in such amounts as to be of economic importance the condition has come to be known in the West as alkali. It is a broad term and includes all soluble salts. For convenience it has been subdivided into white alkali and black alkali. The former term represents one or more of the neutral salts better known as salines. The latter represents the truly alkaline salts but primarily sodium carbonate. Sodium sulphate and sodium chloride are the most common salines. In virgin lands the alkali is derived from the original rocks and has accumulated during soil formation because evaporation from the soil surface is greater than rainfall in semiarid regions. In cultivated lands alkali arises from the use of irrigation water containing excessive amounts of soluble salts, from a high water table, from canal seepage, from overirrigation, and from poor drainage.

Originally the relation between soil alkali and soil structure problems was not recognized. An alkali soil was looked upon as merely a soil in which alkali salts were comingled with a conglomeration of mineral particles. Their conversion to normal soils was considered merely a matter of neutralizing black alkali and then leaching all the salts from the soil with water. During this time no direct relation between white and black alkali was recognized. Likewise no relation between alkali and soil structure was recognized, although it had been observed that supposedly reclaimed soils were seriously lacking in productivity.

With a recognition of a direct relation between alkali and soil structure on western lands, soil reclamation is no longer the baffling problem it formerly was. From years of soil research it has been shown that alkali soils are not merely soils in which salts are comingled with particles of disintegrated mineral matter but are soils in which salts have reacted chemically with the minerals and in this reaction have definitely influenced the mechanical properties. On the one extreme there is the jellylike plasticity of the sodium saturated soil and on the other the well-crumbed structure of the calcium saturated clay. Therefore the salts must not only be leached out of the soil but, if the chemical reactions have adversely affected the structure of the soil, these effects of the reaction must be also changed. This is the reason for using such soil correctives as gypsum, sulphur, manure, and others—namely, to correct the chemical conditions that developed while the alkali was in the soil or that might develop while the soil is being reclaimed. The heavier the soil—that is, the more clay it

contains—the more reactive it is, and this is the reason clay soils are more difficult to reclaim than sandy soils.

Reclamation Methods

Leaching

Many alkali and structurally deteriorated soils can be reclaimed by the simple process of leaching. A chemical analysis of the soil and of the water to be used in leaching will determine when this is possible. Sandy soils are most adaptable for this type of reclamation and clay soils least. If the salinity of the soil and irrigation water is predominantly calcium salts (hard water) most any type of soil can be reclaimed by leaching, for as already mentioned calcium salts have a flocculating effect on fine soil particles. If the condition is caused by a high water table, from which salts are drawn to the surface by evaporation, the soil may be reclaimed by drainage wells or ditches extending to a depth well below that of the water table. The water table should be 6 to 10 feet below the surface of the soil. Soils which are easy to reclaim by leaching are usually not badly deteriorated in structure.

In many cases where the soils are calcareous—that is, contain an appreciable amount of calcium carbonate—even those partially saturated with sodium and containing some black alkali can be reclaimed by leaching if time is not an important factor. It is however not advisable to follow this plan, for leaching without the use of a soil corrective will sometimes injure the soil structure. Sulphur or gypsum should be used in the operation if they are available at reasonable cost. In some cases this structural injury is only temporary, and the soil will gradually change to a somewhat normal state, but only after prolonged leaching.

As already mentioned, structural deterioration is often due to excessive absorption of sodium by the soil because of a high ratio of sodium to calcium in the irrigation water or the soil solution. When the soil contains large amounts of salt, any kind of neutral salt, the soil will be fairly well flocculated and may take water well when first wet. As the salt is removed from the soil, by the leaching operation, it will take water progressively slower. Finally the soil may “freeze up” because the sodium saturated clay begins to swell as soon as the excess of salt is leached out. Sodium clay becomes excessively dispersed at this stage of the leaching if no gypsum or sulphur has been used. If a head of water is maintained indefinitely on the soil it may pass over this frozen condition, open up, and take water like a normal soil. The reason for this final opening up is that all Arizona alkali soils contain calcium carbonate, caliche. This calcium carbonate, while not very soluble in water, will with patience finally bring about a displacement of enough sodium to effect complete reclamation.

Reclamation of alkali and structurally deteriorated soils by leaching is then entirely possible but is not advisable except in

a few specific cases which can be determined by an analysis of the soil and irrigation water.

Gypsum

Gypsum was one of the first materials used in regulating soil structure and in alkali soil reclamation in western irrigated lands. It is still one of the most satisfactory materials used for this and is extensively employed, for fortunately it occurs in large quantities and is widely distributed throughout the West. The continued use of gypsum is of special interest because, while the early conception of soil alkali has been changed materially in the last 25 years, gypsum fits the new conception as well or possibly better than it did the old. Originally it was believed that gypsum neutralized black alkali. It is now known that this neutralization is only partial and far from complete. Therefore black alkali soils cannot be reclaimed nor structurally deteriorated soils benefited merely by the *addition* of gypsum. The soils *must* be leached after the addition of gypsum to the soil. The combined treatment, gypsum and leaching, will remove both white and black alkali because of the partial neutralization of the black alkali and because, in the presence of gypsum, the soil will be converted to such a mechanical state that the salts can be effectively leached out. It is highly essential that the soil be thoroughly leached after treatment with gypsum regardless of whether the intent is to remove black or white alkali.

There is some tendency to overrate the value of gypsum in soil reclamation and so many failures have resulted and many mistakes have been made. If the soil is not thoroughly leached during the reclamation operations, the partial neutralization of black alkali may go backward thus losing all neutralizing effect. Also if the alkali is not leached down below the zone of capillarity—that is, the depth to which salts may be drawn back to the surface soil—alkalinity will soon return to the surface soil. It is admitted therefore that mistakes can be made, but it should also be stated that none of these mistakes will ever result in injury, for gypsum will never injure the soil.

If it is impossible to get water through the soil, there will be no improvement in the soil from gypsum treatment and such cases often are met. Therefore the land should be well tilled and even opened up with a subsoil buster in extreme cases especially if the soil is badly “frozen up” and the bad structure exists to any great depth.

Gypsum has been extensively employed in soil reclamation by farmers in the state and in experiments conducted by the Agricultural Experiment Station in Yuma, Pinal, and Pima counties. In all the experiments successful reclamation has been attained. On individual farms there have been some failures, the reasons for which have already been mentioned.

There are two motives behind the use of gypsum in soil reclamation. One is its use on good soils as a means of maintaining the

soil in good mechanical condition—that is, as insurance against structural deterioration or alkali accumulation—and the other is in the reclamation of structurally deteriorated or alkali injured soils. Obviously each will require a different method of treatment.

For preserving a good soil structure or as insurance against the development of alkali soil conditions only light occasional applications of gypsum are recommended—for example, about 100 to 200 pounds per acre annually or 200 pounds every 2 years depending somewhat on the crop grown, tillage methods, chemical composition of the irrigation water, and other factors. Another method of using gypsum for insurance of soil structure is to apply it in the irrigation water. Since it is not very soluble a supply can be easily kept in the irrigation ditch where it will be picked up by the irrigation water and thus carried to the field. Such an item of cost should be viewed in the same light and be considered just as important as the occasional repair of fences, barns, and farm machinery.

For alkali reclamation or the reclamation of soil structure obviously larger amounts of gypsum must be used, and the method of application guided by the condition of the soil. In no case should less than 1,000 pounds per acre be used in reclamation and usually the maximum economic limit is about 2 tons per acre because of the relation between cost of reclamation and the value of the land. High priced land can of course absorb a higher cost. One ton per acre will usually suffice if it is properly incorporated with the soil and the leaching is properly conducted.

When gypsum was first used in alkali soil reclamation its action was looked upon entirely as one of neutralization of black alkali, sodium carbonate. Thus it was customary to make a chemical analysis of the soil and determine from this just how much sodium carbonate was present and how much gypsum it would take to neutralize it. Recommendations as high as 20 tons gypsum per acre were frequently made. Since it is now known that one of the principal functions of gypsum is to furnish soluble calcium for replacement of sodium and to improve soil structure and thus the rate of drainage, smaller amounts are now known to be thoroughly effective. One reason this small application is effective is that once the soil is opened up the calcium in the soil caliche will help carry on the progress of the reclamation.

