THIS ARTICLE begins with a brief survey of the effect of the World War in stimulating the fertilizer industry in the United States, and then outlines the situation today. First the sources of nitrogen, phosphorus, potassium, and some elements not commonly used in fertilizers are broadly discussed. Then certain effects of fertilizer materials are considered. A detailed appendix, arranged for ready reference, describes the commercial materials now available and their uses, together with some materials still in the experimental stage.

Fertilizer Materials

By Oswald Schreiner, Albert R. Merz, and B. E. Brown

The use of fertilizer materials as a means of supplementing the natural food supplies of the soil is of considerable importance among the various factors involved in the economical production of crops as well as in the proper maintenance of soil fertility. Without certain elements, such as nitrogen, phosphorus, potassium, calcium, magnesium, and some others, plants cannot live. With inadequate amounts of these elements plants are undernourished and fail to grow and produce normally. Undernourished plants, in turn, are likely to mean undernourished men and animals. It is to supply deficiencies in these essential elements that fertilizer materials must be added to the soil.

Because fertilizer materials increase the production and improve the quality of crops, they have become an essential element in farming in all countries practicing modern agricultural methods. It is probably true that there has never been a greater need than now of aiding farmers to secure maximum returns from fertilizer materials. They represent a considerable share of crop-production costs and should therefore be bought and used with care. The farmers of the United States spend annually a sum in excess of $200,000,000 for fertilizers.

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2 It should be emphasized at this point that the use of fertilizer materials or fertilizer mixtures is only one of a number of means for maintaining soil fertility and crop production at a high level. Proper drainage, maintenance of soil organic matter, prevention of soil erosion, proper care and use of manure, improvement of the physical condition of the soil if this is essential, and liming when indicated, are all necessary to productive farming. Combined with these should be good cultural care and close observation of the crops grown. The greatest benefit from the use of fertilizer materials results when these other controllable factors are taken care of. On poorly drained acid soils that are lacking in organic matter or on soils very leached in character, fertilizer materials cannot be expected to give a good account of themselves. With improved drainage conditions, the proper amount of lime to control soil acidity, and the addition of some form of organic matter to the soil, a much better response to fertilizers may be expected. Until the controllable factors are properly taken care of, the indiscriminate use of fertilizer materials may be considered to be more or less of a gamble.
Fertilizer materials not only possess great agricultural value for crop production (fig. 1), but they are of importance in domestic and foreign trade. As civilization becomes more complex, so do food requirements and standards, and as population increases, the demands on the soil increase also. In the future it will be necessary to guard the soil and its products from deterioration more carefully than ever. To produce the right quantity of foodstuffs of the right quality will increasingly tax the energies of scientists and farmers alike in the years to come.

**INFLUENCE OF WORLD WAR ON FERTILIZER MATERIALS**

The influence of the World War on the production of new fertilizer materials was very marked. The insistent demand for propellant powders, high explosives, and other death-dealing materials, chemical in nature, was so great that huge chemical plants were erected to meet the requirements.

The chief concern of all belligerents, insofar as explosives was concerned, was to have a plentiful supply of nitrogen. Those who were cut off from natural supplies of fixed nitrogen, such as Chilean sodium nitrate, had recourse to the greatest source of nitrogen—the atmosphere. The situation from a chemical point of view was a difficult one. First of all, nitrogen is one of the most inert of all the known elements with respect to entering into combination with other elements to form stable compounds. Under ordinary conditions it refuses to react with other elements. Thus special conditions for such reactions had to be provided. Separation of nitrogen from the other gases in the atmosphere proved to be the first requirement. Then through controlled chemical processes it was made to react with other elements, a process generally known as nitrogen fixation. The final step was the production of stable compounds.

In Germany, inability to obtain sodium nitrate from Chile had been anticipated in advance, and the development of economically successful methods of nitrogen fixation had been accomplished before hostilities got under way, so that Germany was independent of outside supplies.
of combined nitrogen. This utilization of atmospheric nitrogen as a raw material so impressed certain of the Allies that steps were taken to install plants capable of extracting and fixing atmospheric nitrogen. The United States, for example, is now in a position to protect itself adequately in this respect, agriculturally and otherwise.

When the World War terminated, the huge chemical plants, geared to capacity production of wartime necessities, faced a difficult situation. In order to avoid ruin, these plants turned to the manufacture of nitrogen and other compounds for fertilizer use. It was not long before many new compounds were being produced. Some of these contained nitrogen alone, others nitrogen and phosphorus, others nitrogen and potassium; and in some cases compounds were produced containing all three fertilizer elements.

Two lists of fertilizer materials, one showing materials available about 1900, the other those in use or proposed for use in 1936, are given in tables 1 and 2 (48). These two lists typify the marked changes that have taken place during this period, a great many of which resulted directly from the World War.

In comparing the two lists one is impressed with the fact that most of the changes during this transitional period have been confined largely to the nitrogen and phosphorus columns. Another point worthy of notice concerns the high plant-food or nutrient content of some of the materials in the 1936 list. Two materials serving to illustrate this are (1) urea, with a content of practically 46 percent of nitrogen, and (2) diammonium phosphate, which contains 21 percent of nitrogen and 53 percent of phosphoric acid ($P_2O_5$), a total of 74 percent. The development of urea, a highly concentrated nitrogen material, from more or less of a laboratory curiosity to its present commercial importance as a fertilizer material is an excellent illustration of what chemical research means to agriculture.

Fertilizer materials available for fertilizer use in 1900 present a decided contrast to urea and diammonium phosphate. Aside from the two high-grade potash salts, potassium chloride and potassium sulphate, no such plant-food concentration was found in fertilizer materials then. Among nitrogen materials at that time, ammonium sulphate ran highest in nitrogen content—about 20 percent nitrogen. Sodium nitrate contained about 15.5 percent of nitrogen. In the phosphoric acid group, ordinary superphosphate was practically the main source of phosphoric acid for fertilizer use. For many years it was designated "16 percent super" and only in comparatively recent years have 18- and 20-percent superphosphate materials been produced. The modern trend has been one of providing fertilizer materials with greater plant-food concentration as a means of effecting economies in the manufacture, handling, and transportation of fertilizers.

Other materials proposed for fertilizer use today but not appearing in this list include ammonium formate, formamide, melamine nitrate, melamine phosphate, melamine sulphate, guanidine sulphate, diguanidine phosphate, triguanidine phosphate, phytin, and nucleic acid. These and similar compounds testify to the development of chemical research.
Table 1.—Fertilizer materials available for use in 1900

<table>
<thead>
<tr>
<th>Nitrogen sources</th>
<th>Phosphoric acid</th>
<th>Potash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium nitrate.</td>
<td>Fish scrap.</td>
<td>Basic slag.</td>
</tr>
<tr>
<td>Ammonium phosphate.</td>
<td>Rough ammoniates.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.—Fertilizer materials used or proposed for use in 1936

<table>
<thead>
<tr>
<th>Nitrogen sources</th>
<th>Phosphoric acid sources</th>
<th>Potash sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen solution II.</td>
<td>Urea-ammonia liquor.</td>
<td>Diammonium phosphate.</td>
</tr>
<tr>
<td>Ammonium bicarbonate.</td>
<td></td>
<td>Calcium metaphosphate.</td>
</tr>
</tbody>
</table>

1 Not intended to represent a complete list. There are other compounds, particularly of foreign production, that are not included. Most of the compounds listed have been tested under greenhouse and field conditions to determine their nutrient value for agricultural crops.

2 Cal-Nitro and Nitro-Chalk are essentially the same, the former being sold by German interests and the latter by English. Both are mixtures of ammonium nitrate and calcium carbonate.

3 Complete fertilizer.

Some interesting studies of new organic materials—called organophosphates—have been reported by Spencer and Stewart of the Nevada Agricultural Experiment Station. They have conducted extensive studies of what has been designated “positional availability”—that is, the location of soil nutrients with respect to the ability of plants to reach and utilize them. Stewart (388), in explaining the significance of such compounds, including calcium sorbitylphosphate, calcium glycolphosphate, calcium glycerophosphate, calcium glucose phosphate, and others for fertilizer use, states:

It has been clearly shown that the ordinary forms of superphosphates, when applied to the soil, are fixed in the soil at or near the surface of the soil. At the same time the roots of the plants penetrate deeply into the soil, far beneath the applied fertilizer materials, and, under these conditions, only a portion of the root system of the plant is in contact with the applied fertilizer, and we have shown that under these conditions, the plant cannot secure a sufficient amount of nutrient or the best production of growth. . . . We have shown that this problem thus
created may be solved by the application of the well-known principle in organic chemistry, that the introduction of a hydroxyl group into the various forms of inorganic phosphates confers water solubility upon the resulting compounds, and will permit those compounds to retain their water solubility in contact with the various soil particles.

The different materials mentioned are not commercially available at the present time, but if they are found to be worth while as nutrient materials for plants methods will probably be found to insure comparatively low production costs, just as happened with urea.

Prior to the World War potash required for fertilizer in the United States was obtained almost entirely from Europe. During the war the blockade of Germany cut off potash supplies, since that country was the chief source of potash used in the United States. Stocks on hand were used up to such an extent that crops suffered, and in a number of sections well-recognized cases of potash hunger developed. Notably was this true with cotton, potatoes, and a number of special truck crops. As a result of this experience serious efforts were made to locate sources of potash in the United States and to develop them commercially. Some potash was produced as a byproduct of blast furnaces, cement mills, and distilleries, and from natural salines and seaweeds. Because of the limited supply and high cost of production, potash so produced sold at exceedingly high prices. After the war, when European potash reappeared on the American market at prices comparable with the pre-war prices, the American producers, unable to meet the competition, ceased production with the exception of one company producing potassium chloride from the brines of Searles Lake, Calif.

In 1923, which may be considered the first normal post-war year so far as potash is concerned, domestic producers supplied approximately 9 percent of the potash materials consumed in fertilizers. By 1928–30 domestic production accounted for 16 percent of that used in fertilizers. The period 1931–35 not only marked the development and placing into production of the potash mines of New Mexico, but also those of Spain and the Union of Soviet Socialist Republics. The competition between foreign interests and the American industry for the American market resulted in potash prices for 1935 averaging approximately 57 percent below those of 1928–30.

The proportion of the home market supplied by the domestic producers increased continuously, with the exception of 1934, until in 1935 they supplied about 50 percent of the total potash used in fertilizers. During this period the total potash consumed in fertilizers increased 23 percent from an average of 368,000 tons of potash (K₂O) in 1928–30 to 453,000 tons in 1935, of which the domestic industry supplied 225,000 tons, or an amount greater than was consumed by the entire American fertilizer industry in 1923. The successful attempts to establish a domestic potash industry can be better appreciated by comparing records of production in the United States for 1934, 1935, and 1936 with imports from foreign sources for the same years (table 3).

In 1936 domestic production of potash exceeded foreign importations by more than 40,000 tons. Comparing this with any year before the World War, it will be found that until then importations accounted for
most of the potash consumed for fertilizer purposes in the United States.

So far the American producers have been content to market various grades of chlorides of potash and have not attempted to supply sulphate, nitrate, or other special salts. This country should and doubtless will establish and maintain a diversified potash industry.

Thus the war made this country more independent so far as the nitrogen and potassium compounds needed by crops are concerned.

In the case of phosphorus the United States is independent of other nations and need feel no concern about phosphatic fertilizer materials for many years to come. However, our natural phosphorus resources should be conserved to the fullest extent, which means wise utilization from every standpoint. Proper mining operations, proper safeguards with reference to exportation, and proper use as fertilizer material will go far toward accomplishing this conservation.

THE ESSENTIAL ELEMENTS IN COMMERCIAL FERTILIZERS

Fertilizer materials are generally understood to be commercially obtainable individual materials that contain one or more of the three essential chemical elements, nitrogen, phosphorus, and potassium, in such forms that when the materials are applied to soils, crops may make use of the elements needed for their processes of growth. In European countries, farmers customarily purchase fertilizer materials singly and apply them separately to the soil. In this country, however, it is usual for the fertilizer manufacturers to prepare mixtures from the materials and for the farmer to apply the mixed products to his land. This difference in practice is apparently primarily the result of the higher cost of farm labor in the United States.

