fertilizer distributed; and the inspection, sampling, and analysis of fertilizers and the publication of the data.

Satisfactory operation of fertilizer-control laws necessitates, among other things, the use of standardized methods of sampling and chemical analysis. The development and publication of such methods is a function of the Association of Official Agricultural Chemists. The State laws or the accompanying regulations generally specify the use of the A.O.A.C. methods in official fertilizer inspections.

Variations in certain phases of the fertilizer-control laws among the individual States or groups of States reflect largely the differences in the character of the agriculture and in the soil and crop requirements for plant nutrients. The laws generally afford protection to the consumer as well as to the manufacturer.

IT MAY BE SAID with confidence that fertilizers will play an increasingly significant role in the Nation's agricultural economy and that in the years to come the trend in their production and use will continue markedly upward.

The country is richly endowed with resources of fertilizer raw materials and of their requisites for processing, which are economically usable under present conditions, and far larger resources reside in less favorable situations.

We have extensive facilities for winning and processing the raw materials by modern methods and techniques, all of which constantly are undergoing improvement. For the most part, those facilities are widely distributed over the country.

For the foreseeable future, the problem of adequate supplies of fertilizer for the American farmer appears to be largely one of continuing to expand the productive capacity to keep pace with the demand. But it should be emphasized that great opportunity remains for technological advances in fertilizers and for improving the efficiency of their use in crop production and in other phases of farm management.

New and Better Fertilizers

E. L. Newman and W. L. Hill

Better fertilizers have been coming on the market for years.

New fertilizers are rarely new from the chemist's viewpoint. They generally are composed of known chemical compounds, although the proportions of the compounds actually present may be difficult to determine.

Usually a promising new fertilizer undergoes lengthy development before it is offered commercially. Also, a nutrient-bearing compound often is used as a raw or intermediate material in the manufacture of fertilizers for some years before it may become available to the farmer for direct use. Anhydrous ammonia and phosphoric oxide are two of many examples.

Novelty in a fertilizer must then be regarded as newness to the retail market. In this light, our subject demands a discussion of the things that are likely to influence new or improved fertilizers.

The development of a new fertilizer to market status is a response to the need for some particular quality or set of qualities that are expected to lower the cost, provide easier handling, or supply soil and crop requirements better. Examples are the water-soluble phosphorus of ammonium phosphates, the water-insoluble nitrogen of urea-formaldehyde, the noncaking and dust-free character of granular fertilizers, balanced nutrient contents of polynutrient fertilizers, and the low-cost nitrogen afforded by anhydrous ammonia.

Because needs vary from region to region, reflecting a diversity of soils, crops, climates, and farm practices, the nature of the most suitable fertilizer also differs among the regions. Often the fertilizer is expected to do more than supply additional nutrients.

These circumstances are illustrated by the following specifications for an ideal fertilizer, compiled by T. P. Hignett of the Tennessee Valley Authority, from suggestions by agronomists, farmers, and fertilizer manufacturers:

The ideal fertilizer—Mr. Hignett was advised—should carry high concentrations of the three primary plant nutrients (nitrogen, phosphorus, and potassium), generous amounts of the secondary nutrients (calcium, magnesium, and sulfur), and small amounts of several micronutrients. It should be in the form of hard, round granules, about 0.1 inch in diameter, that are impervious to moisture until placed in the soil, whereupon the nutrients should dissolve immediately, even though the soil be dry, and become completely utilizable by short-season crops. At the same time the nutrients should neither be fixed by the soil nor leached from it, so that a residual effect will extend over a period of years. It should have an alkaline reaction on acid soil, and an acid reaction on alkaline soil. It should be adaptable to manufacture by unskilled labor in whatever equipment happens to be available in the factory. Finally, it should kill weeds and bugs and condition the soil.

Obviously this is an absurd specification and was meant to show the impossibility of achieving the perfect fertilizer. Nevertheless the respective specifications are desirable under certain conditions and must be given proper consideration in the design of improved fertilizers. The specifications can be used also as factors in judging the possibilities of materials yet to come. The several elements of value arise in one or more of three avenues of approach to fertilizer appraisal—character, effectiveness, and cost.