In applying gypsum to badly deteriorated soils it should be applied when the soil is dry and disked or plowed in. This will greatly increase its effectiveness by making contact with a greater volume of soil. Many failures have been due to surface applications, for such a method will not bring about a thorough incorporation with the soil. In extreme cases where alkali extends to considerable depth some type of subsoiler should be used to break up the soil after the gypsum is applied. Following these operations the land should be flood irrigated and flood irrigation con-

tinued until the alkali has been leached out, at least to a depth of 8 to 10 feet, and the soil tests show an improvement in soil structure. Chemical analyses of the soil are a great help in measuring the progress of reclamation, for both white and black alkali can be determined and mechanical tests can be conducted to measure the progress of the change in soil structure. The Experiment Station will be glad to co-operate with reclamation endeavors by making such analyses.

Sulphur

In some cases acids, notably nitric and sulphuric, have been used as correctives in soil reclamation, and since practically all alkali soils are calcareous, they have proved extremely effective. They are, however, somewhat hazardous to handle because of their corrosive properties. With the discovery that there are bacteria in soils which can convert sulphur to sulphuric acid another and more effective method of reclaiming alkali soils with acid was developed. At present sulphur is recognized by most soil scientists as the most effective and most satisfactory corrective for soil reclamation in the West. Its use is limited somewhat by the greater cost per ton, especially in districts located near a deposit of gypsum or where gypsum is available at very low cost. Sulphur not only acts as a flocculant like gypsum but has an additional acidity for the complete, rather than partial, neutralization of black alkali. It acts slower than gypsum as sulphur itself is entirely inert until it has undergone a change by oxidation to sulphuric acid. For immediate results from sulphur it should be started in a compost of soil or organic matter and then applied to the land.

The comparative value of sulphur and gypsum is best shown by a comparison of their chemical composition and properties. Gypsum produces only partial neutralization of alkali and furnishes only the soluble calcium which is a part of it. Sulphur produces a complete neutralization of alkali and brings into solution, from the soil, more than five times as much calcium as is added in an equal amount of gypsum. Since the soluble calcium is the active element in soil reclamation, the greater value of sulphur is self-evident. Sulphur is first oxidized to sulphuric acid in the soil but is eventually converted to calcium sulphate (gypsum), because as already mentioned alkali soils are calcareous and gypsum is formed by the reaction between sulphuric acid and caliche. One part of sulphur will change to three parts sulphuric acid and this in turn to five parts gypsum. On this basis 400 pounds of sulphur is equivalent to an application of 1,200 pounds of sulphuric acid or 2,000 pounds of gypsum. But there is still an additional value from sulphur. From its acidity some calcium bicarbonate is formed in the soil, and since this calcium salt is more soluble than gypsum it is more effective both in alkali reclamation and structural reclamation. In reality then sulphur has more than five times the value of gypsum and at a price of \$5 per ton for the

latter, one could afford to pay about \$30 per ton for sulphur and get the same or better results.

Sulphur should be applied at the rate of about 400 pounds per acre and mixed well with the soil by disking. The rate of oxidation and therefore the time required before a response will show will vary with the moisture content and other soil conditions. The soil should be kept moist but never allowed to become waterlogged. Also since the oxidation of sulphur to sulphuric acid requires the presence of air the soil should be kept in a loose open condition. Usually 8 months to a year will elapse before any effect from sulphur is noticeable. When sulphur is used alone leaching should be delayed until oxidation is well started.

Some form of sulphur dust is used in insect and disease control on many Arizona crops notably cotton, truck crops, and grain. The total amount applied will often amount to as much as 100 pounds of sulphur per acre annually. All this sulphur ultimately reaches the soil. This sulphur dusting has a dual purpose and such continuous light applications should be of immense benefit in helping to maintain a good soil structure and prevent alkali accumulation.

Organic matter

Both green manures and animal manures are useful in soil reclamation especially in reclaiming structurally deteriorated soils. Their principal value lies in the fact that during decomposition in the soil the acids which they liberate react with caliche to form calcium bicarbonate the value of which has already been mentioned in discussing the value of sulphur. Organic matter has the further value in that it is about the best binding agent known for building fine soil particles into crumbs or aggregates which are highly stable when wet. Thus organic matter increases the ability of the soils to take water, increases drainage rate, and thus aids materially in leaching the alkali out of the soil. The most common application for animal manure is 10 to 20 tons per acre.

Another method often applied in soil reclamation and one which should be included under organic matter is that involving the use of alkali resistant crops. With their active root systems and tolerance of alkali some soils can be opened up by the roots and their drainage thus improved. Principal among crops used in alkali soil reclamation is Bermuda grass.

Combination methods of reclamation

As already mentioned, experiments conducted on western soils have demonstrated that of the several soil correctives for soil reclamation, sulphur is the most effective single agent. All the correctives, however, have slightly different effects and therefore various combinations have been suggested as a means of increasing the effectiveness of the reclamation and reducing its cost. For example experiments have shown that a combination of sulphur

and manure is far more effective than either alone. In somewhat the same manner the combination of gypsum and manure is extremely effective in obtaining a permanently reclaimed structure. Gypsum and sulphur possess the immediate effect of gypsum and the later but prolonged effect of sulphur. Regardless of single or combined treatments all must be accompanied by leaching.

Gypsum and sulphur.—In this combination the gypsum acts immediately by partially neutralizing black alkali and through its soluble calcium improves drainage conditions so that the alkali can be leached out. Later the sulphur becomes oxidized to sulphuric acid, completes the neutralization of black alkali, if any is present, further improves drainage, and thus completes the reclamation by conversion to a calcium saturation.

Gypsum and manure.—In this combination gypsum is again immediately active. The manure like the sulphur must undergo decomposition before it becomes active. It therefore follows the immediate effect of the gypsum with an evolution of carbonic acid which like the sulphuric acid from sulphur provides more soluble calcium for reclamation. Manure has the additional and extremely important property, too, of binding the soil particles into crumbs.

Sulphur and manure.—This is an excellent combination for soil reclamation and by far the most complete where immediate results are not imperative. Both must undergo decomposition before any influence upon the soil is noticeable. The value of this combination is as follows. Sulphur decomposition proceeds rather slowly in semiarid soils which are sadly deficient in organic matter. Therefore manure furnishes organic matter to speed up the rate of sulphur oxidation. The sulphur will effect a complete neutralization of black alkali and will bring soluble calcium into the soil solution for starting improved drainage. The organic matter then binds the fine clay particles into stable crumbs, and therefore a permanently reclaimed structure, for organic matter is the most effective agent for developing a permanent or water stable crumb in the soil. There is also a formation of calcium bicarbonate from both the sulphur and manure, the value of which has already been mentioned several times.

Sulphur, gypsum, and manure.—It is evident from the above that the ideal combination for effective soil reclamation is a combination of all three correctives—sulphur, gypsum, and manure. It combines the primary effects of all—namely, the immediate effects of gypsum, the acidity of sulphur for complete neutralization of alkali with its slower and more extended effects, and finally the binding properties of the organic matter in manure to transform the soil into a loose, open structure.

It is possible to prepare a corrective with the combined effects of all three by using only two, sulphur and manure. This may be done by composting manure and sulphur for a period before applying it to the soil. During this composting period some of the sulphur will be converted to gypsum and thus the sulphur-

manure combination will have the combined effects and value of all three.

Summary

For reclamation of alkaline or structurally deteriorated soils the following suggestions are made:

1. The feasibility of reclamation should be learned from a chemical and mechanical analysis of the soil. Sometimes reclamation may be too costly for the value of the land to absorb.

2. Drainage must be provided, or there can be no reclamation.

3. Gypsum should be worked into the soil and not just broadcast over the surface.

4. Sulphur must be worked into the soil so it will keep moist, and time must be allowed for its oxidation before leaching.

5. Regardless of the soil corrective used, the alkali can only be removed by leaching.

6. The best single corrective is sulphur. The best combination of two correctives is sulphur and manure. The most effective combination is composed of all three—sulphur, gypsum, and manure.

For maintaining a good soil structure, for prevention of alkali accumulation, and for prevention of structural deterioration the following summary is offered:

1. Avoid using an excess of irrigation water.

2. Prevent seepage from irrigation canals and ditches.

3. Spread irrigation water evenly.

4. By leveling, adjust slopes for even water penetration in borders and runs.

5. Give the land at least one good flooding annually in areas where the alkali problem is acute, preferably during the winter. Where alkali is not acute this heavy flood irrigation should only be applied when evidence of alkali appears.