Fertilizer materials do not consist of the fertilizing elements, nitrogen, phosphorus, and potassium, as such. They are more or less pure chemical compounds of these elements with other elements, or they are complex vegetable or animal materials. The chemical compounds may have been obtained from natural sources, as in the case of Chilean sodium nitrate; or manufactured expressly for fertilizer use, as in the case of superphosphate; or obtained as byproducts in the manufacture of other materials, as in the case of the ammonium sulphate obtained in the manufacture of metallurgical coke or city gas. The vegetable or animal materials may be of natural origin, as in the case of guano;

<table>
<thead>
<tr>
<th>Year</th>
<th>Produced in United States</th>
<th>Imported</th>
</tr>
</thead>
<tbody>
<tr>
<td>1934</td>
<td>144,342</td>
<td>178,533</td>
</tr>
<tr>
<td>1935</td>
<td>228,556</td>
<td>241,510</td>
</tr>
<tr>
<td>1936</td>
<td>247,340</td>
<td>207,194</td>
</tr>
</tbody>
</table>

Table 3.—*Production of potash \(\text{K}_2\text{O}\) in the United States compared with importations from abroad, 1934–36*
or obtained as residues in processes for the utilization of plants and animals, as in the case of cottonseed meal and dried blood; or recovered from wastes, as in the case of sewage sludge.

Fertilizer materials are classed as nitrogenous, phosphatic, or potassic according to whether they contain nitrogen, phosphorus, or potassium as their principal or most valuable constituent. As is so often the case in the setting up of classifications, some fertilizer materials may be placed in more than one of these classes.

In the fertilizer trade it is customary to speak of fertilizer materials and mixtures as containing nitrogen, phosphoric acid, and potash instead of nitrogen, phosphorus, and potassium. Until recent years it was also the practice to speak of the ammonia instead of the nitrogen content of fertilizers, a usage that still persists in one southern State. The terms ammonia, phosphoric acid, and potash refer to compounds of nitrogen, phosphorus, and potassium, respectively. The early chemists calculated the results of their analyses in terms of these compounds, which served them as convenient means for comparing the relative values of the fertilizers they analyzed, even though these compounds of nitrogen, phosphorus, and potassium were not actually present in the fertilizers as such. The present custom is merely a relic of the earlier practice.

**NITROGEN FERTILIZER MATERIALS**

**Classification of Nitrogen Materials**

The nitrogenous fertilizer materials are classed according to the manner in which their nitrogen is combined with other elements. Some, such as sodium nitrate (nitrate of soda), have the nitrogen combined in the nitrate form. These are all characterized by ready solubility in water, and the nitrogen is more quickly utilized by most crops than is that in nitrogenous materials of the other classes (figs. 2 and 3). The nitrate form of nitrogen is, however, the most readily leached from the soil by rains because of its easy solubility and its failure to be retained or fixed in the soil to any considerable extent.

Other nitrogenous fertilizer materials, such as ammonium sulphate (sulphate of ammonia), contain their nitrogen combined in the form of ammonia or its compounds. Although they are also soluble in water, the nitrogen, known as ammoniacal nitrogen, is less readily removed from soils by leaching than nitrate nitrogen because it has a tendency to be fixed by certain of the soil constituents. Ammoniacal nitrogen can also be used directly by crops, though much of it is first converted to nitrate nitrogen through the action of soil bacteria before plants make use of it.

A third class of nitrogenous fertilizer materials comprises such animal and vegetable materials as animal tankage and cottonseed meal, which are commonly called organic ammoniates. The nitrogen in these materials is combined in the form of complex organic compounds such as proteins, which are for the most part insoluble in water. The insoluble organic nitrogen cannot be used directly by plants but must first be converted as a result of processes of decay into soluble forms. Some of these materials, such as horn meal and ground leather, decay so slowly in the soil that their nitrogen is of
FIGURE 2.—On light sandy loams, wheat is often starving for nitrogen in the early spring. The wheat on the left received a spring top dressing of soluble nitrogen, that on the right did not. (Courtesy Michigan Agricultural Experiment Station.)

FIGURE 3.—Corn responds well to available nitrogen, which is important in promoting foliage and stalk development. Corn plants on the right received an application of soluble nitrogen in addition to fertilizer, plants on the left, fertilizer alone.
little value for promoting crop growth. Fertilizer manufacturers, however, subject such inferior materials to different processes, such as treatment with superheated steam with or without the addition of sulphuric acid, or mixture with phosphate rock and subsequent treatment with sulphuric acid, to make products the nitrogen of which is mostly in forms that are readily utilized by crops. The steam-treated products are known as process tankages.

Another class of nitrogenous fertilizer materials includes the chemical compounds urea and calcium cyanamide, which contain their nitrogen in the amide form. They are usually considered as organic fertilizer materials, since they are carbon compounds and are therefore classed in textbooks of chemistry among the organic compounds. They are, however, simple nonproteid compounds, manufactured from inorganic materials, and their nitrogen, unlike that of the organic ammoniates, dissolves entirely or for the most part in water. Through bacterial action in the soil the nitrogen of these compounds usually changes quickly to the ammoniacal and nitrate form.

Nitrogen Availability

Much time and energy have been spent in endeavors to devise chemical methods for determining the extent to which the nitrogen in fertilizers is "available," or readily made use of by plants. It is generally conceded that the nitrogen that is readily soluble in water is available. This includes nitrate nitrogen, ammoniacal nitrogen, and amide nitrogen, as well as a portion of the organic nitrogen contained in the organic ammoniates. The nitrogen in the organic ammoniates that is not dissolved by water is called water-insoluble organic nitrogen.

Two procedures have been devised for obtaining an approximate idea of the value of this nitrogen to plants. They do not, however, measure the availability of the nitrogen but simply help to distinguish between the better and poorer sources of water-insoluble organic nitrogen, and it is generally admitted that the available nitrogen can be measured only after carefully conducted vegetation experiments with plants.

In the neutral permanganate method, the material, to which powdered rock phosphate has been added and from which the water-soluble nitrogen has then been removed, is digested under specified conditions with a solution of potassium permanganate containing sodium carbonate. The nitrogen that goes into solution during the digestion is called active nitrogen and is considered to be more available to plants than that which resists the action of the permanganate.

In the alkaline permanganate method, a solution containing potassium permanganate and caustic soda is substituted for the solution of potassium permanganate containing sodium carbonate. The nitrogen that goes into solution during the digestion is called active nitrogen and is considered to be more available to plants than that which resists the action of the permanganate.

1 Amides are compounds resulting from replacement of one or more atoms of hydrogen in ammonia (NH₃) by acid radicals. urea is CO(NH₂)₂. The amides are classified as primary, secondary, and tertiary, depending on how many atoms of hydrogen are replaced.

6 Digestion is conducted by immersing the container in a steam or hot-water bath for a period of 30 minutes.
gives lower results for active nitrogen than does the neutral permanganate method.

The two permanganate methods are customarily used to distinguish between the better and poorer sources of water-insoluble nitrogen in the organic ammoniates that have been employed in the preparation of mixed fertilizers. Such methods are employed when the water-insoluble nitrogen in the mixture amounts to 0.3 percent or more of the weight of the fertilizer. When the water-insoluble nitrogen shows an activity of less than 50 percent by the alkaline method and less than 80 percent by the neutral method, it is classed as an inferior source. It has been found that the use of either method alone may result in the condemnation of good materials; thus, the alkaline method gives comparatively low activities for the water-insoluble nitrogen of cottonseed meal, castor pomace, and Peruvian guano, which are recognized to be good sources of nitrogen. This necessitates the use of both methods before classifying a given material as inferior.

A comparison of the availabilities of the nitrogen of a series of organic nitrogenous materials as determined by vegetation tests, with the activities as determined by the permanganate methods, is given in table 4, from Wiley's Principles and Practice of Agricultural Analysis (466, p. 310).

Table 4.—Availability of water-insoluble nitrogen by vegetation experiments and activity

<table>
<thead>
<tr>
<th>Source of nitrogen</th>
<th>Average relative availability by vegetation experiment 1</th>
<th>Comparative activity by—</th>
<th>Source of nitrogen</th>
<th>Average relative availability by vegetation experiment 1</th>
<th>Comparative activity by—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alkaline permanganate method</td>
<td>Neutral permanganate method</td>
<td></td>
<td>Alkaline permanganate method</td>
<td>Neutral permanganate method</td>
</tr>
<tr>
<td>Dried blood:</td>
<td></td>
<td></td>
<td>Percent</td>
<td>Percent</td>
<td>Percent</td>
</tr>
<tr>
<td>Red</td>
<td>80</td>
<td>71</td>
<td>98</td>
<td></td>
<td>57</td>
</tr>
<tr>
<td>Dark</td>
<td>92</td>
<td>54</td>
<td>94</td>
<td></td>
<td>77</td>
</tr>
<tr>
<td>Foreign process tankage</td>
<td>53</td>
<td>48</td>
<td>79</td>
<td></td>
<td>74</td>
</tr>
<tr>
<td>Hoof meal</td>
<td>78</td>
<td>80</td>
<td>94</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Peruvian guano</td>
<td>90</td>
<td>44</td>
<td>90</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Milorganite</td>
<td>70</td>
<td>62</td>
<td>80</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Imported process tankage</td>
<td>51</td>
<td>49</td>
<td>94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Dried red blood at 80 basis. Crop grown, Japanese millet.

Composition of Nitrogen Fertilizer Materials

The principal nitrogenous fertilizer materials on the market, together with their approximate contents of nitrogen and its forms, are given in table 5. Although fertilizer consumers can employ most of these as well as a number of other less important materials, only the fertilizer manufacturers can afford to make the large investments necessary for the machinery and other equipment required for the utilization of the high-nitrogen liquid products—anhydrous liquid ammonia, etc.—listed at the end of the table, which are sold only in tank-car lots for fertilizer-manufacturing purposes.
Table 5.—Nitrogen content of principal commercial fertilizer materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Ammoniacal nitrogen</th>
<th>Nitrate nitrogen</th>
<th>Organic nitrogen</th>
<th>Amide nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Percent</td>
<td>Percent</td>
<td>Percent</td>
</tr>
<tr>
<td>Sulphate of ammonia</td>
<td>19.5-21.2</td>
<td>14.2-16.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate of soda</td>
<td></td>
<td>13.7-15.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate of potash</td>
<td></td>
<td>12.7-15.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate of soda-potash</td>
<td>10.4-11.7</td>
<td>18.0-20.0</td>
<td></td>
<td>23.0-25.0</td>
</tr>
<tr>
<td>Calcium cyanamide</td>
<td>20.5-23.5</td>
<td>20.5-23.5</td>
<td>1.0-1.5</td>
<td>46.0-46.2</td>
</tr>
<tr>
<td>Ammonium sulphate-nitrate</td>
<td>19.5</td>
<td>6.5</td>
<td></td>
<td>27.2</td>
</tr>
<tr>
<td>Cal-Nitro 2</td>
<td>7.8-12.5</td>
<td>7.8-12.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amo-Phos 3</td>
<td>10.4-11.7</td>
<td>18.0-20.0</td>
<td>1.0-1.5</td>
<td>46.0-46.2</td>
</tr>
<tr>
<td>Calurea 4</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td></td>
<td>13.0-15.5</td>
<td>5.5-10.0</td>
<td>27.2</td>
</tr>
<tr>
<td>Animal tankage</td>
<td></td>
<td></td>
<td>6.0-14.0</td>
<td></td>
</tr>
<tr>
<td>Dried blood</td>
<td></td>
<td>6.5-10.0</td>
<td>5.3-7.5</td>
<td></td>
</tr>
<tr>
<td>Fish scrap, dried</td>
<td></td>
<td>4.0-7.0</td>
<td>6.5-10.0</td>
<td></td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td></td>
<td></td>
<td>5.3-7.5</td>
<td></td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td></td>
<td></td>
<td>4.0-7.0</td>
<td></td>
</tr>
<tr>
<td>Process tankage</td>
<td></td>
<td>4.0-7.0</td>
<td>6.5-10.0</td>
<td></td>
</tr>
<tr>
<td>Sewage sludge, activated</td>
<td></td>
<td></td>
<td>4.0-7.0</td>
<td></td>
</tr>
<tr>
<td>Garbage tankage</td>
<td></td>
<td></td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>Cocoa shell meal</td>
<td></td>
<td></td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Ground bone and bonemeal</td>
<td></td>
<td></td>
<td>0.7-1.3</td>
<td></td>
</tr>
<tr>
<td>Tobacco stems</td>
<td></td>
<td></td>
<td>1.3-1.6</td>
<td></td>
</tr>
<tr>
<td>Anhydrous liquid ammonia</td>
<td>82.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aqua ammonia</td>
<td>20.5-23.5</td>
<td>20.5-23.5</td>
<td>15.1</td>
<td></td>
</tr>
<tr>
<td>Urea-ammonia liquor-A 5</td>
<td>90.4</td>
<td></td>
<td>20.1</td>
<td></td>
</tr>
<tr>
<td>Urea-ammonia liquor-B 7</td>
<td>25.2</td>
<td>7.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude nitrogen solution 8</td>
<td>37.0</td>
<td>7.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen solution II 9</td>
<td>27.0</td>
<td>10.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Often sold as nitrate of potash or Chilean nitrate of potash.
2 Usually sold under the trade name "Cyanamid."
3 Trade name for a commercial product consisting of ammonium nitrate mixed with calcium carbonate.
4 Trade name for a commercial product containing approximately 11 percent of nitrogen and 48 percent of phosphoric acid; the other consists of ammonium phosphate and ammonium sulphate and contains approximately 16 percent of nitrogen and 20 percent of phosphoric acid.
5 Trade name for a commercial product comprising the compound, calcium nitrate-urea.
6 Also called nitrate of lime.
7 Trade name for a commercial product containing urea and ammonia dissolved in water.
8 Trade name for a commercial product containing sodium nitrate and ammonia dissolved in water.
9 Trade name for a commercial product containing ammonium nitrate and ammonia dissolved in water.