THE CHARACTER OF A FERTILIZER depends largely on such chemical properties as concentration and reactivity of the major nutrients.

Reactivity, as we use the word here, means the tendency of the fertilizer substance to dissolve and become available to plant roots. It can be measured reasonably accurately as solubility.

Among the factors that influence the character of fertilizer are certain physical properties that facilitate handling in storage, transportation, and application to the soil. Emphasis on physical character has increased notably in recent years. Farmers no longer tolerate caked fertilizers. Powdery materials are becoming less acceptable.

The benefits of some high-analysis products have been gaining recognition over a very much longer period. These trends are especially marked in the regions where the use of fertilizer is relatively new. Considerable attention also has been given to the reactivity or solubility of nutrients. Some results along this line are the development of urea-form, a synthetic nitrogen fertilizer of controlled solubility, and recognition of the importance of water-soluble, phosphorus-bearing fertilizers for fast-growing crops.

THE EFFECTIVENESS OF A FERTILIZER is measured in terms of crop response to its use. Responses are determined to a large extent by environmental factors peculiar to the farming region—soil type, climate, and water supply. These conditions must be accepted much as they are, and farming is thereby regionalized. Response is also influenced by cultural practice, in which some noteworthy factors are kind of crop, crop rotation, kind and amount of fertilizer, placement of fertilizer in soil, and time of application. Effectiveness of a fertilizer thus depends not only on its character but also on where it is used and the way it is used.

Experimental evaluation of a fertilizer can be approached from two basic viewpoints. A fertilizer of known character may be tested to find the region and cultural practice that provides the conditions for best performance, or a particular cultural practice may be studied to determine fertilizer characteristics that will induce the greatest response. The sets of conditions under which present-day fertilizers prove effective have been broadly demonstrated experimentally, although in farming practice the choice of fertilizers is not always in line with experiment.

Cost is probably the most important consideration in the consumer's choice of a fertilizer. The farmer's first thought is usually, "How much does it cost?" Only so much can be spent for fertilizer, and he wants the most for his money. This is a proper view, provided he measures cost in terms of the quantity of plant nutrients purchased rather than on the basis of the weight of material received. For example, the Illinois farmer who chooses a 5–10–10 (the numbers indicate percentages of nitrogen, phosphate, and potash, in that order) fertilizer at 59 dollars a ton may not realize that a 10–20–20 fertilizer at 104 dollars a ton is the better bargain. Adding the costs of distribution and application to the purchase price widens the margin, because the same amount of nutrients can be handled and applied more cheaply in the concentrated material.

Prospects for better fertilizers may be gaged on the basis of the criteria for appraisal—character, effectiveness, and cost.

The manufacturer alone can make alterations in fertilizer character, but both manufacturer and consumer can make contributions to effectiveness and lower the cost, especially the cost after application to the soil. The farmer who uses a fertilizer of low reactivity as a starter fertilizer for a fast-growing crop is not getting the best out of the fertilizer. Conversely, a farmer sometimes may integrate fertilizer application with crop rotation in such a way that application of one low-cost major nutrient is required only once in several years. He thus achieves economies in tonnage and cost greater than any price advantage that the manufacturer could provide.

Improved physical character of fertilizers, particularly the polynutrient goods, has been a subject of much research. Great strides have been made toward the development of noncaking, free-flowing fertilizers. Much remains to be done, of course.

For years diluents known as conditioners have been incorporated into fertilizers, either deliberately or incidentally, to prevent caking by formation of a coating on the fertilizer particles or by simple mechanical separation of the particles. The trend to goods of higher analysis has squeezed out diluents to a marked extent and thus has necessitated a search for other ways to keep fertilizers free-flowing.

Physical nature is controlled by one or more procedures—choosing the best-adapted ingredients, selecting favorable proportions of ingredients, granulating the fertilizer, reducing the moisture content, coating the granules with suitable agents, and packaging in moisture-resistant bags.

Each nutrient combination usually presents a special problem, so that considerable research is nearly always required for the development of an economic technique that permits production of the fertilizer in free-flowing form. Despite the many obstacles, the current effort to better the physical character of fertilizers is improving the marketed products.