6. Always provide for good drainage.

7. Make an occasional check on height of water table unless it is definitely known to be at a safe depth.

8. Growing crops reduce alkali accumulation because they shade the soil and thus reduce evaporation from the soil surface. This explains why slick spots grow so rapidly once they appear in a field—namely, water evaporates more quickly from these bare spots and therefore they spread rapidly.

9. On account of the rapid evaporation from bare, slick spots they should be bordered immediately on appearance and ponded with water during the next irrigation.

10. Carefully regulate time between irrigations.

11. Remember that neither chemical treatment nor leaching will take the place of good soil management, for these are only supplementary to soil handling.

12. Remember that a deteriorated soil structure is more damaging to a crop than alkali itself, except when alkali is present in greatly excessive amounts.

13. Make occasional light applications of sulphur or gypsum.

14. Make the manure compost a farm institution and preferably mix some sulphur or gypsum in the compost as an insurance against alkali and structural soil deterioration when the composted material is applied to the field.

15. Don't expect one application of gypsum or sulphur to permanently correct an injured soil. It usually takes many years for alkali salts to accumulate in soils. During this long period, the salts have slowly reacted with the mineral soil particles. In reclaiming these soils the reactions must be reversed and held in reverse. Obviously this is no small task, and one treatment is rarely sufficient. Security from alkali and therefore from a deteriorated soil structure can only be obtained by the continuous, or at least occasional, use of sulphur or gypsum.

16. An excellent plan for ridding soil of alkali or improving its structure is to use a straw mulch with sulphur or gypsum applications to the soil. In this plan a layer of straw or crop residue is spread over the land and allowed to remain on the surface of the soil indefinitely. This prevents pore clogging, surface compaction or crusting of the soil, reduces surface evaporation, increases infiltration, and in many other ways aids in the reaction between gypsum or sulphur and soil.

COMPOSTING FARM MANURE AND ORGANIC FARM WASTE

Introduction

Throughout American industry factories have turned to by-products and wastes for a goodly share of their profits, but this policy has been slow to take its rightful place in the agricultural industry. It is only in very recent years that such a trend has been developed in this field and probably only because the industry has been faced with a huge surplus, and some means is being sought to utilize this surplus. While most effort is being spent on surpluses, it is inevitable that in such a program some attention should be given to waste products. In such a plan the difficulty arises in that large scale waste utilization is only profitable in sections where farm wastes are plentiful. However, there are some wastes which individual farms can utilize, and among these animal manures and other organic materials are important.

The use of animal manure as fertilizer and soil conditioner is as old as agriculture itself so there is little need for stressing its value. This has been thoroughly established and is well appreciated by all farmers. There is though much that farmers do not appreciate about the handling and preservation of manure in a manner that will retain its maximum value. Through the extensive mechanization of many farm operations, a shortage of farm manure exists in many sections, and this has created interest in methods of composting manure to preserve its full fertilizer value and an additional interest in the use of other organic farm wastes, in compost, to supplement the diminishing supply of animal manure.

Organic Matter in Soils

The soil is often separated, for discussion, into two fractions—namely, the organic and the inorganic or mineral fraction. The inorganic fraction is composed of mineral particles which supply the mineral plant food required by plants and form a structure which provides space for moisture and air. It also provides an anchorage for the plant. The organic fraction is composed of plant debris and contributes to the productivity of the land in numerous ways both directly and indirectly. For example, it serves as a medium for the growth of the microorganisms of the soil; it aids in rendering mineral plant food available to the crop; it contributes to a better mechanical condition and thereby better water holding capacity, drainage, and other desirable properties.

The organic fraction of the soil being subject to decay is continuously changing. Unless it is replenished in some way, such as manuring, it will gradually disappear by complete decomposition. Depletion of organic matter is more rapid in cultivated soils because aeration stimulates the growth of the soil organisms which are responsible for decay. Research, experience, and farm

practice have all demonstrated the necessity of maintaining a desirable level of organic matter in soils. The principal ways in which this can be accomplished are by green manuring, application of animal manure or artificial manure, and by the roots left in the soil by crops.

Semiarid soils, such as predominate in Arizona, are characteristically low in organic matter content. Also year-round temperatures are high enough that bacterial life is active in the soil throughout the entire 12 months. Soil conditions are such then that in their virgin state these soils had no opportunity to accumulate organic matter. There are no interrupted periods of decay such as the winter rest period of nondecay prevalent in temperate climates. As a consequence of these facts there is a greater need for conservation of organic waste in the state.

The success obtained with hydroponics, the growing of crops in tanks of water or sand, has led some proponents of this practice to discredit the value of organic matter in crop production. As a matter of fact, in spite of the fact that crops are grown by hydroponics without the use of organic matter, it actually proves the need of organic matter in the cropping of soils. In tank cultures the water in which the roots are growing must be continuously circulated or stirred with a stream of air otherwise the roots will die. In soils organic matter serves the same purpose as the air in the tank cultures, for it is the principal agent which, by its decomposition, provides for aeration (soil breathing) which is so vital to root growth.

For too long a period the American system of agriculture has been based on the exploitation of virgin land the productivity of which is largely due to the organic debris accumulated in these virgin lands over long periods of time. Experience has shown that as the process of cultivation and cropping "burns up" the organic matter in the soil, much of the original reserve fertility is progressively lost. This practice of exploiting virgin lands has also been true in times of emergency when demands have been made on agriculture for increased crop production. The fallacy of bringing in new lands, especially those of a marginal nature, was well demonstrated in 1917-18 when the dust bowl of the Southwest was created. The maintenance of the fertility of the soil is the first requisite in any permanent system of agriculture. It has been demonstrated that commercial fertilizers can be relied upon to maintain the plant food level of the soil in most particulars. In spite of this, however, soil deterioration will eventually occur if the organic matter is depleted, for soil fertility is not a simple matter of sufficiency of plant food but involves a large group of co-ordinating factors, many of which are favorably influenced by organic matter.

This part of the bulletin is prepared in response to many requests for information on the fertilizing value of manure and other organic farm wastes, which by composting can be converted into an artificial manure not greatly unlike animal manure and

in many cases of equivalent value. A conservative estimate states that one half the value of farm manure produced in the United States never reaches the field because of losses occurring in careless handling. This loss is estimated in millions of dollars, much of which could be conserved if farmers were in possession of information which explains the nature of these losses and would thus help them to store farm manure in such a manner as to retain its maximum value.

Some Facts about Animal Manures

Farm manures are composed of solid and liquid portions in which one half the nitrogen, practically all the phosphate, and two fifths of the potash are in the solid portion. These three elements give manure its principal fertilizer value. Of course the composition varies over wide limits depending upon the kind of animal, the age, the kind of food the animal eats, and finally the handling or storage of the manure preceding its application to the land. In Table 1 is given the average composition of animal manures produced on the farm (from Lyon and Buckman, *Nature and Properties of Soils*).

TABLE 1.—COMPOSITION OF ANIMAL MANURES (PER CENT).

Manure	Water	Nitrogen (N)	Phosphate (P ₂ O ₅)	Potash (K ₂ O)
Wet basis				
Horse.....	78	0.69	0.25	0.55
Cattle.....	86	0.59	0.15	0.45
Sheep.....	68	0.94	0.35	1.00
Swine.....	87	0.49	0.35	0.45
Poultry.....	57	1.08	0.40	0.50
Dry basis				
Horse.....	—	3.14	1.14	2.50
Cattle.....	—	4.22	1.07	3.21
Sheep.....	—	2.94	1.09	3.12
Swine.....	—	3.78	2.70	3.08
Poultry.....	—	2.51	0.93	1.16
Pounds supplied to soil by 10-ton application of manure				
Wet basis				
Horse.....	—	138	50	110
Cattle.....	—	118	30	90
Sheep.....	—	188	70	200
Swine.....	—	98	70	80
Poultry.....	—	216	80	100

The figures in this table apply to manure which contains no litter or bedding and has lost none of its fertilizer constituents from decomposition or leaching. Animals fed on concentrated feeds like cottonseed meal will produce richer manure, and those fed on grass or cereal hay will produce manures of less fertilizer

value. When manure is purchased, a chemical analysis is useful for estimating its fertilizer value and for judging the care with which it has been stored.

For those interested in the amount of manure (lbs. daily) produced by animal units the following data are given.