Relative Merits of Nitrogen Fertilizer Materials

Sodium nitrate and ammonium sulphate are undoubtedly the most widely used nitrogen fertilizer materials at the present time. The results of experimental findings have given both of these materials a high evaluation, and furthermore have shown how and when both should be used to best advantage. In large measure this high evaluation applies also to many of the synthetic materials more recently proposed for fertilizer use, such as ammonium chloride, ammonium nitrate, ammonium phosphate, urea, and various other nitrogen fertilizer materials. A number of the agricultural experiment stations in cooperation with the United States Department of Agriculture have conducted field experiments to compare different nitrogen sources and, in general, report pretty much the same results with all materials when compared as individual sources of nitrogen in complete fertilizer mixtures.

As pointed out elsewhere, the so-called organic ammoniates, such as cottonseed meal, dried blood, fish scrap, tankage, etc., render excellent support to the more available nitrogen materials, such as nitrate of soda, ammonium sulphate, and urea. The latter are quickly avail-
able to crops, whereas the organic ammoniates have to go through a decomposition process whereby their organic nitrogen combinations are converted through bacterial action to ammonia nitrogen and then to the nitrate form. This means a slower availability of the organic fertilizer materials, but it also means that they furnish a continuous supply of available nitrogen, which is considered an important factor in fertilizer practice. However, the higher cost of nitrogen in the organic ammoniates, because of the utilization of the materials for feeding purposes, has very considerably reduced the demand for them as fertilizers in recent years, except for special crops.

PHOSPHATIC FERTILIZER MATERIALS

Classification of Phosphatic Fertilizer Materials

The phosphatic fertilizer materials contain phosphoric acid in different forms. The favorable influence of phosphoric acid fertilization upon plants is illustrated by figures 4 and 5. After this favorable influence became known, it was discovered that different phosphates might have the same phosphoric acid content and yet not have the same action; in fact, that they frequently affected the growth of crops to a quite different extent. It was found that the phosphoric acid in phosphates of organic origin, such as bones, had a more favorable influence on crop yields than that in raw mineral phosphates of the same degree of fineness, because of the more readily soluble condition of the former.

![Figure 4](image_url)

**Figure 4.**—A suitable combination of fertilizer materials furnishing the elements nitrogen, phosphorus, and potassium results in better grain: A, Wheat kernels from fertilized land, B, from unfertilized land. Same weight of wheat in each case. (Courtesy Michigan Agricultural Experiment Station.)
FIGURE 5.—An application of a phosphatic fertilizer material to sugar beets pays on phosphorus-deficient soil. Sugar beets on right benefited tremendously from such treatment. Those on left grown on unfertilized land.

The more pronounced action of the phosphates of organic origin was explained by the assumption that in these phosphates the individual particles of the calcium phosphate are separated from each other by organic substances and that upon the decomposition of the organic matter they are exposed and become more susceptible to the action of soil agents, such as water and carbon dioxide, than do the less finely divided particles of the mineral phosphate. The dissolution of the phosphates of organic origin is also promoted by the products of the decomposition of the organic matter, since those products have a solvent action upon the calcium phosphate. Thus it was shown that when bonemeal was mixed with water and allowed to putrefy, phosphoric acid passed into solution; and that the oxalic acid in guano would free the phosphoric acid contained therein from its combination with calcium.

The solution of the phosphoric acid is also facilitated by the presence in the soil of substances having an acid reaction, since calcium phosphate is fairly soluble in weak acids. Furthermore, such acid-reacting substances as carbon dioxide, excreted by the roots of living plants, have a solvent action upon the phosphate particles in their immediate vicinity. Carbon dioxide, which is continually present in the soil where organic substances are always decomposing, has been shown
by the experiments of many investigators to attack all phosphates of calcium more or less.

Soon after the application of bones to the soil to provide plants with phosphoric acid came into vogue, it was observed that the finer the material the greater was the effect. The proposal of Liebig in 1840, therefore, that the insoluble phosphoric acid in bones be rendered soluble by means of sulphuric acid was soon widely put into practice, since superphosphate thus produced was soluble and could mingle much more intimately with the soil than that in an insoluble state. For the purpose of estimating the value of superphosphate a distinction was made between the phosphoric acid in water-soluble form and that still in the original or insoluble form; much greater value was ascribed to the water-soluble phosphoric acid while, so far as commercial determination of price was concerned, little or no value was attached to the insoluble phosphoric acid. Liebig's suggestion was soon followed by one emanating from Sir John Lawes, of the Rothamsted Experiment Station, in England, that phosphate rock likewise be treated with sulphuric acid. This marked the beginning of the superphosphate industry.

Not long after superphosphate from mineral phosphates appeared on the market, it was discovered that the phosphoric acid rendered soluble by sulphuric acid made a more or less rapid return to an insoluble form, so that in a few months the water-soluble phosphoric acid had at times diminished to but one-third of the original quantity. This circumstance proved quite disconcerting to chemists, manufacturers, and consumers since the commercial value of the product at that time depended primarily on the content of water-soluble phosphoric acid. It was soon found, however, that when applied to the soil the phosphoric acid that had been water-soluble and had become water-insoluble (variously called retrograde, regenerated, reduced, or reverted phosphoric acid) exhibited a more beneficial effect on crops than that which had never been water-soluble, because it was very finely divided throughout the whole mass and therefore offered a large surface for attack by various agents in the soil. In trying to find a means for determining this phosphoric acid analytically, chemists discovered that it dissolved in an ammonium citrate solution. By this time, as a result of vegetation tests, the reverted, or citrate-soluble, phosphoric acid began to be considered of equal value with the water-soluble phosphoric acid, and the value of a superphosphate or other fertilizer material, so far as phosphoric acid was concerned, was based on the quantity of available, i.e., water-soluble plus citrate-soluble phosphoric acid that it contained. This evaluation has continued to hold up to the present time, with the single exception of phosphoric acid in basic slag. The forms of phosphoric acid that are not soluble in water and ammonium citrate solution are considered of practically no agricultural value.

Shortly after the development in 1878 by Thomas and Gilchrist of the basic Bessemer process for converting pig iron into steel while simultaneously removing the phosphorus, the slag produced in the process was used as a liming material for acid and lime-deficient soils. But it was soon recognized that the effectiveness of the phosphoric acid in the basic slag was often only slightly less than that of the
phosphoric acid in superphosphate and also that its effectiveness became the greater the more finely the slag was ground. Vegetation tests showed, however, that basic-slag meals of different origins were of quite different effectiveness as regards plant growth. It was originally thought that the ammonium citrate method could serve as a means for evaluating the effectiveness of the phosphoric acid in such slags, since much of this phosphoric acid is citrate-soluble. Experience has shown, however, that the method, although applicable to the reverted phosphoric acid in superphosphates, is of little value when applied to phosphatic slags, probably because of their different chemical constitution, which interferes with the solvent action of the citrate solution. After much experimental work, the phosphoric acid of Thomas Bessemer slags that was soluble in a 2-percent citric acid solution was found to correspond to the availability figures as established by vegetation tests, and the available phosphoric acid in basic slags is now considered to be that which dissolves in this solution.

It should be kept in mind that the chemical methods for the determination of water-soluble, citrate-soluble, and citric acid-soluble phosphoric acids have been developed in purely empirical ways. Whereas the total phosphoric acid in a fertilizer material is a definite fixed quantity and different methods for its determination should give no appreciable variation in results, the water-soluble, citrate-soluble, and citric acid-soluble phosphoric acids are rather arbitrary quantities and are dependent on a number of factors, such as time of digestion, degree of fineness of the sample, kind and quantity of solvent, agitation, etc., which have been so chosen as to give results that harmonize with vegetation tests.

Some phosphatic materials, such as ammonium phosphate, have their phosphoric acid entirely or mostly in water-soluble form, which is readily usable by crops. In other materials, such as precipitated phosphate, all or most of the phosphoric acid though practically water-insoluble is nevertheless citrate-soluble (or in the case of basic slag, citric acid-soluble) and still readily available for use by plants. Still other materials have much or most of their phosphoric acid in forms that are even less soluble. Since they are contained in the residue that remains when the chemist dissolves out the citrate-soluble phosphoric acid from fertilizers, these forms of phosphoric acid are collectively known as citrate-insoluble phosphoric acid or simply as insoluble phosphoric acid. Their sparing solubility is often such that they cannot be readily utilized by plants, though under some conditions insoluble phosphoric acid is rendered sufficiently soluble in the soil to be utilizable by crops. Acid soils, particularly, favor their solution.

In soils that contain considerable organic matter, certain products of the decay increase the solubility of the insoluble phosphoric acid so that it may be more readily taken up by crops. Of the materials with considerable quantities of insoluble phosphoric acid, those that contain organic matter and are therefore also valuable as nitrogenous materials—such as bonemeal and fish scrap—are most used without previous chemical treatment for fertilizer purposes; but ground or other finely divided forms of phosphate rock are also employed to some
extent. Only the total quantity of phosphoric acid in such materials is customarily determined.

The principal phosphatic fertilizer materials with their approximate phosphorus content expressed as phosphoric acid (P₂O₅) are listed in table 6.

<table>
<thead>
<tr>
<th>Material</th>
<th>Available phosphoric acid</th>
<th>Total phosphoric acid</th>
<th>Material</th>
<th>Available phosphoric acid</th>
<th>Total phosphoric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superphosphate</td>
<td>14.5–22.0</td>
<td>13.5–22.0</td>
<td>Bonemeal and ground bone</td>
<td>17.0–30.0</td>
<td></td>
</tr>
<tr>
<td>Double (treble, triple) superphosphate</td>
<td>40.0–50.0</td>
<td>40.0–50.0</td>
<td>Animal tankage</td>
<td>5.0–18.0</td>
<td></td>
</tr>
<tr>
<td>Ammo-Phos</td>
<td>30.0–22.8</td>
<td>30.0–22.8</td>
<td>Garbage tankage</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Precipitated phosphate</td>
<td>37.0–12.0</td>
<td>37.0–12.0</td>
<td>Fish scrap, dried</td>
<td>5.0–8.0</td>
<td></td>
</tr>
<tr>
<td>Basic slag</td>
<td>5.0–30.0</td>
<td>5.0–30.0</td>
<td>Ground phosphate rock and other phosphate rock and other phosphate mineral products</td>
<td>12.0–35.0</td>
<td></td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>2.0–3.6</td>
<td>2.0–3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 See footnote 4, table 5.
2 The basic slag produced in this country is sold on the basis of a content of 8 percent total phosphoric acid.