The difficulty of maintaining a fertilizer in good condition usually increases with the solubility of the nutrients. Highly soluble and concentrated forms of nutrients frequently present major problems. In such cases, one answer to the question of poor physical condition is direct use in solution form. The direct application of liquid fertilizers is a growing practice. The problem here is transferred from the physical condition of a solid to the nutrient level in a liquid. Poor condition is nicely avoided at the expense of nutrient concentration. At the same time, the cost of storage and transportation is increased. Because liquids of higher nutrient content thus become a chief objective of improvement, the problem in this case shifts from physical to chemical character.

Chemical character, which includes such properties as concentration and reactivity, is an avenue for the further improvement of fertilizers. The trend toward high-analysis goods persists. It has perhaps approached the practical limit in a few of the newer market areas, but in the old and at the same time heavy-consuming regions the acceptance of higher concentrations is slow. Progress can be made as rapidly as the consumer is convinced of the advantages of higher grades.

Adjustment of nutrient proportions in polynutrient fertilizers, to reach proper balance for crop needs, provides another opportunity for betterment. The manufacturer must look to the agronomist for guidance here.

Continued expansion of the use of anhydrous ammonia and nitrogen solutions for side and top dressings could have a pronounced effect on the formulation of solid fertilizers. Because this practice relieves the need for nitrogen-rich fertilizer at planting time, a part of the nitrogen will likely be dropped from the starter fertilizer and, in the interest of economy and effectiveness, transferred to later applications. The lowered content of nitrogen compounds would alter somewhat the physical and chemical nature of the fertilizer used at planting time. The net effect would probably be improvement.

The choice of nutrient-bearing ingredients of mixed fertilizers to improve character has not received adequate attention. Intimate association of chemical compounds in a mixture may bring about an increase or decrease of nutrient reactivity. High ammoniation of superphosphate reduces its solubility. Favorable effects are to be expected normally from the influence of nitrogen and potassium compounds, which are soluble, on slightly soluble phosphates. The influence is not the same for all soluble compounds. For example, potassium sulfate increases the solubility of dicalcium phosphate to a far greater extent than does potassium chloride. Furthermore, the effect is magnified in intimate mixtures that are granulated. Investigation of this aspect of fertilizers should yield worthwhile information on possibilities of improvement.

We noted the need for raising the nutrient content of liquid fertilizers. This end must be reached by suitable choice of ingredients. Most fertilizer compounds are less soluble at low temperatures than at high temperatures. Hence a liquid fertilizer that is quite satisfactory for summer use, for example, may salt out during cool days in spring or fall. Then the fertilizer may truly be said to be in a poor physical condition. In order to prevent salt deposition as a consequence of normal fluctuations in temperature, the grade of the liquids must be lower than would otherwise be necessary.

Enhancement of the grade of liquid fertilizers will follow systematic studies of the solubility of various ingredients to find combinations that are less susceptible to salt deposition. It is likely also that additives will be found that will inhibit or delay crystallization. The wide interest in liquids has stimulated such studies.

Improved effectiveness, as far as the manufacturer is directly concerned, must proceed largely from modifications in the character of fertilizers. The producer can use the most desirable nutrient-bearing substances and proportion them accurately in a recommended ratio. He can process the mixture into a uniformly granular, free-flowing fertilizer. He can add conditioner and package the product in moisture-resistant bags to insure preservation of its good character. He can supervise delivery to the farm. At that point he relinquishes control of the fertilizer. As to its mode of use, he can only recommend, unless he is one of the few manufacturers who also apply fertilizers and can carry out his own recommendations. Some manufacturers have representatives in leading market areas whose chief responsibility is to advise consumers about the choice and use of fertilizers. This growing practice, maintained in accordance with acceptable ethical standards, enhances the prospects for efficient use of fertilizers.

Increased nutrient concentration, exemplified in high-analysis fertilizers, does not necessarily contribute to effectiveness. The trend to high-grade products at first provided incentive for the elimination of inert fillers. Later the squeeze came on the components that bear the secondary nutrients. The extra high grades often contain little or no calcium, magnesium, or sulfur.