Horse.....	43.5
Cattle.....	72.0
Sheep.....	4.0
Swine.....	9.5
Poultry.....	0.1

These data are taken from the 1938 Yearbook of the United State Department of Agriculture to which the reader is referred for several valuable articles on manure and farm waste.

These data and those given in Table 1 will acquaint farmers with the approximate fertilizing value of farm manure and with the productive capacity of animal units on the farm. The fertilizing value of this form of farm waste is clearly evident from these data and should help the farmer to appreciate the value of its conservation. To further amplify these data, a 10-ton application of farm manure is approximately equivalent to 500 pounds of ammonium sulphate, 100 pounds of treble superphosphate, and 200 pounds of sulphate of potash, and on this basis has a value of about \$2 per ton. Thus while manure is generally classed as a low-grade fertilizer, on the basis of its plant food content, its proper preservation will materially reduce the commercial fertilizer expense on the farm. Furthermore if it is applied with commercial fertilizer it will greatly increase the efficiency of both.

It should be pointed out, however, that the value of manure should never be based entirely on its plant food analysis, for in reality it is worth what it will produce in crop gains when applied to the land. That it has much value in addition to its plant food content has been demonstrated many times, and this is especially true for semiarid soils such as exist in Arizona. Soil productivity, in the semiarid lands of the Southwest, is just as much dependent upon the mechanical condition of the soil and the activity of beneficial soil bacteria as upon available plant food. In fact, in many cases the value of commercial fertilizer may be completely lost in irrigated lands because of an undesirable soil structure limiting drainage and therefore root development. Manure, when properly incorporated with the soil, improves soil structure and thereby eliminates many growth limiting factors common to irrigated lands. It is of interest that all soil types are benefited by manure—the heavy clay soils on the one extreme and the light sandy soils on the other. In clay soils it increases porosity and reduces plasticity; in sandy soils it has a binding effect and retards excessively rapid percolation of irrigation water.

It may also be of interest to mention the vitamin B₁ content of manure. It is generally conceded that most soils contain sufficient vitamin B₁ for normal plant growth, but since this vitamin is associated with organic matter in soils, and semiarid soils are so

deficient in organic matter, it is not unreasonable to suppose that manure is of some value as a source of vitamin B₁ for Arizona soils. Chemical analyses have definitely shown the presence of vitamin B₁ in animal manure.

The only way to get the full value of manure as a soil amendment is to provide some means for its complete transfer, both liquid and solid portions, to the land. This is not always possible and thus it has become the practice to store or compost the manure awaiting a convenient time to apply it to the field. Furthermore when straw bedding is mixed with the manure it is not advisable to apply it directly to the land, especially just preceding the planting of a crop or during the growing period. A word about straw at this point may be of interest. Many farmers have learned by experience that crops, following the plowing under of straw, make very poor growth. The reason for this is that the bacteria which break down the straw in the soil compete with the crop for nitrogen as food. If there is insufficient nitrogen for both the crop and the bacteria, the crop will suffer. Leguminous crops, which obtain their nitrogen from the air, are the only crops that can be planted after straw. Because of this many farmers have adopted the practice of burning grain stubble and straw stacks rather than returning the straw to the soil where it rightfully belongs. For the same reason if manure contains much straw litter, ample time for decomposition of the straw should be allowed before planting a crop, or better it should be composted until the straw has been decomposed.

Some Pointers on Composting Manure

Many factors must be considered in the storage or composting of manure if one desires to preserve its fertilizer value and produce a final product which is suitable for incorporation with the soil. The losses occurring in the composting of manure are largely loss of nitrogen by volatilization as ammonia or free nitrogen and loss of soluble constituents such as the salts of nitrogen, phosphate, potash, and calcium by leaching.

The principal loss of nitrogen is as ammonia and to prevent this loss chemicals which fix nitrogen are added to the compost. *Gypsum* is one of these and should be added to the compost at the rate of about 100 pounds per ton of manure. *Superphosphate* is another material that is extensively used for fixing nitrogen. It has the additional value from a fertilizer standpoint of adding a valuable plant food. A glance at the chemical analysis of manure will show that it contains far less phosphate than nitrogen or potash and phosphate is much needed on many Arizona soils. It should be mixed with the manure at the rate of about 25 pounds per ton. *Liquid phosphoric acid* which is now being used to a certain extent as a fertilizer in Arizona and is applied in the irrigation water also lends itself well to composting as a fixing agent for nitrogen. Its acidity neutralizes the alkalinity formed by

ammonia, and it can be conveniently sprayed on the compost, in dilute form, as the compost is being built. It should be used at the approximate rate of 20 pounds per ton of manure. *Sulphuric acid* is another acid which may be used for fixing ammonia, but it lacks the fertilizer value of the phosphoric acid. Finally *sulphur* is an extremely suitable material. During the composting period it changes to sulphuric acid and thus acts as an agent for nitrogen fixation. All these materials may be used to advantage, and in the selection of the one best suited the cost of the various materials should be given due consideration. If provision is made to prevent leaching while the manure is in compost, an effective preservation of the fertilizer value can be accomplished.

In some cases much of this loss can be prevented without the use of chemicals by compacting the manure sufficiently to exclude most of the air. This prevents overheating with its attendant loss of ammonia, insures less alkalinity during decomposition, and reduces danger of leaching loss. However, since all the fixing agents mentioned above have a beneficial effect on the soil, their use is advisable even in compacted composts.

Manure exposed to the weather, without provision for protection from losses, will lose one half its fertilizer value in just a few months' time.

Composting in pits will keep the compost at a lower temperature and reduce the loss of nitrogen. A small amount of straw litter in the manure compost will also help to prevent nitrogen losses.

For above-ground composts the smaller the piles the less the danger of firefanging.

Turning the compost will increase the rate of decomposition but will tend to form higher temperatures and may cause the compost to catch fire.

At the Rothamstead Experiment Station in England, where at least a century of study on manure and its utilization has been conducted, four rules are suggested for manure storage and composting: (1) a thoroughly compact pile; (2) sufficiently moist but not too wet material; (3) shelter or other type of protection; (4) no disturbance of the pile once it is constructed.

Suggestions for Composting Manure in Arizona

Having shown the fertilizer value of manure, its other properties which are useful in maintaining soil productivity, and the danger of losing part of the fertilizer value in storage, how should manure be composted under Arizona conditions?

Two types of compost are possible—namely, the above-ground compost and the pit, cistern, or trench type of compost for storing below the ground surface. The ideal method of storage is of course the concrete pit. It is the only way in which leaching losses can be effectively prevented but in spite of the fact that the saving in plant food from leaching loss would pay for the

concrete in a few years, few are willing to invest in the initial cost of such a pit. The next best plan is to use a soil pit, in the bottom of which the soil is tightly packed, or even a pit above ground constructed in such a way as to protect the sides.

Regardless of the method employed there are several objectives to keep in mind. The straw in the manure must be broken down and the manure brought to a mechanical state in which it can be thoroughly incorporated with the soil. If the amount of straw is excessive it will be necessary to mix about 20 pounds of ammonium sulphate per ton of manure while the compost is being constructed. If the straw content is not excessive, most manures will contain sufficient nitrogen to support a good decomposition of the straw. A slow decomposition in a well compacted pile is more advisable than a rapid decomposition in an open pile or one which is turned at regular intervals. The cost of labor involved in turning is also a factor to consider. As much of the nitrogen as possible should be fixed, for nitrogen is the most expensive form of plant food in commercial fertilizer. It is advisable therefore to use a fixing agent in the compost. Probably the greatest point in favor of the pit compost in Arizona is that an above-ground compost will dry rapidly and therefore require frequent watering with its attendant danger of losses from leaching. A properly prepared pit compost should require little or no watering once its construction is complete.

On the basis of available information the following recommendations are offered for building manure composts in Arizona:

1. Start with a layer of manure about 1 foot deep, well compacted.
2. Sprinkle with superphosphate, sulphur, gypsum, or whichever fixing agent is selected.
3. Cover with a layer of soil 1 inch deep.
4. Repeat these three steps until the pile reaches a height or depth of about 5 feet or 5 layers of manure.
5. Cover final top layer with about 6 inches of soil (or a layer of gypsum) to prevent the surface from drying.
6. Allow to remain undisturbed until the mass is mechanically conditioned for spreading on the field.