Relative Merits of Phosphatic Fertilizer Materials

From an industrial standpoint the principal phosphatic fertilizer materials used in the United States are superphosphate (ordinary strength 16- to 20-percent phosphoric acid), treble superphosphate (40- to 48-percent phosphoric acid), and ammonium phosphate, chiefly monoammonium phosphate (11-percent nitrogen, 48-percent phosphoric acid), which contains nitrogen in the ammoniacal form. To these can be added bonemeal (raw and steamed), basic slag, and finely ground rock phosphate, largely because each of these three is more suitable for direct application to the soil than for the preparation of complete fertilizer mixtures.

The results of many years of experimental studies, coupled with practical experience and observation, have definitely established the value of the different superphosphates. Enough has been done in an experimental way with ammonium phosphate to have determined that it is an excellent source of phosphorus, particularly adaptable to the preparation of concentrated fertilizers or for direct application to the soil where its individual use is indicated as being desirable. Ammonium phosphate, in common with certain other ammonia compounds, has a tendency to increase soil acidity, and it may be necessary to lime the soil or add some neutralizing agent such as ordinary or dolomitic limestone to counteract this potential acidity.

Basic slag, owing to its high lime content, is not used in mixed fertilizers, for fear of liberating ammonia through chemical interaction with the ammonium salts incorporated with the mixture. However, it has been evaluated as a good source of phosphoric acid for heavy soils acid in reaction and for soils deficient in available lime. It promotes the growth of meadows and pastures and in common with other phosphatic fertilizer materials encourages the germination and development of various root and tuber crops as well as other phosphorus-responsive crops.
Bonemeal, either raw or steamed, when sufficiently fine, rates well as a source of phosphorus and to a considerable degree its value is increased by its nitrogen content. Its lasting character and its safety make it very serviceable to greenhouse and other specialists. Because the phosphorus in bonemeal becomes available slowly, it is effective for more than one season. It is best applied to mellow soils containing an ample supply of organic matter.

**POTASSIC FERTILIZER MATERIALS**

All commercial potassic fertilizer materials contain their potash in water-soluble forms which can be readily absorbed by plants.

Figure 6 illustrates the effect of addition of potash to a light soil.

![Figure 6](image_url)

**Figure 6.—On light soils potash is necessary to optimum plant growth.** The millet in the pot on the left received no fertilizer; that in the center, a mixture of nitrogen and phosphorus fertilizer materials; that on the right, potash in addition.

<table>
<thead>
<tr>
<th>Material</th>
<th>Potash (Percent)</th>
<th>Material</th>
<th>Potash (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium chloride (muriate of potash)</td>
<td>47-61.5</td>
<td>Sulphate of potash-magnesia</td>
<td></td>
</tr>
<tr>
<td>Potassium sulphate (sulphate of potash)</td>
<td>47-52</td>
<td>Kainite</td>
<td>14-22</td>
</tr>
<tr>
<td>Potassium nitrate (salt peter)</td>
<td>42.9-45.2</td>
<td>Cotton hull ashes</td>
<td>20.5-34.8</td>
</tr>
<tr>
<td>Nitrate of soda-potash</td>
<td>13.7-16.4</td>
<td>Hardwood ashes</td>
<td>1.5-8.0</td>
</tr>
<tr>
<td>Manure salts</td>
<td>19-32</td>
<td>Tobacco stems</td>
<td>4.4-5.4</td>
</tr>
</tbody>
</table>

1 Usually sold as nitrate of potash or Chilean nitrate of potash.
The principal potassic fertilizer materials and the approximate ranges of their potash contents are given in table 7.

SECONDARY ELEMENTS IN FERTILIZER MATERIALS

The different fertilizer materials contain other elements in addition to nitrogen, phosphorus, or potassium. The quantities of these elements present in a given material may vary from none or extremely little to quantities greater than those of the three elements thus far discussed. Although certain of these elements are just as essential for normal plant growth as nitrogen, phosphorus, and potassium, their presence has customarily been given little or no consideration in the use, or determination of the value, of fertilizer materials, since they were generally thought to be present in soils in quantities sufficient to meet crop requirements.

The elements calcium, magnesium, sulphur, boron, copper, manganese, zinc, and iron are of more immediate practical interest to fertilizer investigators and the fertilizer industry. The three elements calcium, sulphur, and magnesium are used by crops to a greater extent than the other secondary elements.

Ordinary superphosphate, the most extensively used of all phosphatic fertilizer materials, contains about 19 to 22 percent of calcium. Calcium is also a prominent element in most of the other phosphatic fertilizer materials, the sole exception being the ammonium phosphates, as well as in certain nitrogenous fertilizer materials, calcium cyanamide, calurea, calcium nitrate, and Cal-Nitro.

Superphosphate also contains about 10 to 12 percent of sulphur, and ammonium sulphate, the most extensively used of the nitrogenous fertilizer materials, contains about 23 percent, while sulphur is present in considerable quantity also in the potassic fertilizer materials—potassium sulphate, sulphate of potash-magnesia, and manure salts. While most ordinary commercial fertilizer mixtures contain superphosphate and ammonium sulphate as ingredients, and therefore furnish sufficient calcium and sulphur to the soil to prevent a deficiency of either element, there are other fertilizer materials that are almost completely lacking in both elements. If such materials were utilized in the production of complete fertilizers it is conceivable that their continued use would in time accelerate the exhaustion of the available calcium and sulphur naturally present in the soil to such an extent that it would be necessary to add calcium and sulphur compounds to the fertilizer to prevent the deficiency. Notable cases of sulphur deficiency have been observed and reported in connection with certain soils of Oregon and Washington. Under eastern conditions no serious case of either calcium or sulphur soil deficiency has as yet been observed under ordinary field conditions.

Magnesium deficiency in all probability has affected crop production more widely than that of any other secondary plant food. Its widespread occurrence along the Atlantic seaboard in recent years has been due primarily to two factors—(1) the use of commercial fertilizers made from materials containing very little magnesium,

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7 For a discussion of the results of deficiency of these elements in soil, see Neglected Soil Constituents That Affect Plant and Animal Development, p. 807.
and (2) increasing soil acidity resulting from the heavier use of acid-forming salts, which facilitated the leaching of magnesium from the soil. Both of these factors have tended to lower the content of available magnesium in the soil to a point below the requirements of crops.

Formerly, the main sources of magnesium in fertilizer mixtures were the low-grade potassic materials, which contained considerable quantities. These materials, once the most extensively used means for supplying potassium in fertilizers, have now been largely displaced by high-grade potassium salts that contain little magnesium. The kainite, containing about 13 percent of potash, also contained about 7 percent of magnesium; but potassium chloride, the potassic fertilizer material most used at present, with 50 percent or more of potash, generally contains less than 0.1 percent of magnesium; and potassium sulphate, with about 48 percent of potash, usually contains less than 0.5 percent of magnesium.

Although the organic ammoniates, formerly the principal sources of nitrogen in fertilizers, contained only small amounts of magnesium—about 0.5 percent in cottonseed meal, for example—nevertheless they supplied considerable quantities because of the large tonnages used. They have now been largely displaced by cheaper products containing practically no magnesium. Realizing the necessity for the addition of magnesium-containing materials to fertilizers for use on soils requiring this element, many fertilizer manufacturers have in recent years incorporated calcined kieserite, an anhydrous form of magnesium sulphate that contains about 19 percent of magnesium in water-soluble form, or sulphate of potash-magnesia (a potassic fertilizer material), which contains about 6 percent of water-soluble magnesium.

Magnesium-containing or dolomitic limestones and dolomite, which contain up to about 12 percent of water-insoluble magnesium, are also extensively employed as additions to fertilizer mixtures at present. The primary purpose, however, in many cases is not to supply magnesium but to prevent the increase in soil acidity caused by certain nitrogenous fertilizer materials. Although the magnesium in these additions is water-insoluble, a portion is rendered water-soluble as a result of chemical reactions that take place with the superphosphate of the mixtures to which they are added. It is known also that the water-insoluble magnesium in the soil becomes slowly available for use by crops, but no chemical procedure has yet been developed for determining its availability. In order to determine practical procedures, much more information is needed on the responses of different crops to different magnesium compounds. Progress is being made in this direction through field tests in many places.

There is occasional need for the addition to fertilizers of other elements in decidedly smaller amounts than calcium, sulphur, and magnesium. The necessity for the use of special materials to supply these elements to fertilizers is infrequent, yet in particular cases successful crop production is dependent on using them either as direct additions to the soil or as additions to mixed fertilizers or spray materials. The compounds being used chiefly as sources of these elements in fertilizers are manganese sulphate, copper sulphate, zinc sulphate, borax, and ferrous sulphate, all of which are water-soluble.
It is essential to keep in mind that too heavy an application of any secondary element to the soil in fertilizers may readily lead to serious crop injury. The use of compounds supplying these elements should be based on the results of actual experimentation with different crops and soils. The promiscuous use of secondary elements in fertilizer mixtures without such information is both unwarranted and uneconomical.

**EVALUATION OF FERTILIZER MATERIALS DEPENDENT UPON EFFECT ON CROP GROWTH**

When a new material is proposed for fertilizer use, one of the first things to determine is its effect on plant growth. Before attempting this, however, its solubility, hygroscopicity, reaction, and behavior when mixed with standard fertilizer materials are determined. When these physical properties have been found to be satisfactory, the new material is tested to determine what nutrient value it may possess. Such tests are generally initiated under controlled greenhouse conditions, pots or other containers being used to hold the soil. Suitable crop plants are grown and the new materials are evaluated in terms of standard fertilizer materials of known performance, which are utilized as controls. In this way results are obtained more quickly than is possible otherwise.

Field experiments conducted under actual field conditions, however, when properly supervised, afford the best proof in the long run. By these methods a great many of the new fertilizer materials have been evaluated by some of the State agricultural experiment stations and the Department of Agriculture. Information of this kind is essential because the commercial exploitation of a material for fertilizer use is predicated upon its having sufficient nutrient value to warrant large-scale production.

A discussion of the residual effects of fertilizer materials on soil reaction is given in the Appendix (p. 519).

**APPENDIX**

**Description and Uses of Important Fertilizer Materials**

**Nitrogen Materials**

**AMMONIA**

Ammonia (NH₃) is the basic constituent of many ammonium compounds. It is a gas containing 82.25 percent of nitrogen. There is a liquid anhydrous form obtained by compressing ammonia gas under suitable conditions as to pressure and temperature. This form of ammonia is now of importance to the fertilizer industry for the ammoniating of superphosphate either to produce base mixtures or to make complete fertilizers. Another form, aqua ammonia (NH₄OH), or ammonia liquor, results from the absorption of ammonia gas (NH₃) in water, in which it is quite soluble. Commercial grades of ammonia liquor may run as high as 30 percent of ammonia (NH₃). Various ammonium salts result when ammonia is made to react with different acids, such as sulphuric to form ammonium sulphate, phosphoric to form ammonium phosphate, and nitric to form ammonium nitrate. Anhydrous liquid ammonia is used to some extent in California for introduction into irrigation water.
Fertilizer Materials

AMMONIUM CHLORIDE

The ammonium salt of hydrochloric acid, ammonium chloride, is a white crystalline compound with a nitrogen content of about 26 percent. It possesses an excellent physical condition, and aside from the fact that its chlorine content may prove detrimental to certain crops, particularly tobacco and certain starch-forming plants, the results of experimental studies in the United States have shown that it compares favorably with ammonium sulphate. On account of the higher cost of hydrochloric acid, however, ammonium chloride is not being used in fertilizers in the United States.