The concentrated fertilizers can be effective if the amounts of calcium, magnesium, and sulfur in the soil are adequate to supply crop needs, but they may be unsatisfactory on soils deficient in those secondary nutrients. Potential difficulties of this kind can be avoided by a suitable choice of market areas, so that the products offered in trade contain (although often in insufficient amounts) secondary elements needed for the farming practices of the region. Adequate amounts of secondary nutrients can be provided, however, at less expense by generous application of low-cost separate materials, such as limestone, dolomite, or gypsum, once in several years. The growth of this practice in a region relieves the need for secondary nutrients in the marketed fertilizers and helps prepare the way for products of higher analysis.

The addition of micronutrients, such as zinc, manganese, boron, copper, iron, and molybdenum, to otherwise regular grades of fertilizers often is advantageous and is customary in some areas. Present practice generally provides for one or two micronutrients in fertilizers that move into certain areas or to particular crops. The opinion of some informed persons is that fertilizers generally would give better performance if several of the micronutrients were incorporated in them. Since the manufacturer could expect little if any premium for the additional nutrients, the problem is to find suitable low-cost micronutrient substances for such use. This matter has received attention.

Lower consumer prices for a product usually follow reduction in costs of manufacture and distribution. In the fertilizer industry, basic manufacturing costs are being reduced gradually as a consequence of process integration that eliminates expensive steps formerly necessary. Distribution costs are being lowered by moving manufacturing plants into favorable locations with respect to market areas and by the trend toward fertilizers of higher analysis that permits shipment of more nutrients per freight dollar. In many instances, however, the savings are offset somewhat by the increased cost of processing and packaging the fertilizer, so that it will meet consumer demands as to physical character.

The reduction in price the manufacturer may be able to pass to the consumer depends on the pattern of fertilizer use for the market area. In regions where the dominant preference of the farmer is for low-analysis goods, little can be expected, because the cost is just as much for handling, shipping, and applying a ton of low-analysis material as it is for a ton of concentrate. The marked differences among the use patterns of different regions are shown by consumption figures. Thus, in the region that includes Virginia, the Carolinas, Georgia, and Florida, nearly three-fifths of the tonnage of the 15 dominant grades of polynutrient fertilizer moved as goods containing 16 to 20 percent of nutrients in 1954. But in the region comprising Ohio, Indiana, Illinois, Michigan, and Wisconsin, only 1 percent of the tonnage moved as material carrying as low as 20 percent of nutrients.

The concentrated materials, such as anhydrous ammonia, triple superphosphate, and muriate of potash (potassium chloride) show up as the cheapest fertilizers. Although normally they are the farmer's best bargains, he often prefers a mixed fertilizer at a higher price to save the time, trouble, and expense of mixing it himself.

Nitrogen is the most expensive of the three major nutrients. Such relatively new materials as anhydrous ammonia and ammonium nitrate demonstrate wide margins of cost advantage over the older materials, ammonium sulfate and sodium nitrate. Urea and nitrogen solutions are examples of concentrated and fairly cheap nitrogen fertilizers that are being applied in increasing tonnages. When cost differences are great, a movement toward the cheaper materials is inevitable, barring unusual advantages for an expensive material.

Cost advantages of the concentrated phosphate and potash materials over the lower analysis materials are apparent. Triple superphosphate, though far from a new material and costing more to make than ordinary superphosphate, is much more concentrated and therefore usually has an advantage in final cost.

The cost factor varies less among polynutrient fertilizers than among others but still is definitely weighted in favor of the newer and more concentrated products. For example, in comparing fertilizers of similar ratios, the 4–16–16 grade usually reaches the land cheaper than 3–12–12, and 10–20–20 is more economical than 5–10–10. Liquids are competitive with solids in some localities. Nitric phosphates and ammonium phosphates (especially diammonium phosphate) show economic advantages in some areas.

Cost figures prove that the high-analysis fertilizers are to be preferred to the low-analysis products wherever the more concentrated materials meet agronomic requirements. One of the most beneficial effects of advanced fertilizer technology, as far as the farmer is concerned, is lower final cost. This indicates good prospects for the improved types of fertilizers.