Suggestions for Composting Waste for Artificial Manure

For a full appreciation of the value of all kinds of organic farm waste one must turn to the Oriental countries of the world where agriculture has been practiced since ancient times or to Europe where it is much older than in the United States and where they have already felt the "pinch" of organic matter depletion in their soils. In India they even go so far as to remove about 6 inches of soil from the dirt floors of stables and feed lots every 3 months and use this as fertilizer on their fields. Each time this is done fresh soil is carried from the field to replace that taken from the stable or feed lot. In many of the European countries the produc-

tion of artificial manure by composting organic farm waste has been practiced on a large scale, and it has been conclusively demonstrated that a good grade of manure can be prepared in this way. In India such materials as paper, sawdust, shavings, and even dry cotton stalks are utilized.

In recognition of the conservation of organic matter in the Orient and the necessity of maintaining soil productivity in thickly populated countries of Europe, where animal manures are no longer produced in sufficient amounts to maintain the organic level in the soil, an extensive study has been made of the process of manufacturing artificial manure on the farm. Most of the materials which are available are high in cellulose and with the development of knowledge of the kind of bacteria which can break down cellulose and the kind of food these bacteria need in order to be most active, composting of such waste has been placed on a well-controlled basis. The "ADCO" process of composting farm waste has received the most publicity and was developed in England. In this process an "ADCO" mixture of chemicals is recommended for use in bringing about a decomposition of the compacted waste. During the past 20 years considerable interest in artificial manure has developed in the United States. This is due to a growing scarcity of animal manure and the knowledge, especially existant among farmers in the semiarid Southwest, that manure does definitely have a place in any efficient productivity program.

In the past it has been the common practice to burn cereal straw or stubble in the field, and this is true also for weeds and grass. It has been the experience of farmers that straw and similar crop wastes, which are high in cellulose, decompose very slowly in the soil. They have also observed that when straw is plowed into the ground and is not thoroughly decomposed by planting time the growth of the crop will be affected and sometimes seriously injured. As already stated this is due to competition for nitrogen between the crop and the bacteria decomposing the straw, and the crop is usually the loser. In view of the above the farmer has had just cause, in the past, for following such a practice, but with present knowledge of composting and the requirements of the bacteria which can decompose straw there is no excuse for a continuation of such a practice.

In the United States a number of agricultural experiment stations have investigated the practicability of making artificial manure on the farms of this country. Notable among these are the Iowa, Indiana, Michigan, New York, Wisconsin, and Missouri stations.

The Michigan station recommends the following procedure in building a compost from farm waste, principally straw. Start with 1 foot of straw, sprinkle with a chemical mixture and repeat this until the pile is 5 feet high. The chemical mixture they recommend is composed of forty-five parts by weight of ammonium sulphate, fifteen parts single superphosphate, and forty

parts limestone and is added to the compost between the layers of straw at the rate of 150 pounds per ton of dry straw. On the basis of their observations the following suggestions are offered: the rate of decomposition in the compost depends upon (1) green or dry plant material, the former being more rapid, (2) presence of nitrogenous food for the bacteria, (3) moisture content of the compost, (4) temperature of the compost. Water absorption by straw is very small at the start but increases as decomposition proceeds. During the compost period most weed seeds sprout and are destroyed. Composting from June to November yielded a good manure under Michigan conditions. If any great volume of legume hay is available or if some manure is mixed with the straw the farmer may save some of the expense by eliminating the chemical mixture, as the manure and legume hay contain considerable nitrogen.

The New York station recommends a similar type of compost structure but finds that best rotting takes place if some potash is included in the chemical mixture. The mixture which they recommend for addition to the compost is composed of 60 pounds of ammonium sulphate, 50 pounds of limestone, 30 pounds of superphosphate, and 25 pounds of muriate of potash per ton of dry straw. They recommend that special attention be given to (1) building the pile, (2) proper treatment and application of the chemical mixture, (3) adequate watering of the compost, (4) subsequent watering to keep down the temperature and to keep the pile moist, (5) occasional forking over.

The chemical mixture recommended by the Wisconsin Experiment Station is composed of 60 to 70 pounds of ammonium sulphate, 50 to 60 pounds of limestone, and 20 to 25 pounds of superphosphate per ton of dry straw. They recommend a 5 to 6 months' period of decomposition provided the pile is kept properly moistened.

At the Iowa Experiment Station it was found that aeration, turning the pile, is not only unnecessary for best decomposition of the waste but may actually be undesirable. It brings about a decrease in the extent of decomposition and causes considerable loss of nitrogen. A small degree of aeration is however beneficial.

The so-called "ADCO" process, developed in England, is essentially as follows: Each layer, consisting of about 6 inches of compacted straw, is sprinkled with the ADCO chemical mixture at the rate of 150 pounds per ton of dry straw. The ADCO chemical mixture is a patented formula. It is then washed in thoroughly by wetting. Each successive layer is treated in this way until the pile is about 4 feet high. The pile should be left flat on top. Fermentation soon starts, and the temperature rises. The temperature is kept down by frequent additions of water until sufficient decomposition has taken place to reduce the temperature permanently. Less frequent watering is required from this point. After about 3 months, depending upon conditions,

the straw will be rotted to a mass resembling rotted manure in general appearance. One ton of fresh straw will make from 2 to 3 tons of rotted manure.

Preparing Artificial Manure under Arizona Conditions

The following procedure is recommended for producing artificial manure from straw and similar agricultural waste on Arizona farms.

When equal parts of manure and straw, or other similar waste, or mixtures containing more manure than straw are used in building the compost, it will not be necessary to add any ammonium sulphate or other nitrogenous fertilizer unless the manure is of very poor grade. In the case of composts containing straw in greater proportion, it is advisable to use ammonium sulphate or other chemicals in the compost. In such cases a mixture of 20 pounds of ammonium sulphate and 15 pounds of treble superphosphate per ton of straw is suggested. In view of the fact that cattle feeding is a major industry in the irrigated valleys of Arizona, manure is obtainable in most sections of the state. Therefore straw-manure composts are recommended rather than straight straw composts.

Each 1-foot layer of composting material is sprinkled with the chemical mixture, if needed, at the rate given above. The material is then wetted provided it is not already sufficiently wet. Ordinary wet manure will contain 50 to 70 per cent water. It is then sprinkled with a layer of about 1 inch of soil. These steps are repeated until the compost contains five layers—namely, a height of about 5 feet. The top should then be covered with a layer of about 6 inches of soil. If gypsum is available at low cost, it may be used instead of soil. An occasional examination of the compost will show whether additional water is needed to keep the compost wet.

Additional Pointers

Above-ground composts are not recommended nor is rapid decomposition advisable under Arizona conditions. In other words pit composting and slow decomposition are best suited to Arizona conditions.

Above-ground composts will require frequent watering in this climate. Also weed seeds on the edge of the pile will probably not germinate. Pit composts will require little or no watering if covered with a layer of soil or gypsum as recommended. An advantage in pit composting is that the mass can be kept uniformly wet thus assuring uninterrupted decomposition and the destruction of a greater number of weed seeds. Loss of volatile and soluble fertilizer constituents will be reduced to a minimum.

The layer of soil suggested for placement between layers of compost material has several functions. Practically all the arable soils of Arizona are calcareous. It therefore serves to maintain the reaction of the compost at near neutrality. It also acts as an

absorbent for any volatile ammonia, and finally it will add body to the final compost and thus assure a more even distribution in the soil when it is applied to the field.

A further recommendation, and one that is extremely important, is that for most efficient composting two separate pits should be used. This will permit a year, or approximately so, for each compost to remain in process of decomposition. While one pit is being emptied another lot is undergoing decomposition in the second pit.

An occasional examination of the compost is advisable, for it should be continuously wet but never allowed to become waterlogged. Straw will absorb about five times its weight of water.

In Arizona where many farms have feeding pens, a good way to mix farm waste and manure is to place the straw and crop residues in the feed yard. Then when it is thoroughly saturated and mixed with the manure the whole will be better suited to composting.

In constructing a pit for composting, it is advisable to make it at least the width of a truck and leave one end open or fitted with a temporary gatelike end. This will be found useful in transporting the compost to the field, for the truck can then be backed into the pit for loading.