AMMONIUM NITRATE

Ammonium nitrate is a white crystalline salt generally prepared by neutralizing nitric acid with ammonia. It is rich in nitrogen, generally having a content of this element of from 33 to 35 percent. It is quite hygroscopic, which renders it undesirable as a complete source of nitrogen in mixed fertilizers. In some measure a mechanical treatment termed granulation will alleviate this moisture-absorbing tendency, the granules being further protected by a light coating of oil. Another method to overcome this hygroscopic nature of ammonium nitrate consists in the preparation of a product made by mixing ammonium nitrate with calcium carbonate. This material, given the trade name "Cal-Nitro" by German interests and "Nitro-Chalk" by English producers, has half of its nitrogen in the nitrate form and half in the ammonium form. Its content of lime carbonate makes this material well adapted to soils low in lime. Strictly from the standpoint of plant food, however, it has given an excellent account of itself, largely because it contains both the ammoniacal and nitrate forms of nitrogen.

AMMO-PHOS

"Ammo-Phos" is a trade name for two commercial grades of monoammonium phosphate used as fertilizer materials and in mixed fertilizers to furnish nitrogen and phosphoric acid. Two grades, A and B, are on the market. Grade A, most commonly used for fertilizer purposes, contains about 11 percent of nitrogen and 45 to 48 percent of available phosphoric acid. Grade B contains about 16.5 percent of nitrogen and 20 percent of available phosphoric acid, being largely a mixture of ammonium phosphate and ammonium sulphate. Both grades possess an excellent mechanical condition, and extensive experimental studies with various crops on important soil types have shown them to be dependable fertilizer materials.

AMMONIATED SUPERPHOSPHATE

Ammoniated superphosphate is a product resulting from treating superphosphate with anhydrous or aqueous ammonia (aqua ammonia). The ammoniation of superphosphate is recognized as an excellent practice, because it makes for quicker curing and better mechanical condition, neutralizes acidity, adds nitrogen, reduces bag rotting and storage difficulties, and finally insures good drillability and uniform distribution.

Other materials for ammoniating fertilizer materials containing superphosphate are "Urea-ammonia liquor A" and "Urea-ammonia liquor B." Both are essentially solutions of crude urea in aqua ammonia. Urea-ammonia liquor B, however, contains a higher ratio of urea nitrogen to ammoniacal nitrogen, so that by its use more nitrogen may be introduced into the ammoniated product without reversion of the phosphoric acid to nonavailable forms. Other ammoniating solutions have been designated "crude nitrogen solution" and "nitrogen solution II," respectively. The former is a mixture of nitrate of soda (45 percent), anhydrous ammonia (45 percent), and water (10 percent). The normal composition of nitrogen solution II is by weight: Ammonium nitrate (60 percent), ammonia (20 percent), and water (20 percent). All these liquors are employed in the preparation of either base mixtures or complete fertilizers. Still more recently formamide (HCONH₂), containing about 30 to 31 percent of nitrogen, has been suggested as a source of nitrogen in the preparation of ammoniating solutions. Recent greenhouse studies made to evaluate formamide and its hydrolytic product, ammonium formate, as nitrogen sources for plants, indicate that they compare favorably with certain standard sources of nitrogen, including ammonium sulphate and urea.

* When the formamide liquor is added to superphosphate the formamide hydrolyzes to form ammonium formate.
AMMONIUM PHOSPHATE

The two principal ammonium phosphates are monoammonium phosphate and diammonium phosphate, both containing two fertilizer elements, nitrogen and phosphorus. The former when comparatively pure contains about 11 percent of nitrogen and 60 percent of available phosphoric acid; and the latter 21 percent of nitrogen and 53 percent of available phosphoric acid. While both compounds have been used as fertilizer materials, particularly monoammonium phosphate in the United States under the trade name "Ammo-Phos," diammonium phosphate is preferably used with other materials owing to its tendency to lose ammonia. It is alkaline in reaction and reported cases of crop injury following its use on light sandy soils appear to have been due to the liberated free ammonia adversely affecting root development.

AMMONIUM SULPHATE

Ammonium sulphate is a salt resulting from the interaction of ammonia and sulphuric acid, the ammonia being either a volatilization product in the manufacture of coke from coal or synthesized from atmospheric nitrogen. It is also produced on a large scale in foreign countries from ammonia, gypsum, and carbon dioxide. Commercial sulphate of ammonia for fertilizer use should contain not less than 20.5 percent of nitrogen. Arcadian sulphate of ammonia differs from the ordinary commercial grade by being neutralized, dried, and screened to remove lumps. The process of manufacture—neutralizing, drying, and screening—insures excellent physical condition and uniform distribution of the material when applied to the soil.

Ammonium sulphate and sodium nitrate for many years were the chief sources of inorganic nitrogen and in large measure still are. Of all inorganic fertilizer materials ammonium sulphate is at the present time the most universally produced, being manufactured, according to report, in 15 of the leading countries of the world.

Sulphate of ammonia is used in practically the same way as nitrate of soda, and under most soil conditions just as effectively. It differs from the latter, however, in its effect on soil reaction, tending to increase soil acidity, particularly if used continuously. Its best effect is on soil not too acid in reaction. If the acidity of the soil becomes too great, harmful compounds, chiefly of aluminum, may go into solution, resulting frequently in what is termed aluminum toxicity.

This acid-forming tendency on the part of ammonium sulphate as well as other ammonium compounds may be counteracted by liming the soil to a point conducive to the greatest activity of nitrifying bacteria, or by adding enough finely ground limestone to the ammonium sulphate to offset the tendency. When this is done, sulphate of ammonia has been found to give results on a par with those from equivalent quantities of nitrogen in nitrate of soda.

CALCIUM CYANAMIDE

Calcium cyanamide, a synthetic fertilizer material, is a grayish-black powder containing considerable lime, some free carbon, and other incidental materials of no special significance. Owing to its high neutralizing power, it is decidedly suitable for soils having an acid reaction. It cannot be used too freely in mixed fertilizers because undesirable reactions ensue. However, when used at the rate of 50 to 60 pounds per ton it is a good source of nitrogen and helps considerably in providing a fertilizer mixture with a good mechanical condition as well as helping to prevent bag rotting. Commercial calcium cyanamide generally contains about 21 to 22 percent of nitrogen. A chief use in European countries as well as in the United States is for top dressing grassland.

CALCIUM NITRATE

Calcium nitrate (nitrate of lime) is a fertilizer material generally produced from the neutralization of synthetic nitric acid with calcium carbonate or limestone. In its action as a nutrient material it rates on a par with nitrate of soda, but it is more hygroscopic, which makes it somewhat more difficult to apply to the soil. Shipment in paper-lined moistureproof bags and quick application when opened have tended to make it easier to handle. When applied to the soil it behaves similarly to nitrate of soda in that it eventually tends to decrease soil acidity. For some crops, particularly if there is a low available calcium content in the soil, calcium nitrate is especially indicated. It carries about 17 percent of nitrogen and about 34 percent of lime stated as calcium oxide (CaO).
CAL-NITRO

This commercial product is described under Ammonium Nitrate.

CALUREA

"Calurea" is a trade name for a double salt prepared through the interaction of synthetic urea and calcium nitrate. It is a white crystalline product, readily soluble in water. It contains about 34 percent of nitrogen, about four-fifths of which is present as urea nitrogen, the balance in the form of nitrate nitrogen. The results of fertilizer experiments in which Calurea was used indicate it is a satisfactory source of nitrogen.

CASTOR POMACE

Castor pomace is the residue of the castor bean after the oil has been extracted. It is not used as a stock feed, being poisonous, and therefore generally can be purchased at a more reasonable cost per unit of nitrogen than materials such as cottonseed meal, dried blood, or tankage. The nitrogen content of castor pomace is in the organic form, and on an average runs about 5.5 percent, with about 1 to 1.5 percent of phosphoric acid (P₂O₅) and the same percentage of potash (K₂O). Castor pomace rates well as an organic source of nitrogen and for its good effect on the mechanical condition of fertilizers.

COTTONSEED MEAL

Cottonseed meal is a byproduct resulting from the extraction of oil from cottonseed. The remaining press cake residue is ground to give commercial cottonseed meal with a nitrogen content averaging about 7 percent (if contaminated with hulls it may be as low as 6 percent), about 2.5 percent of phosphoric acid, and from 1.5 to 2 percent of potash. Generally it is used as a partial source of nitrogen in mixed fertilizers and is popular in certain sections where special crops such as tobacco are grown. The nitrogen in cottonseed meal is relatively quickly available. It possesses an excellent mechanical condition, and a little of it goes a long way in preventing caking of fertilizer mixtures. In recent years admixtures of cottonseed meal and certain inorganic nitrogen fertilizer materials, chiefly sulphate of ammonia and nitrate of soda, have been recommended for the early spring treatment of lawns. Owing to the fact that cottonseed meal, especially the better grades, is used for stock-feeding purposes, the price is higher per unit of nitrogen than the inorganic nitrogen materials.

DRIED BLOOD

Dried blood is a byproduct of the abattoir and the packing-house industry. At the present time it is less used as a fertilizer material than in former years, owing in large measure to the demand for it for stock-feeding purposes, the resulting competition tending to raise the nitrogen cost to the consumer. The best grades of dried blood generally are not used for fertilizer purposes unless specified, the poorer off-color grades being reserved for this purpose. Ordinarily good dried blood will have a nitrogen content ranging from 12 to 14 percent down to as low as 9 percent, owing to dilution with animal parts containing less nitrogen than blood. The nitrogen of blood becomes available in a relatively short time and is prized by greenhouse specialists on this account as well as for its good mechanical condition, ease of distribution, and noninjurious action on plants.

FISH SCRAP

Fish scrap is prepared from nonedible fish and offal from fish canneries. After the fish have been cooked with steam and the oil pressed out, the residue is dried and ground and sold for fertilizer and other purposes. Another product, designated "acidulated fish scrap" or "acid fish," represents residual fish waste treated with an acid to prevent decomposition. Both the raw and the acidulated fish scrap possess a good mechanical condition and their nitrogen becomes available to crops in a relatively short time. Raw fish scrap contains on an average about 8 percent of nitrogen and 6 percent of phosphoric acid, and acidulated fish, 5 percent of nitrogen and 4.5 percent of phosphoric acid.

GARBAGE TANKAGE

Garbage tankage is a low-grade organic nitrogen material resulting from the treatment of household, hotel, and restaurant kitchen wastes in about the same
way as slaughterhouse wastes. It contains on an average about 3 percent of slowly available nitrogen, 3.5 percent of phosphoric acid, and 0.75 percent of potash. Garbage tankage is dry and bulky, making its chief value that of a conditioner for fertilizer mixtures.

**LEUNAPHOS**

"Leunaphos" is a trade name for a mixture of diammonium phosphate and ammonium sulphate. It carries 20 percent nitrogen in the ammonium form, and 20 percent available phosphoric acid (P₂O₅). Its most extensive use as a fertilizer material has been in Germany.

**LEUNASALPETER**

"Leunasalpeter" (26 percent nitrogen) is a trade name for a double salt of ammonium sulphate and ammonium nitrate (ammonium sulphate-nitrate), with one-fourth of the nitrogen content in the nitrate form and the remainder in the ammonia form. It is manufactured in Germany in large quantities for fertilizer use. Chemically it is a double salt, not a simple mechanical mixture of the two salts. It has given good results in field and greenhouse tests in comparison with standard nitrogen sources.

**LINSEED MEAL**

Linseed meal is a material resulting from the pressing of flaxseed to obtain linseed oil. The press cake is afterward ground. The demand for it for stock-feeding purposes is sufficient to make it too expensive a nitrogen source for fertilizer use, except on a very limited scale. It behaves similarly to cottonseed meal and contains approximately 5.5 percent of nitrogen. In addition, there is a small percentage (1.7) of phosphoric acid (P₂O₅), and about 1.3 percent of potash (K₂O).