Highly seasonal demand prevails for fertilizer products. Since deliveries reach the peaks during spring and fall plantings and drop to almost nothing the rest of the year, storage and transportation are big problems. Efforts to remedy this situation with lower prices during the off season thus far have met with only modest success. Nevertheless, the future seems to hold promise of progress in this direction. Many fertilizers produced today will hold up in bag storage for several weeks or months; some years ago fertilizers often deteriorated rapidly. If the farmer could be convinced that with reasonable care he can keep his fertilizer in storage on the farm for extended periods without deterioration in quality and if the price inducements were made attractive enough, the peak-season rush would be lightened.

New fertilizers will appear from several directions in response to specific needs. The trend toward higher analysis can be expected to bring the extra high grades.

Fertilizer grades such as 5–20–20, 10–20–20, and 14–14–14 are on the market. Still higher grades are realizable. Development work has begun on 17–17–17 and 26–26–0 fertilizers. They are combinations of ammonium phosphates and ammonium nitrate with or without potash, and are termed ammonium phosphate-nitrates. Various ratios can be produced from a variety of ingredients. This class of product is entirely soluble in water.

Other new fertilizers are on the horizon, especially one- and two-nutrient materials with built-in desirable characteristics that meet predetermined specifications.

The compounds used in fertilizers vary in water solubility. All the conventional compounds of potassium and of nitrogen, with the exception of natural organic materials, dissolve to about the same extent as table salt, whereas the natural organic nitrogen-bearing materials and some of the phosphates dissolve scarcely at all. This circumstance hampers adjustment of the nutrient reactivity of fertilizers to specific crop requirements. Adjustment is obtainable only by choosing compounds with either high or low solubilities, or mixtures of the two. There is a need for compounds that possess intermediate reactivities.

A urea-formaldehyde reaction product, termed urea-form and on the market under the names *Urea-form*, *Uramite*, *Nitroform*, and *Borden's 38*, represents a step in the direction of specially designed fertilizer compounds of nitrogen. This high-grade synthetic product is classed as water insoluble and was designed to supply the need for nonleachable nitrogen. It has quickly become competitive with natural organic products on the basis of nutrient cost. Urea-form should be regarded as a prototype of things to come. We envision a whole series of graduated reactivities, intermediate between the extremes now available.

Development work on potassium fertilizers of controlled solubility has started. Noteworthy is a study of the possibilities of fused potassium phosphates. Both potassium and phosphorus of these compounds are of intermediate solubility.

The metaphosphates, particularly the vitreous forms, are of similar type. Calcium metaphosphate, which has been produced as a fertilizer by the Tennessee Valley Authority for more than 15 years, is classed by conventional fertilizer criteria as a water-insoluble phosphate. Nevertheless, the quality of its insolubility differs from that of the common insoluble phosphates, because it can absorb water slowly and change to soluble monocalcium phosphate. The pattern of behavior of this phosphate under soil environments has been placed under close study. The results of this research may point up the possibilities of this type of material in providing an intermediate phosphate reactivity.

Ammonium metaphosphate, analyzing about 17–73–0, is an experimental fertilizer with varying degrees of quick solubility in water. It is under study as a new material offering advantages of high concentration and possible improvements in other characteristics. As an ingredient for liquid fertilizers, it appears to give unusual opportunities for making more concentrated products.

Micronutrient materials for direct use and also for incorporation in mixtures containing major and secondary nutrients have been studied. Much of this work is concerned with adjustment of reactivity to soil environment for the improvement of nutrient utilization by crops. Thus chelating agents (organic complexing compounds) and glasses (frits) are used to control reactivity of micronutrients such as iron, copper, or boron.

Applying Fertilizers

R. L. Cook and Walter C. Hulburt

Plant nutrients differ in the way they may be applied most effectively as fertilizers because of the differences in their chemical properties, the amounts plants need, the chemical and biological activity in the soil, and their solubility, which varies according to their formula and physical condition.

The nitrogen that exists in the soil as organic matter is a basic consideration. Organisms decompose it and release the nitrogen as ammonia. Other organisms change the ammonia to the nitrate form. The organisms themselves use nitrogen to build the tissues of their own bodies.

If the organic matter (such as straw and corn stover) in the soil is high in