SOIL ANALYSIS AND FERTILIZER PROBLEMS

Foreword

The Arizona Agricultural Experiment Station maintains two laboratories, as a service to farmers of the state, for making analyses of soils, waters, and miscellaneous agricultural products. The number of such samples submitted to these laboratories and analyzed annually approximates 5,000. Of this number about 2,000 are soil samples many of which are submitted with a request for information on whether commercial fertilizer is needed for cropping them. This means a determination of the supply of available nitrogen, phosphate, and potash in the soil. In view of the large amount of time required to perform this type of work it seems highly essential that some means should be devised by which the farmer can get some practical benefit from this information, if it has any useful application. Some food manufacturers and producers who own or control the operation of large areas of land are using soil analysis quite successfully as a guide to soil fertilization. This part of the bulletin is intended to convey information to farmers of the state by which it will be possible from soil analysis to make inventories of the supply of available plant food in their soils and from a knowledge of the plant food required to produce a crop assist them in determining the need for commercial fertilizer. This section has been prepared to supply frequent demands for information on how best to regulate the plant food supply in the soil so that maximum crop yields will be possible.

Introduction

The importance of commercial fertilizer in crop production continues to increase steadily from year to year in the United States and still has far to go before reaching a condition of partial stability. When one examines the fertilizer consumption of the United States by the separate states, it is evident that the consumption in the West is only a very small fraction of the total. Actual tonnage consumption in the United States has continued at an approximate 8,000,000 tons now for about 10 years (consumption in Arizona is about 8,000 tons). It must be recognized that this apparent stability of tonnage is due to an increase in the plant food content of fertilizer, to more efficient methods of application, and to other progressive steps which science has contributed to crop production. The greater care and precision of methods used by fertilizer manufacturers in mixing their product, in increasing the plant food content, and the manner in which their advertising has publicized the accomplishments of research in soils and plant nutrition have been instrumental in the growing appreciation of the value of fertilizers among farmers.

Where the use of fertilizer is necessary, it becomes an important item in the farmer's cost of production. He is therefore inter-

ested in spending wisely, using fertilizer only where and when it is needed, and applying it in the most economical amounts. Excessive applications greatly reduce the return in yield per unit of fertilizer applied, and applications which are too small to meet the crop's requirement may produce no increase in yields. As a guidance in planning the fertilizer program farmers have solicited the aid of the soil chemist, for the science of chemistry lends itself well to the analysis of soils. To what extent then can soil analysis help?

Soil Analysis

It is interesting to note that soil analysis antedates the commercial fertilizer industry by many years. Upon the entry of chemistry into the field of applied sciences, one of its earliest applications was in the field of soils and plant nutrition. Since crops require mineral elements for food and the only source of such food is the soil, it appeared to be a relatively simple matter to make an inventory of the plant nutrient resources of the soil by means of a chemical analysis. For more than a century soil chemists have worked on the problem of soil analysis, and many are still quite pessimistic about its value in spite of the fact that much progress has been made. The difficulty is not in the analysis itself, for the analysis is a relatively simple procedure. Many methods are available by which it is possible to determine the total amount of mineral plant food in the soil regardless of whether it is present in large amounts or in infinitesimally small amounts. Then again it is possible to determine the solubility of these minerals in everything from strong acids on the one extreme to water on the other. The difficulty lies in trying to interpret the analysis on the basis of the ability of the plant roots to withdraw it from the soil. In other words, can the solvent action of the root be imitated with sufficient exactness? Since there is much doubt about this, the chemist is forced to resort to empirical methods of interpreting the data on the basis of the known properties of soil minerals in general.

The steps through which soil analysis has gone during the last 100 years, notably the methods employed in estimating the fertilizer requirements of the soil, are herewith outlined. At first no attempt was made to estimate the availability of the plant food minerals. It was considered merely a matter of taking inventory of the total amount present in the soil, assuming that all minerals gave up mineral food to plants. For this type of analysis the soils were treated with strong acids, and such methods continued in use among soil chemists for many years before a variation in degree of availability of minerals to plants was suspected. It is of interest to state that the major part of the phosphate and potassium and a large part of the other plant food elements present in the soil are there in forms which are not immediately available to crops. That is, they do not respond to the solvent action of plant roots.

When this condition was recognized, soil chemists attempted to imitate the solvent action of the roots. On the basis of a belief that roots secrete acids, and in this manner can dissolve the soil minerals with which the roots make contact, chemists began to use weak solutions of many acids. By a comparison of many such analyses for soils which gave response to fertilizer and those which did not respond, it has been possible to use several of these dilute acid solutions with much success on some soil types and some crops. But the system does not lend itself to universal application.

Somewhere in the chain of events a question arose which contributed much to the recent developments in soil analysis and has brought it to a point of notable usefulness. The question involved a recognition of the fact that in applying for example 300 pounds per acre of a 5-10-5 fertilizer (5 per cent nitrogen, 10 per cent phosphate, 5 per cent potash) to a soil, the amounts were actually so small that they could not be determined by any known methods of chemical analysis, yet such an application will produce a profitable increase in crop yield on many soils. Obviously then more delicate methods were needed in soil analysis if it was to be of any practical value in determining the fertilizer requirement of the soil.

The following will illustrate this. An acre-foot of soil weighs approximately 4,000,000 pounds. This depth of soil is chosen because most of the feeding roots of a crop are confined to this depth. Arizona soils will of course vary in their composition but on an average will contain 2.16 per cent potash (K_2O), 0.25 per cent phosphate (P_2O_5), and 0.06 per cent nitrogen (N). On this basis an acre-foot of Arizona soil will contain 86,000 pounds of potash (K_2O), 10,000 pounds of phosphate (P_2O_5), and 2,400 pounds of nitrogen (N). In a 300 pound application of a 5-10-5 fertilizer to an Arizona soil, which application will give a profitable return where deficiencies exist, there is added only 15 pounds of nitrogen, 30 pounds of phosphate, and 15 pounds of potash. If such an application is distributed through an acre-foot of soil it will represent, on a percentage basis, 0.00037 per cent nitrogen (N), 0.00074 per cent phosphate (P_2O_5), and 0.00037 per cent potash (K_2O). This will illustrate the magnitude of the problem before the soil chemist in working out a practical method for estimating the fertilizer requirement of the soil.

Few chemical methods up to a short time ago could measure such small percentages of nutrients accurately. Also it must be hard for a farmer to accept the fact that 30 pounds of phosphate per acre will, in the form of commercial fertilizer, increase yields on a soil that already contains 10,000 pounds. Such knowledge has stressed the value of small amounts of available plant food in soils and is sufficient reason why the soil chemist has continued at his task of searching for methods of measuring plant food availability.

Faced with this situation he has turned to the so-called micro-methods of analysis—namely, methods by which extremely small amounts of mineral plant food elements, even less than the amounts ordinarily applied as fertilizer, can be determined in soils. Their efforts in this field have been crowned with notable success. It has allowed the use of much weaker solvents for extracting soils—that is, solvents of acidity more closely corresponding to the acidity developed around the immediate feeding zone of the root. It is not advisable to express such small amounts in percentage, and so the plan of expressing the analysis in parts per million parts of soil (p.p.m.) has been adopted. The advantage of this method lies in the fact that whole numbers can be used and further that, since an acre-foot of soil weighs 4,000,000 pounds, parts per million can be converted to pounds per acre-foot simply by multiplying by four.

Method of Analysis

In the Soils Department of the Arizona Agricultural Experiment Station a great deal of time has been devoted to studying chemical methods for determining available plant food in Arizona soils. The so-called quick field tests, which are so extensively employed in many sections of the United States by means of small kits carried into the field from which many tests are conducted at very low cost with a thoroughness in sampling not practicable in laboratory methods, have not been found to be suited for the alkaline-calcareous soils of this state. By use of the field test, results are usually expressed as blank, low, medium, and high. The failure of such methods on Arizona soils is true principally for phosphate, a nutrient which is widely deficient in availability. The method which is thus far best suited to Arizona soils appears to be extraction with carbonic acid and for the present is strictly a laboratory method.