**POTASSIUM NITRATE**

Potassium nitrate is one of the earliest discovered chemical nitrogen compounds for both agricultural and industrial uses. From the standpoint of natural supplies only small deposits of potassium nitrate occur in different parts of the world. These deposits have no particular value for commercial exploitation. The raw material from which refined sodium nitrate is produced—caliche—contains from 2 to 3 percent of potassium nitrate. The latter constitutes the main source of this salt. A crude form of potassium nitrate containing both sodium and potassium nitrates, constitutes the commercial grade most frequently used as a fertilizer material. This has a nitrogen content of 14 to 15 percent and a potash content (K₂O) of about 14 percent. When refined or produced synthetically, potassium nitrate contains close to 14 percent of nitrogen and about 45 percent of potash.

Potassium nitrate is much less hygroscopic than other fertilizer nitrates and has the advantage of carrying two fertilizer elements. An evaluation of potassium nitrate, in greenhouse and field tests, indicates it is a valuable fertilizer material. This is primarily due to its nitrogen being in the nitrate form and therefore immediately available to crop plants, and also to its better retention than sodium nitrate by the soil.

**SEWAGE SLUDGE**

Sewage sludge is a product resulting from the treatment of city or town sewage. The two chief methods of treating sewage are the Imhoff and the activated. The activated sludge method gives a higher grade product and one better adapted to fertilizer use, averaging about 5 percent of nitrogen and 3.5 percent of phosphoric acid. Imhoff sludge contains on an average only 2.5 percent of nitrogen and about 1 percent of phosphoric acid. Dried activated sludge is produced and marketed by the sewerage commission of the city of Milwaukee and sold under the trade name "Milorganite." It is also being produced by the city of Pasadena, Calif., and sold under the trade name "Nitroganic." Activated sewerage products are made from sewage free from grit and coarse solids, and aerated after being inoculated with micro-organisms. The resulting flocculated organic matter is withdrawn from the tanks, filtered with or without the aid of coagulants, dried in rotary kilns, ground, and screened.
Fertilizer Materials

SODIUM NITRATE (NITRATE OF SODA)

There are two principal commercial sources of sodium nitrate, (1) Chilean sodium nitrate or saltpeter, and (2) synthetic sodium nitrate (made in the United States as Arcadian sodium nitrate). Chilean nitrate is a relatively pure salt containing approximately 95 to 98 percent of sodium nitrate, equivalent to 15.6 to 16 percent of nitrogen. Synthetic sodium nitrate, containing 16 to 16.25 percent of nitrogen, is made from synthetic ammonia (this being converted to nitric acid) and sodium carbonate.

Sodium nitrate is one of the main sources of available nitrogen, having been used extensively as a fertilizer material in the United States for practically a century. Its popularity is due primarily to the fact that much experimental evidence coupled with the practical experience of farmers, fruit growers, and vegetable crop specialists, has clearly shown it to be a quick-acting, dependable source of nitrogen. Its rapid solubility in the soil moisture insures immediate availability to crop plants, thereby rendering this fertilizer material particularly adaptable to the growing of truck crops, and as a supplementary treatment for cotton, corn, small grains, and tobacco. Sodium nitrate is used as an ingredient in complete fertilizer mixtures, but as a general rule the results of field studies comparing different carriers of nitrogen indicate that a better response is obtained from a mixture of sodium nitrate and ammonium sulphate than from one source alone. A mixture of sodium nitrate and ammonium sulphate is much to be preferred to either alone.

Sodium nitrate is used principally in three ways: (1) Direct application to the soil as side or top dressing, (2) in commercial and home-prepared fertilizer mixtures, and (3) in the production of greenhouse crops. Used properly as to rate and time of application, sodium nitrate influences crop quality, especially in the case of leafy crops or those to be eaten raw for salad purposes. A mixture of equal parts of sodium nitrate and ammonium sulphate diluted with cottonseed meal makes a good early spring lawn treatment, providing the grass with a supply of quickly available nitrogen. The properties of sodium nitrate in relation to soils and crops are discussed in detail in a publication of the United States Department of Agriculture.

TANKAGE

Tankage is the refuse from slaughterhouses, and from all other sources furnishing dead animals or waste parts. After being cooked with steam, generally under pressure, and the fat pressed out or skimmed off, the residue is dried and ground. The composition of tankage varies, chiefly in accordance with the proportion of bone to meat, etc. A good grade of tankage will contain as much as 10 percent of nitrogen; lower grades scale down to 5 percent. It also has a phosphoric acid content of from 9 to 14 percent. Tankage possesses a good mechanical condition, and so far as nitrogen availability is concerned it is practically on a par with cottonseed meal and similar byproduct organic ammoniates.

UREA

Urea is a white crystalline organic compound. It is produced synthetically on a large scale in the United States as well as in Germany. Commercial urea is relatively pure, containing about 46 percent of nitrogen against 46.65 percent for pure urea. Urea, the nitrogen of which is classified as nonproteid organic nitrogen (the amide form), is water-soluble. In availability to crop plants it rates high, and the results of experimental studies conducted under field conditions with different crops on a wide range of soil types show it to be an excellent fertilizer material. While urea is fairly hygroscopic, recent methods of production largely offset this.

MISCELLANEOUS NITROGEN MATERIALS

There are a number of refractory organic materials containing nitrogen—refractory in the sense that they resist decomposition to a marked extent. A list of such materials includes hair, hide scrapings, hoof and horn meal, leather meal, wool waste, feathers, shoddy and felt, scrap fur, silk waste, etc. These are termed rough ammoniates. Such materials have to be suitably treated in order to possess more rapid availability. This can be done by adding one or more of the organic materials to phosphate rock and treating the mixture with sulphuric acid in the same way superphosphate is made—ordinarily termed the "wet-mixed
process." By the action of the sulphuric acid on the nitrogenous materials the unavailable nitrogen is converted into an available form, partly ammonium sulphate and partly organic compounds that are readily transformed in the soil and made assimilable by plants.

By such a method it is practicable to convert inert materials into forms furnishing appreciable quantities of valuable plant food, and at the same time to produce the primary product, superphosphate. The acidulation process leads to the production of base goods, or as commonly designated in Europe, ammoniated superphosphate, a product differing from the one obtained when superphosphate is treated with ammonia.

There are also various vegetable and fruit wastes termed pomaces, including chiefly apple pomace— the pulp left after apples are pressed for cider— tomato, pumpkin, and cranberry pomaces. Generally speaking, such materials must be used locally and in some cases should be composted before using. If used in any great quantity the precaution of liming should be taken to neutralize any acidity that might develop.

**Phosphatic Materials**

**Basic slag**

Basic slag is a byproduct obtained in the manufacture of steel by the basic Bessemer and basic open-hearth processes. Open-hearth basic slag, as a rule, contains less phosphorus and is more variable in composition than that produced by the Bessemer process. The slags from the two processes also differ greatly in the availability of the phosphorus as measured by the solubility in citric acid and by vegetative tests. This difference is due to the practice in many open-hearth plants of adding fluor spar to the furnace charge for increasing the fluidity of the slag and aiding in the desulphurizing of the iron. The availability of the phosphoric acid in basic slag increases with the fineness of grinding and with the silica content, and decreases as the fluorine content increases. Basic slag made without the addition of fluor spar is generally more effective on acid soils than superphosphate; the reverse is true on alkaline soils. As a result of its free lime content, basic slag is of special value for the reclamation of acid soils, particularly such as are rich in organic matter, like many marsh or muck soils. It has also proved very beneficial to clover, alfalfa, and the grasses, being particularly suitable as a top dressing for old meadows and pastures. Its availability to soybeans at the New Jersey Agricultural Experiment Station was found to be approximately equivalent to that of superphosphate (37). Although fluor spar slags generally give somewhat increased yields, they are less effective than the more soluble basic slags.

**Bones**

The use of bones as a fertilizer material to supply phosphoric acid and some nitrogen antedates the use of rock phosphate or superphosphate by a great many years. While it was recognized in ancient days that an application of bones did something toward increasing crop yields, there was no explanation of the effects until the discovery of the element phosphorus by Gahn in 1709, which disclosed that phosphorus is a vital constituent of bones. The earlier idea was that the fertilizer value of bones was due to certain organic constituents, fat and gelatine. It is now known that bones are rendered more efficient for fertilizer purposes when these organic substances are largely removed by steaming or other treatment. This indicates that the effect of bones is due chiefly to their calcium phosphate content, although some benefit may be ascribed to the nitrogenous organic constituents.

Acidulated bone, also termed "bone superphosphate," contains on an average about 14 or 15 percent of available phosphoric acid and from 1 to 2 percent of nitrogen. To Sir John Lawes, founder of the famous Rothamsted Experiment Station at Harpenden, England, goes the credit for developing a process of treating bones with sulphuric acid to render the phosphoric acid more available. His experimental studies more than a century ago proved the value of such treatment. This material has at the present time only historical value, for the reason that the same treatment when applied to mineral phosphates, generally designated rock phosphates, produces equivalent results in rendering the phosphoric acid of the

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9 Ammonium phosphate and Ammo-Phos, sources of phosphoric acid as well as of nitrogen, are described under Nitrogen Materials, pp. 508 and 507.
Bonemeal (raw) results from grinding bones to a fine state of division without other treatment. It is a carrier of both nitrogen (averaging 3.5 percent) and phosphoric acid (ranging from 20 to 25 percent). The use of raw bone as a fertilizer material goes back many years and its value depends largely upon how finely the bones are ground. It is a "safe" material and can be used in comparatively large quantities without causing injury to crops. Its use in greenhouses and for special purposes is fairly heavy, owing to its lasting qualities.

Bonemeal (steamed) is a product resulting from grinding animal bones that have been previously steamed under pressure. Steamed bonemeal contains less nitrogen than raw bonemeal, only about 2 percent on an average, but with an average higher content of phosphoric acid. In comparison with raw bonemeal the nitrogen and phosphoric acid of steamed bonemeal are more quickly available, owing to finer grinding of the latter and the removal of interfering fat. The nitrogen and phosphoric acid in bonemeal, whether raw or steamed, cost more than when bought in the form of inorganic nitrogen materials and superphosphate.

Precipitated bone is a byproduct obtained in the manufacture of glue stock from bones. It contains about 40 percent of available phosphoric acid chiefly in the form of dicalcium phosphate, the phosphoric acid of which, though not soluble in water, is soluble in neutral ammonium citrate. Precipitated bone phosphate is obtained by neutralizing the hydrochloric acid solution of processed bone with calcium hydroxide.

Calcined phosphate

The term "calcined phosphate" refers to two products. One results from heating to a high temperature a mixture of ground phosphate rock with a compound of an alkali. This thermal treatment is claimed to render the phosphorus in the rock soluble in neutral ammonium citrate. The second product has been produced on a laboratory scale by heating ground phosphate rock, containing 5 to 10 percent of silica, in the presence of water vapor for 30 minutes at about 1,400° C. This effectively removes all its fluorine and renders the phosphorus in the resulting product available to crop plants. The phosphoric acid (P₂O₅) content averages about 34 percent, and when the treatment is effectively regulated it is soluble in neutral ammonium citrate solution. Tests made under greenhouse and field conditions show that these calcined phosphates rate highly as nutrient materials for different crop plants.

Monopotassium phosphate

Monopotassium phosphate has considerable potential value as a fertilizer material if it can be produced on a commercial scale at a reasonable cost. It contains two nutrient elements, phosphorus and potassium, in an available form and would also be very adaptable to the preparation of concentrated fertilizers.

Rock phosphate

Rock phosphate occurs in great deposits throughout the world, those of greatest commercial importance in the United States being located in Florida and Tennessee in the East, and in Idaho, Montana, Utah, and Wyoming in the West. Besides the commercially recognized phosphate rock deposits in the United States, other deposits of importance occur in Nauru and Ocean Islands in the Pacific Ocean, in Morocco, Tunis, Algeria, and Egypt, and in the Union of Soviet Socialist Republics. On numerous other islands in the Pacific phosphate deposits have been located, but these have not always warranted commercial exploitation. Commercial utilization of phosphate rock deposits was first made in South Carolina in 1867-68, and for a number of years most of the phosphate rock utilized for the manufacture of superphosphate came from these deposits. The South Carolina deposits are now of no importance from a commercial standpoint and the heaviest production is in Florida and Tennessee where deposits were discovered, respectively, in 1888 and 1894. In the West there has gradually developed a demand for phosphate rock which has been met by supplies from the Western States mentioned above.