Carbonic acid is best suited for alkaline-calcareous soils because it is the weakest acid which lends itself to analytical procedure, and it is the solvent used by roots in extracting their mineral food from the soil. The reaction at which plant food is most readily dissolved from the soil and absorbed by roots is a faintly acid reaction. Carbonic acid best supplies this faint acidity for this type of soil. The method is given here for those who are interested in the procedure:

Weigh 50 grams of soil into a wide mouth bottle, 1 liter capacity, fitted with a two-way stopper, and add 250 milliliters of distilled water. Shake thoroughly by hand and connect with a source of carbon dioxide gas, preferably a tank of liquid carbon dioxide. The two-way stopper is fitted with an inlet tube reaching to the bottom of the bottle and an outlet tube extending only slightly below the cork. If more than one soil is analyzed at a time they should be connected in series of not more than six. A longer series than this is not advisable. Pass a vigorous stream of carbon dioxide gas through the soil-water mixture for 15 minutes,

twirling the bottle occasionally to bring into suspension any soil that tends to settle out on the bottom of the bottle. This will insure better contact of the entire soil with the carbonic acid. At the end of the 15 minutes replace the two-way stopper with a solid stopper and shake vigorously by hand. Filter immediately and determine phosphate, nitrate, and potassium in aliquots of the filtrate by any acceptable colorimetric method. The data obtained from this analysis may be considered a workable inventory of the supply of available plant food in the soil.

By calculating such an analysis to pounds per acre-foot of soil and comparing this with pounds of plant food removed from the soil by a crop, or pounds of fertilizer which are known to give crop response, the analysis can be placed on a fairly intelligible basis. Productive soils must contain an adequate supply of plant nutrients in an available form, and chemical tests are the best known means of rapidly diagnosing plant food deficiencies in soils. The chemical analysis will definitely show when a deficiency exists and also when there is a surplus. It is the border line analyses, between deficiency and sufficiency, that must be interpreted with some degree of speculation, for plant food availability is by no means the only growth limiting factor in a soil. If a correct interpretation of borderline analyses is to be made, all other soil conditions must be known to be normal, a condition which is rarely true.

Among the other growth limiting factors is the mechanical or physical condition of the soil commonly referred to as soil structure. Soil structure regulates drainage, air movement, and root growth. Other growth limiting factors are tillage methods, soil temperature, water supply, seasonal variations in climate, and many others. For Arizona soils white and black alkali, which are always present in more or less degree, must be added to the list. These factors not only affect the solubility of mineral plant foods but also affect the absorptive mechanism of the roots. Any single growth limiting factor, regardless of the importance of all others, may act as a controlling factor in crop production. Thus in many cases soil analysis fails to diagnose the role of plant food availability in crop behavior because of the existence of another growth limiting factor which is not under control.

Soil Sampling

Before going further with the discussion of soil analysis, it should be of interest to present some information on soil sampling. The greatest source of error and therefore the greatest limitation in the accuracy of soil analysis is the degree to which the soil sample actually represents the field in question. In spite of this, no strict rule can be laid down to govern the taking of soil samples except that the sample, in the judgment of the sampler, should represent, as nearly as possible, the area under investigation. The amount of soil actually used by the chemist in an analysis is very small—namely, about one 200 millionth part of

an acre-foot of soil. Since the chemical analysis is extremely accurate the need for judgment and care in taking the sample is self-evident.

Composite samples made up of borings from several locations in a field are preferable to single samples. However, if there is a variation in soil type within the area, composite samples should be confined to single types. For a determination of available plant food in the soil only the surface foot of soil should be represented in the sample. Many other things should be considered, a few of which are as follows:

1. The depth of sample is important because available plant food is always greatest in the surface soil and decreases in amount with depth of the soil layer. This is especially true of phosphate and potash which unlike nitrogen are permanently fixed in the soil and only slightly soluble in the soil solution.

2. Time of sampling with respect to time of irrigation is important in considering the soluble nitrogen in the soil, for nitrate nitrogen moves readily with the water.

3. Samples taken from a soil supporting a growing crop will usually show a lower available plant food analysis than a fallow soil.

4. If the field has been fertilized, the soil will test higher in available plant food than if unfertilized.

5. If a field is spotted with good and poor areas, these should be sampled and analyzed separately.

6. Slopes are usually less fertile than level areas and should therefore be sampled and analyzed separately.

For taking soil samples three methods are commonly employed in Arizona—namely, the soil tube, the soil auger, and the spade.

Interpretation of Analyses

In reports issued from this laboratory the analysis is expressed as parts per million parts of soil or as pounds per acre-foot of soil. This type of report is illustrated by the following typical soil analysis.

	P.p.m.	Lbs. per acre-foot
Phosphate (PO_4)	5	20
Potassium (K)	60	240
Nitrate nitrogen (N)	22	88

Nitrate nitrogen

Nitrate nitrogen is determined as nitrate (NO_3) but expressed as nitrate nitrogen (N) because the nitrate form is immediately available for plant use. All soils possess a nitrogen reserve, usually in organic form, but the organic matter content of Arizona soils is so low that the reserve supply is low in consequence. For this reason except for special purposes, total nitrogen is not determined in the routine analysis of Arizona soils. The best test for available nitrogen would be to incubate a weighed portion of soil at a favorable temperature and moisture content for a

given period of time and then determine the amount of nitrate formed in the soil during this period. Such a test would not only show the total available nitrogen in the soil but would also show the supplying power of the soil. This test requires considerable time and outlay of equipment so is not used except in special cases.

Nitrate nitrogen is very soluble in water and, since it is not fixed by the soil, moves about in the soil with the movement of the water—namely, downward with an irrigation and returning to the soil surface by capillarity as water evaporates from the surface of the soil. Obviously then when water evaporates on the surface of the soil, at the top center of a lettuce or cantaloupe bed, or on the crest of a cotton row, nitrate is deposited and accumulates at these points. During a single lettuce season 200 to 300 parts per million nitrate nitrogen may be deposited on the surface center of the bed by evaporation of irrigation water drawn to this point by water applied in the furrows between the beds. Since the beds are not flooded, this nitrate remains inaccessible to the plants unless a rain washes it into the beds or back into the furrows. This example is cited to show how many factors must be considered in interpreting an analysis of the soil for nitrate.

It is especially important that in interpreting the nitrate determination the time at which the sample was taken with respect to an irrigation must be considered. Also nitrate is rapidly absorbed from the soil by crops, and it is helpful to know whether the soil sample was taken from a soil supporting an actively growing crop.

The appearance of the foliage of a crop is also helpful in diagnosing nitrogen deficiency in soils. If the nitrate supply is low, the leaves will have a yellowish green color, and the plant will be stunted or slow in growth. If the nitrate supply is excessive the foliage will be dark green, plant tissue will be very succulent, and maturity will be delayed.

In purchasing nitrogenous fertilizer it is often necessary to use some judgment in the selection depending upon how soon after application it will be needed by the crop. Nitrate nitrogen is immediately available to practically all crops. Ammonia nitrogen is only immediately available to a limited number but is fixed in the soil and becomes immediately available to all when it is changed over to nitrate by soil bacteria. Organic nitrogen is not available immediately to any crops but is changed to ammonia and nitrate forms by soil bacteria. Since soil temperatures greatly influence the nitrogen transformations in the soil and both summer and winter crops are grown in Arizona, season should be considered in selecting the best form of nitrogen for a given crop.

Phosphate

Because of the strong fixing power of soils for phosphate and the poor availability of the form in which phosphate exists in Arizona soils, the measurement of phosphate availability is of

major importance. The choice of carbonic acid as the reagent for determining available plant food in Arizona soils was largely because of its suitability for the measurement of available phosphate. There is no deficiency of total phosphate in Arizona soils. As already mentioned they contain, on an average, about 10,000 pounds per acre-foot. This would support crops for a great many years if it was present in a form which roots could extract from alkaline-calcareous soils. Because of the form or combination in which it exists, because of the highly calcareous nature of the soils, and finally because of the high pH (alkalinity) many crops are not able to use this natural supply efficiently. It is rendered quite soluble by acidulation. In fact it is so soluble in acids that it is necessary to use the weakest possible acid, carbonic acid, to accurately measure the availability.

On this same basis—namely, the solubility of soil phosphate in weak acids, any soil treatment which will reduce the pH of Arizona soils will increase the solubility and availability of the phosphate. Therefore the phosphate problem, as it concerns Arizona soils, is an economic problem—is it cheaper to buy soluble phosphate fertilizers when the soil analysis shows a phosphate deficiency or to reduce the alkalinity (pH) of the soil by using some acidulating agent or manure? For crops which require heavy phosphate fertilization it is good practice to use both manure and phosphate fertilizer for most effective results.