While a certain quantity of finely ground rock phosphate is used for direct application to the soil, it is slight in comparison with the enormous quantity of rock converted into superphosphate by acid or other chemical treatment. There

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are, no doubt, certain soil conditions and farm practices that enable finely ground phosphate rock to give a good account of itself, but taken by and large most soils and crops require a more available source of phosphoric acid, such as superphosphate, ammonium phosphate, or other phosphatic material the phosphoric acid of which is either water- or citrate-soluble. "Colloidal phosphate" is a trade name applied to a finely divided, comparatively low-grade rock phosphate or phosphatic clay. It is also designated "waste pond phosphate" for the reason that in the hydraulic operation involved in mining rock phosphate in Florida a considerable quantity of fine phosphatic material, virtually colloidal from a mechanical standpoint, is washed into ponds and settles out. When removed, following drainage and evaporation of the water, it contains a relatively high proportion of clay, so that the Colloidal phosphate usually contains only from 18 to 23 percent of phosphoric acid. On account of the presence of so much foreign material, principally clay, Colloidal phosphate is considered to be unsatisfactory for treatment with sulphuric acid. The claim is made for this material and others of a similar nature that not only is the phosphoric acid more quickly available than that of mechanically ground rock phosphate, but also that the content of minor elements in Colloidal phosphate makes it superior to its close relative, rock phosphate. These claims, while highly interesting, have failed of substantiation in a number of States, particularly so when a comparison of such materials with superphosphate is taken into consideration.

As a general rule the effectiveness of any rock phosphate material is dependent upon its degree of fineness, the quantity applied to the soil, and the reaction of the soil. It has been shown that the best response ensues when the soil possesses a relatively strong acid reaction.

SUPERPHOSPHATE

Superphosphate (16 to 20 percent available \( P_2O_5 \)) is an important phosphatic fertilizer material made by treating ground phosphate rock with sulphuric acid in approximately equal proportions by weight, the acid usually having a strength of 52° to 55° B. The resulting product is a mixture of monocalcium phosphate and calcium sulphate practically in equal proportions. This acidulation of phosphate rock converts the relatively insoluble tricalcium phosphate into an available form—monocalcium phosphate. Ordinary superphosphate can be produced to contain as much as 20 percent of available phosphoric acid, largely by selecting high-grade raw phosphate rock and by careful supervision of the chemical operations involved.

Superphosphate ranks first among all phosphatic fertilizer materials with respect to quantity consumed for fertilizer use. While it still occupies a commanding position in this respect it is important to note that when it comes to the preparation of so-called concentrated fertilizers ordinary superphosphate is of less importance, for the reason that its phosphoric acid content is not great enough to permit its use in the preparation of fertilizer mixtures other than those of ordinary strength. The preparation of concentrated fertilizers requires phosphatic materials such as ammonium phosphate or treble superphosphate.

Superphosphate is used principally as a source of phosphoric acid in complete fertilizers; for direct application to certain crops, principally on grassland; for reinforcing stable manure; and as a direct fertilizer treatment for soil deficient in phosphorus but well supplied with available nitrogen and potassium. Applied to decidedly acid soils in sufficiently large quantities, superphosphate reacts with some of the elements associated with such an acid soil condition, chiefly aluminum, thereby relieving crops from the ill effects of any toxic tendency that might result from the presence of soluble aluminum compounds. As a rule, however, such treatment is prohibitive in cost, and the same objective may be more cheaply attained by the use of lime.

When superphosphate was first prepared in the United States the term "acid phosphate" was applied to it. This earlier terminology prejudiced many against the material for the reason that acid phosphate implied an acid-forming tendency. As a matter of fact experimental studies over long periods offer conclusive evidence that this is not so. If anything, the continued use of superphosphate tends to ameliorate acid soil conditions by throwing toxic compounds out of solution. For these reasons the term "acid phosphate" was discontinued a number of years ago.

Triple (or treble) superphosphate (40 to 48 percent available \( P_2O_5 \)) is similar to ordinary superphosphate in appearance but differs from it in containing very little calcium sulphate, which, however, does not appear to lower the effectiveness of
triple superphosphate. It provides a material possessing high concentration in phosphoric acid (P₂O₅) and therefore is exceptionally well suited to the production of concentrated fertilizer mixtures. In the production of triple superphosphate liquid phosphoric acid is used instead of sulphuric acid.

**Potassic Materials**

**Kainite**

Kainite was originally a natural product of the European potash mines and sold in its crude state. It was composed chiefly of muriate of potash and sulphate of magnesium with about 30 percent of common salt, or sodium chloride. Commercial kainite was guaranteed to contain 12.4 percent of potash (K₂O), although some grades ran as high as 14 percent. In the United States kainite found its greatest use in fertilizers for cotton, one of the chief fertilizer-consuming crops grown in this country. Owing to its high chlorine content it was an undesirable source of potash for certain crops, especially tobacco and potatoes. The "Kainit" occurring in the trade at the present time is no longer the natural mine product but is a semi-refined product of potash manufacture corresponding to the 20-percent manure salts mentioned below.

**Manure Salts**

Manure salts formerly included a number of potash fertilizer materials with high chlorine content. The percentage of potash varied, but ordinarily the two principal grades contained approximately 20 and 30 percent respectively. The term "manure salt" as it occurs in commerce is now restricted to the 25- to 30-percent product, the 20-percent product being now called Kainit, as above mentioned.

**Potassium Chloride**

Potassium chloride (muriate of potash) contains about 48 to 62 percent of potash (K₂O). This salt is produced abroad through the refinement of carnallite, a crude potash salt containing approximately 8 to 10 percent of K₂O. The crude carnallite is ground, dissolved in hot water, and purified to the point where it contains from 48 to 50 percent of K₂O. It is also obtained from the brines of certain salt lakes and from sylvinitc, a mixture of potassium and sodium chlorides.

**Sulphate of Potash-Magnesia**

Sulphate of potash-magnesia contains about 25 to 27 percent of potash (K₂O) in the form of the sulphate and about the same percentage of magnesium sulphate. It is made either from kainite or from potassium chloride and magnesium sulphate. Owing to its low chlorine content, generally less than 2.5 percent, this material is useful when a low chlorine fertilizer material is desired or where a shortage of magnesium has been noted.

**Other Potash Sources**

Other potash sources adaptable to fertilizer use include potassium carbonate, double carbonate of potash and magnesia, and potassium nitrate. Besides the important salt brines of Searles Lake in California and the extensive potash deposits discovered in New Mexico, a considerable number of potash sources exist in the United States, including cement mills, blast furnaces, lake brines other than those in California, residues from beet-sugar and molasses plants, wood ashes, tobacco by-products, seaweed, greensand marl, and certain minerals such as alunite, leucite, potash feldspar, phonolite, and nepheline. These last, including

10Potassium nitrate is described under Nitrogen Materials, p. 510.
greensand marl, have not been found equal to the more available potash compounds, even when very finely ground.

Miscellaneous Materials

AGRICULTURAL SALT

Agricultural salt has received considerable attention as an indirect fertilizer material. It is chiefly common salt, and its reputed value is thought to lie in its solvent action on phosphatic and potassic compounds natural to soils. This use of salt is uncommon, since any effectiveness to be ascribed to it may be obtained from the sodium chloride contained in kainite or in other low-grade potash salts.

ARTIFICIAL MANURE

The demand for barnyard manure is so great and the price so high that considerable interest has been aroused concerning the practicability of utilizing some of the waste organic materials to be found on the farm with the idea of converting them through bacterial agencies and certain chemical treatments into artificial, or synthetic, manure. This interest has been particularly keen among grain, fruit, and truck farmers. Artificial manure is a product resulting from treatment of straw and other available plant material with certain fertilizer materials and the addition of water to keep the pile moist at all times. Bacteria do the rest. The straw or other organic material furnishes them a food supply and the added chemicals serve them as sources of energy to such an extent that the straw decomposes in a comparatively short time.11

It is stated that the organic material is converted into the artificial manure in from 3 to 4 months with a considerable shrinkage in the original pile and that the resulting product has the beneficial effects ascribed to well-decomposed barnyard manure. This method of making artificial manure—essentially humus—may have practical value on farms where straw or other organic material is available, particularly where the straw cannot be utilized as feed or litter. Artificial manure as produced by one of the foregoing methods furnishes a material apparently of considerable value to market gardeners, truck-crop farmers, and others who cannot readily obtain good barnyard or stall manure except at prohibitive cost.

COAL ASHES

While possessing practically no fertilizer value, coal ashes, when properly sifted and incorporated with heavy soils (clays and clay loams in particular), exercise a beneficial effect on physical condition through improvement of tilth and drainage. Indirectly, therefore, coal ashes may prove worth while in the amelioration of heavy soils around the home grounds and in small gardens.

COCOA-SHELL MEAL

Cocoa-shell meal is a product resulting from the grinding of cocoa shells and husks of the seeds, the meal averaging 2.5 percent of nitrogen, 0.75 to 1 percent of phosphoric acid, and 2.5 percent of potash. Walton and Gardiner (451) refer to two other cacao byproducts—cocoa press cake and solvent-extracted cocoa—that might well have potential value as fertilizer materials.

COMPOSTS

In addition to numerous commercial fertilizer materials and barnyard manures there are many miscellaneous materials capable of being processed or composted, or applied to the soil direct, which possess fertilizer value. These materials furnish not only organic matter but also a certain amount of nitrogen, phosphorus, potassium, and other elements. They include leaves, weeds, sweepings from the house and barn, moldy feeding stuffs, coffee grounds, kitchen waste, soot, sod, grass clippings, fruit and vegetable refuse, etc. All such materials have some fertilizer value. Leaves alone, when dry, are about twice as rich per pound in plant food as barnyard manure. Instead of burning or discarding these miscellaneous fertilizer materials it is advisable to gather them into some out-of-the-way place and make a compost pile.12

11 The process for making artificial manure was studied at the Rothamsted Experiment Station in England. The agricultural experiment stations in Iowa, Michigan, Missouri, and New York have also made a study of the utilization of straw in the production of artificial manure.
12 For further details on composting see (109).
CRUSTACEAN MATERIALS

Crustacean materials, including the refuse of king crab, mussels, crab, and lobster, are useful as fertilizer materials. King crab is found extensively along the Atlantic coast and is used as a direct application to the soil, composted, or in commercial fertilizer mixtures after being dried and ground. In the latter condition the material contains from 8 to 12 percent of nitrogen, with a comparatively high availability. In the fresh state, the material decays quickly and has a nitrogen content of 2 to 2.5 percent.

Mussels also are plentiful in certain coastal sections. They have a nitrogen content of 0.8 to 0.9 percent (nearly twice that of manure), phosphoric acid 0.1 to 0.15 percent, potash practically the same, and lime about 16 percent. Thus the material is worth carting and applying to the soil. Crab and lobster shells and refuse, which can be obtained for the carting, have some fertilizer value. When dried the material contains from 3 to 4 percent of nitrogen, 2.5 to 3 percent of phosphoric acid, and upwards of 18 to 20 percent of lime. All such materials are of some value if they are obtainable cheaply enough.

GREENSAND MARL (GLAUCONITE)

The greensand marls of New Jersey, where large deposits occur, contain on the average 5 percent of potash (K₂O), 2.2 percent of phosphoric acid (P₂O₅), and 3 percent of lime, all of which are rated as being slowly available. Marls, including greensand marl, are usually classified as soil amendments. In some sections of the country heavy applications of greensand marl have been reported as giving good results; in other sections their use after experimental trials is not recommended. In a great many instances the results from the use of greensand marl are due to the improvement of the physical condition of soils rather than to fertilizer elements.