Phosphate fertilizers are rapidly and strongly fixed by Arizona soils, but experiments have shown that the phosphate fixed from the fertilizer addition remains available over an extended period of time. Since it cannot move from its fixed position in the soil it is only available to roots which come in contact with it. This makes phosphate fertilization a less efficient operation than nitrogen fertilization. Therefore a large excess of phosphate over that actually needed by the crop must be added to the soil. Because of the strong fixing power of the soil for phosphate, the soil solution rarely contains more than a mere trace of phosphate. In determining the availability of phosphate in Arizona soils it is therefore necessary to show the supplying power of the soil rather than the phosphate present in the soil solution. "Supplying power" means the ability of the soil to keep the soil solution supplied with a small amount of phosphate as fast as the crop withdraws it. It is believed that extraction of the soil with carbonic acid supplies this information.

There are a few plant symptoms which are useful in diagnosing phosphate deficiency in soils. When this element is deficient the plant will be stunted in growth but have a normal green color, and there will be a tendency for the plant to seed when quite small. There is less tillering or stooling in grains when phosphate is deficient and the grains are smaller. Such conditions may, however, be changed by variations in ratio of phosphate to other plant foods which is the reason for the great number of mixed fertilizer brands or grades on sale.

Potassium

As in the case of phosphate all Arizona soils contain a large reserve of potassium in several mineral forms of widely varying availability. It differs from phosphate though in that a large part of it is available to crops. Practically all the crops grown in Arizona require large amounts of potassium, some requiring more potassium than nitrogen. It therefore plays an important part in the productivity of Arizona soils. However, thus far the reserve supply in the soil has been amply sufficient to meet all crop requirements and so potash is not often used as a fertilizer in this state. The carbonic acid method appears to be well suited to the determination of available potassium in alkaline-calcareous soils.

As with most plant food elements many plant symptoms are useful in diagnosing potassium deficiency in soils. The symptoms occur in the form of leaf disturbances such as premature shedding, bronzing, and marginal firing.

The Practical Use of Soil Analysis

As previously mentioned, when a plant food analysis of a soil is expressed as parts per million it can be converted to pounds per acre-foot by multiplying by four. If one knows how many pounds of the various plant food elements it takes to produce a crop or the number of pounds removed from the soil by an average crop, a comparison of this with an analysis expressed as pounds per acre-foot forms a practical method of using soil analyses. Such a procedure is actually practiced by organizations engaged in crop production on a large scale which have sufficient acreage to employ a chemist of their own. In Table 2 there are given the pounds nitrogen (N), phosphate (PO_4), and potassium (K) removed from the soil by an average yield of a number of crops grown in Arizona. The yields used in these calculations are also given in the table.

It will be noted from the information given in this table that a crop of 750 boxes of grapefruit per acre will remove from the land 70 pounds of nitrogen equivalent to 436 pounds of sodium nitrate or 350 pounds of ammonium sulphate; 36 pounds of phosphate equivalent to 60 pounds of treble superphosphate; and 90 pounds of potassium equivalent to 200 pounds of sulphate of potash. All these would have to be returned to the soil annually if the soil was deficient in forms available to the feeding operations of the crop. From a comparison of this with the average amount of fertilizer used on Arizona grapefruit groves it is quite evident that the natural reserve fertility of Arizona soils is supplying most of the nutrient requirement of this crop. Since many California and Florida citrus groves spend \$30 or more per acre annually for fertilizer, Arizonans should be interested in and appreciate their reserve soil fertility. Furthermore they should appreciate the nitrate nitrogen found in many underground waters. For example an analysis of a well water taken in the Salt

TABLE 2.—POUNDS NITROGEN (N), PHOSPHATE (PO₄), AND POTASSIUM (K) REMOVED FROM THE SOIL BY CROPS AND THEIR EQUIVALENT IN POUNDS SODIUM NITRATE, AMMONIUM SULPHATE, TREBLE SUPERPHOSPHATE, AND SULPHATE OF POTASH.

Crop per acre	Nitrogen (N)	Sod. nit. equiv.	Am. sulph. equiv.	Phosphate Treble super. (PO ₄) equiv.	Potassium (K)	Pot. sulph. equiv.
Grapefruit, 750 boxes*	70	436	350	36	90	200
Lettuce, 23,000 plants*	75	465	375	32	100	220
Alfalfa-A, 7 tons*	400	2,500	2,000	70
Alfalfa, 7 tons	291	1,820	1,455	110	256	570
Barley, 40 bu.	50	310	250	27	33	73
Cabbage, 15 tons	100	630	500	34	83	184
Corn, 60 bu.	95	590	475	47	58	128
Cotton, 1,000 lbs.	130	810	650	68	82	182
Oats, 50 bu.	50	310	250	27	37	82
Oranges, 600 boxes	90	560	450	40	108	240
Potatoes, 300 bu.	125	718	625	47	140	310
Tomatoes, 10 tons	100	620	500	47	145	320
Wheat, 30 bu.	50	310	250	27	25	55

*Calculated from analyses made at the Arizona Experiment Station; rest of data from information distributed by American Potash Institute.

River Valley during the past year showed about 400 parts per million nitrate nitrogen. While this is an exceptional case, there is no question that much nitrogen is being supplied by that naturally present in well water.

Alfalfa is the largest consumer of nutrients among the crops grown in Arizona. Fortunately alfalfa, like other leguminous crops, is capable of taking nitrogen from the air for use as plant food. As shown in Table 2 a 7-ton crop of hay requires about 400 pounds of nitrogen which is equivalent to 2,500 pounds of nitrate of soda or 2,000 pounds ammonium sulphate per acre. The nodule bacteria on the alfalfa roots therefore save the alfalfa grower at least \$50 per acre annually on his fertilizer bill. This illustrates again a factor that must be taken into consideration in interpreting a soil analysis—namely, that leguminous crops supply their own nitrogen and will leave some available nitrogen for the crop which follows it in the rotation. Alfalfa has a high phosphate requirement as shown by the amount removed from the soil by this crop. This is probably one reason why phosphate fertilization is profitable on many Arizona soils. The large amount of potash required to produce an alfalfa crop testifies strongly to the great reserve of this mineral plant food in Arizona soils, as thus far potash fertilizers have not been needed.

The small grains remove the least mineral plant food from the soil, and the truck crops are intermediate in their food requirements.

It is especially significant that crops remove considerably less phosphate from the soil than nitrogen or potassium. In spite of this fact the phosphate content of mixed fertilizers is often greater than either nitrogen or potash. The reason for this is that the efficiency of phosphate is greatly reduced by its fixation and therefore of low mobility. It is necessary therefore to add about five times as much phosphate in the fertilizer as is actually needed for the crop. In an actual measure of phosphate efficiency in a lettuce experiment conducted in Arizona, the efficiency was found to be 6 to 15 per cent using the band method of application. In other words, in this experiment only 6 to 15 per cent of the phosphate applied as fertilizer was utilized by the crop.

Summary

Information has been given in the nature of suggestions for some practical use of the hundreds of soil analyses being made in the Soils Department of the Experiment Station. While an analysis of a soil for available plant food can hardly be considered conclusive information on which to make a fertilizer application, it is useful in making a quick diagnosis. Furthermore it will become increasingly more valuable as information is accumulated on the general behavior of Arizona soils. Information is steadily being accumulated also on the difference in feeding power and fertilizer requirements of Arizona crops on Arizona soils which

will help greatly in interpreting soil analyses. In soil surveys being made in the state by the United States Department of Agriculture and the Arizona Experiment Station, productivity ratings are being made for the various soil types. This, too, is going to become increasingly more useful.

An excellent way to make soil analysis useful is to have fertilizer experiments scattered over a large number of soil types in the state from which soil samples can be taken for analysis. Such samples will represent soils of known performance toward fertilization, especially the magnitude of the response to fertilizer. By comparing the analysis of such a group of soils a correlation can be established between soil analysis and fertilizer response. In some eastern states such widely scattered experiments exist, but thus far there are too few experimental areas to work out a correlation of this kind in Arizona. It was approached several years ago during a study of lettuce fertilization with results which have been quite useful. The experiments were located in several sections of the Yuma Valley and the Salt River Valley. They showed that soils analyzing less than 5 p.p.m. phosphate (PO_4), 20 pounds per acre available phosphate, were definitely deficient in phosphate. Those analyzing more than 10 p.p.m., or 40 pounds per acre-foot, gave very light response or none at all.