GUANO

Guano (natural) is a substance formerly found in great abundance on some sea-coasts or islands frequented by sea birds and composed chiefly of their excrement and dead bodies. The term also refers to the excrement of bats living in caves.

Guano is comparatively rich in nitrogenous and phosphatic substances. The nitrogen is present largely as ammonium compounds and in organic form. The composition of natural guano is quite variable in accordance with the protection from rainfall afforded the deposits. Analyses show a nitrogen content ranging from as low as 0.5 percent to as high as 10 to 12 percent. The phosphoric acid (P₂O₅) content may run as low as 10 to 12 percent and as high as 20 to 25 percent.

GYPSUM

Gypsum (land plaster) is found in nature and consists of a hydrated calcium sulphate. At the present time, owing to the heavy use of ordinary superphosphate, one-half of the total weight of which is gypsum or closely related to it, gypsum itself is used only when it is considered to be effective for special crops or special soil conditions where a deficiency of sulphur has been reported. In most cases, however, when gypsum has been found to give good results, it is believed that this was due more to its indirect effect in liberating potash from unavailable potash compounds than to its direct effect as a plant food.

LIME

Lime is not, strictly speaking, a fertilizer material but a soil amendment applied to correct soil acidity, improve the physical condition of the soil, and promote bacterial activity. However, one of its functions is to supply calcium if this is deficient in the soil. The chief sources are: (1) Burnt lime (CaO), known as caustic lime, stone lime, etc.—the product resulting from the burning of limestone; (2) hydrated lime or slaked lime, produced by adding the proper amount of water to burnt lime; (3) ground limestone, the most common form of lime used in farming practice, its agronomic value depending on the content of carbonate of lime and how finely it has been ground; and (4) marl, a natural deposit consisting chiefly of calcium carbonate mixed with clay, sand, or organic material.

MUCK AND PEAT

Muck and peat, while used for soil-improvement purposes, particularly in recent years, hardly rate as fertilizer materials. Frequently they are too acid to be used unless adequately limed. Muck and peat are air dried, ground if
necessary, bagged, and offered for sale as a humus material. As a rule they serve a good purpose when used as absorbents in the barn or barnyard. In many cases the effect of muck and peat upon the physical condition of the soil is more valuable than the plant nutrients they contain, particularly as the latter are in unavailable forms.

SEAWEED

Another material about which much has been written is seaweed. It has been used as a fertilizer material for many years. As early as the fourth century reference was made to the use of seaweed by Palladius in Rome. In England during Queen Elizabeth's reign seaweed found considerable use, and according to a contemporary writer named Owens "thereof springeth good corn, especially barley." Seaweed has been aptly termed the "poor man's manure." The history of its agricultural uses may be traced in every country with a seacoast from ancient days to the present time.

It is recorded, too, that in the north of Ireland fishermen who also till the soil collect seaweed by hooking it up from considerable depths. Reports from Bermuda indicate that seaweed—sargassum weed from the Gulf Stream—is much used as fertilizer, especially for bananas, on account of the ease with which it can be applied as well as its abundance.

There are many different kinds of seaweed, and they vary in composition. As a rule they are lacking in phosphorus, are comparatively rich in potassium, and have approximately as much nitrogen as stable manure, although an occasional kind of seaweed will carry twice as much.

Generally speaking, seaweed ranks as a potash fertilizer material. During the World War the giant kelp groves of the Pacific Ocean were given serious consideration as a potential source of potash, inasmuch as the ash of these seaweeds contains as high as 30 percent of potash (K₂O). The cost of extraction was prohibitive when high-grade German and French potash salts were again available.

TOBACCO BYPRODUCTS

Tobacco stems and stalks are waste materials from harvesting and the manufacture of cigars and smoking and chewing tobacco. The stems are often ground and sold as a fertilizer material. They usually contain 2 to 3 percent of nitrogen, from 6 to 10 percent of potash (K₂O), and very little phosphoric acid. The nitrogen occurs in both the organic and nitrate forms, the latter as potassium nitrate. When obtainable locally such material, if well ground, provides a good source of nitrogen and potash in comparatively quickly available combinations.

WATER HYACINTH

The water hyacinth grows abundantly in fresh-water streams and lakes along the Gulf coast. It is rated as a weed pest in localities where it abounds inasmuch as it is very difficult to control, and even more so to eradicate. When practically free of moisture, it contains about 1 percent of nitrogen, 4 percent of potassium, and a small amount of phosphorus. Practical trials by vegetable growers in Florida some years ago indicated that this material was worth while for garden crops, especially cabbages, potatoes, and sweetpotatoes. Its use as a mulch has been favorably reported in citrus and tung tree groves.

The water hyacinth grows profusely in other parts of the world, including Africa, Asia, Europe, and South America. Everywhere it is considered to be a rank pest. The Government of Bengal, India, in attempting to control its spread, sponsored experimental studies to determine whether water hyacinth possessed any fertilizer value. The results of this investigation indicated the material did have potentialities for soil-improvement purposes.

WHALE TANKAGE

Whale tankage represents the dried and ground residue resulting from the rendering of whale meat to obtain the oil. This material finds its way into the fertilizer market as a source of nitrogen. It averages about 7 percent of nitrogen and about 3 percent of phosphoric acid.

WOOD AND OTHER ASHES

Wood ashes rate as a potash material with a comparatively high lime content, some phosphoric acid and magnesium, and small amounts of other elements—all of which are affected by leaching if the ashes are not protected from rain and
melting snow. The composition of wood ashes varies considerably, depending upon whether they are derived from softwood or hardwood and the amount of contamination with other materials. Unleached hardwood ashes contain upward of 6 percent of potash in the form of carbonate, 2 percent of phosphoric acid, and 30 percent of lime. The leaching action of rain may reduce the potash content to as low as 1 or 2 percent. In addition to the fertilizer value of the available potash they contain, both the potassium and the lime carbonate in wood ashes are beneficial on acid soils.

Other kinds of ashes are sometimes used as fertilizer materials. The supply of cotton-hull ashes is very limited at present. They result from the burning of cotton hulls as fuel in ginning and pressing operations. Their composition is quite variable, ranging from 10 to 45 percent of potash, an average content of about 7 percent of available phosphoric acid, and approximately 8 to 10 percent each of calcium and magnesium compounds. Corn cob ashes may run as high as 35 to 40 percent of available potash, although the average content is nearer 12 to 14 percent. The main source of supply comes from grain elevators and milling plants when the corneobs are burned and disposed of for fertilizer purposes. Tanbark ashes are inferior to wood ashes, as a rule containing not over 2 percent of available potash. Lime-kiln ashes are obtained in connection with lime-kiln operations and are even poorer than tanbark ashes in potash (approximately 1.5 percent), but are richer in lime carbonate than other wood ashes, frequently containing as high as 85 to 90 percent of calcium and magnesium carbonate. Owing to their variability in composition, all such ashes should be purchased only upon a guaranteed analysis.

OTHER MISCELLANEOUS MATERIALS

There is a considerable array of miscellaneous materials that possess some fertilizer value. Their use in most cases is economical only locally, and their low plant-food content would hardly warrant hauling and distribution unless they were obtainable at practically no cost. In a publication by C. C. Fletcher (109) is given the percentage composition of a large number of miscellaneous materials that have some fertilizer value if properly utilized.

Residual Effect of Fertilizer Materials Upon Soil Reaction

That certain fertilizer materials exercise an influence upon soil reaction has been recognized for many years. Thus, basic slag was employed as an agricultural liming material in 1881, and it is probable that such use even preceded recognition of the value of the slag as a phosphatic fertilizer material. Again, the ability of commercial calcium cyanamide to neutralize soil acidity has been known from the time of its introduction into the fertilizer trade. These materials, however, are alkaline in character and exhibit their alkalinity to such an extent that basic slag is not used as a source of phosphorus in the preparation of mixed fertilizers, since it would cause the liberation of ammonia from ammonium sulphate and other ammoniacal nitrogenous materials, while calcium cyanamide is used only in limited quantities as a source of nitrogen, since greater quantities would cause reversion of the phosphoric acid of superphosphate to unavailable forms. That such materials should be effective in reducing soil acidity is to be expected.

It has been found that other materials, such as ammonium sulphate and sodium nitrate, which chemically are neutral salts and themselves exhibit no marked alkaline or acid character, also have an ultimate effect upon soil reaction. Since this is not shown immediately upon application to the soil but develops during the course of the utilization of the nutrient elements by the crops, it is termed "residual effect." It has been explained as caused by a preferential intake by the plants of certain elements over others. Thus, in the case of sodium nitrate the nitrogen as the acidic nitrate ion is utilized to a greater extent than the basic sodium ion, which is left to neutralize other acidic ions originally in the soil, so that the ultimate residual effect is a decreased acidity or increased alkalinity of the soil.

In the case of fertilizer materials the nitrogen of which undergoes nitrification, an additional factor is the conversion of this nitrogen into the acidic nitrate ion, which as it is formed neutralizes bases in the soil. Thus, in the case of ammonium sulphate, the basic ammonium ions are converted into acidic nitrate ions, and both these and the residual acidic sulphate ion neutralize bases so that the residual
effect is an increased acidity or decreased alkalinity of the soil. Nitrogen is therefore to be considered as an acidic element regardless of its form in the fertilizer material, whether ammoniacal, nitrate, organic, or amide.

The potash salts customarily used for fertilizer purposes have been found not to affect soil reaction materially, though wood ashes and potassium nitrate, neither of which finds extensive employment as a fertilizer material, cause a decrease in soil acidity. The results of long-continued plot tests have shown that superphosphate has no appreciable effect on soil reaction.

On the basis of the experimental results obtained when various fertilizer materials were employed in vegetation tests, W. H. Pierre (SOO) of the West Virginia Agricultural Experiment Station, drew the conclusion that the differences in the effects of fertilizers on soil reaction are due to differences in their acid-base balance, in that materials containing an excess of a basic element (potassium, sodium, calcium, or magnesium) over the acidic elements (nitrogen, phosphorus, sulphur, and chlorine) give rise to a reduction in soil acidity, whereas materials that have an excess of acidic over basic elements bring about increased soil acidity.

Table 8.—Calculated equivalent acidities and basicities of nitrogenous fertilizer materials

<table>
<thead>
<tr>
<th>Fertilizer material</th>
<th>Equivalent acidity per unit of nitrogen</th>
<th>Equivalent basicity per unit of nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium sulphate</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Sodium nitrate</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Nitrate of soda-potash</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Cal-Nitro (20.5 percent nitrogen)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Calcium nitrate (15.5 percent nitrogen)</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.—Equivalent acidities and basicities of nitrogenous fertilizer materials

<table>
<thead>
<tr>
<th>Fertilizer material</th>
<th>Nitrogen content</th>
<th>Equivalent acidity per unit of nitrogen</th>
<th>Equivalent basicity per unit of nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amno-Phos</td>
<td>11 %</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16.5 %</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Animal tankage</td>
<td>9.12 %</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Garbage tankage</td>
<td>2.5 %</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Process tankage</td>
<td>7.5 %</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Fish scrap</td>
<td>9.25 %</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Do</td>
<td>8.93 %</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td>6.76 %</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Do</td>
<td>6.71 %</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

If, therefore, the amounts of each of these elements in a fertilizer material have been determined, the residual effect of the material should be capable of calcula-
tion. The results of such calculations are customarily expressed as equivalent acidities or equivalent basicities—that is, as the quantities of calcium carbonate (pure limestone) required to neutralize the acidity that would result from the use of residual-acid materials or that are equivalent in acid-neutralizing power to the residual-base materials. Table 8 lists the calculated values for a number of nitrogenous fertilizer materials.

For the determination of the equivalent acidities and basicities of fertilizer materials or mixtures without the necessity of chemical analyses to ascertain the quantities of each of the acidic and basic elements, Pierre (301) devised a chemical method that gave results in agreement with those obtained by calculation for materials of known composition. Since a description of this method in detail is decidedly technical in character, it will not be given here. By means of the method, Pierre obtained the results listed in table 9.