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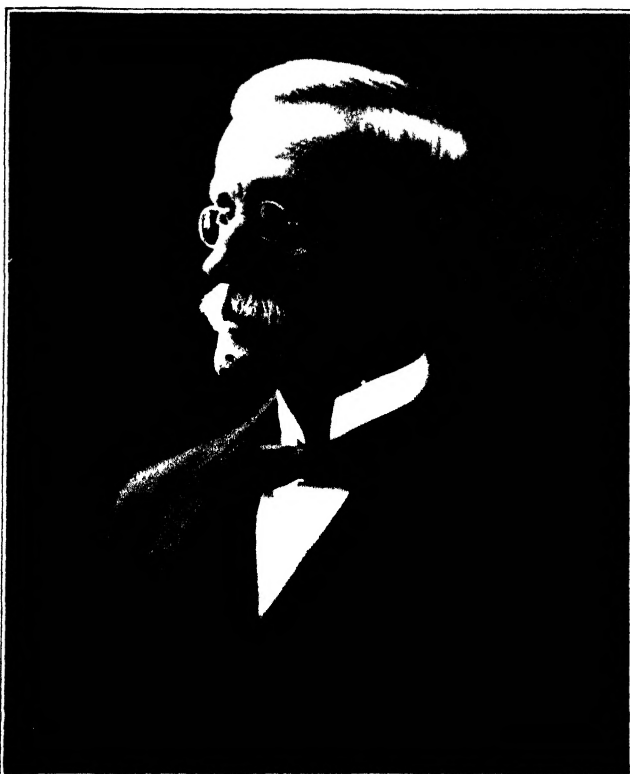
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CHEMISTRY IN AGRICULTURE



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Chemistry in Agriculture

A COÖPERATIVE WORK INTENDED TO
GIVE EXAMPLES OF THE CONTRIBUTIONS
MADE TO AGRICULTURE BY CHEMISTRY

EDITED BY

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CHEMISTRY IN AGRICULTURE

PREFACE

Flower in the crannied wall,
I pluck you out of the crannies,
I hold you here, root and all, in my hand,
Little flower—but *if* I could understand,
What you are, root and all, and all in all,
I should know what God and man is.

Tennyson.

NATURE'S GREAT TRIAD THE SOIL—PLANTS—ANIMALS

The *Farmer* tills the soil that plants may grow that man may live. This is a simple statement, but one that leads to some fascinating stories in its unfolding.

Our bodies, and those of other warm-blooded animals, are wonderful chemical laboratories in which most marvelous chemical reactions are constantly taking place. So long as the body lives these reactions continue without fail. But they can continue only as long as there is brought to the body what we call food and also only as long as the body is breathing in air which contains oxygen. And our food, what is it? The product of another series of chemical reactions taking place in some plant or in the body of some animal which in turn has had its daily food. The plant, too, can live only as it has food supplied to it, and the plant's food comes from the soil, meaning thereby not

only the earth material commonly meant, but also the water and air with which the plant is in contact. Furthermore, when animal bodies die the material which has thus come from the soil returns again to the soil, and a wonderful cycle of chemical transformations is completed. These three, then, the *soil*, *plants* and *animals*, form nature's great triad through which a continuous cycle of chemical change is going on.

The *Farmer* is nature's agent in promoting the unbroken continuity of this cycle, by cultivating the soil for the purpose of growing plants to serve as food for animals and for man. The art which he practices we call *Agriculture*, and that part of the general science of chemistry that has to do with the knowledge and the explanation of the chemical reactions involved in this bio-chemical cycle we may term, in its broadest significance, *Agricultural Chemistry*.

If chemistry could answer all the questions arising from this cycle of transformations it would go far toward giving the answer sought by the poet in the quotation at the head of this chapter. Though that answer may ever be beyond us, still chemistry has done much, through the countless researches of the last century and a quarter, to discover new facts as well as to explain many already known; to make the practices of agriculture more truly scientific and to provide necessary materials for that practice. The stories of how this has been done are told in the following chapters by men who, themselves, are taking part in the work. Agricultural Colleges and Agricultural Experiment Stations are hives of activity in the effort to understand this wonderful cycle of chemical changes, to the end that the farmer may continue to solve one of the greatest problems of all time, viz., the problem of pro-

ducing from the soil, through plants, the food for the human race.

While the problem is not wholly one of chemistry, yet it is true that chemistry is one of the sciences on which must largely rest the responsibility for its solution. If the stories told here, in simple language, succeed in showing the important place which chemistry occupies in its relation to agriculture the hopes of the editors and publisher will be realized.

To the chemists who have given freely of their time and effort in the preparation of the chapters, appreciation and thanks are expressed, as also to many others whose names do not appear, who, by advice and friendly criticism, have assisted in the work.

JOSEPH S. CHAMBERLAIN.

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CHEMISTRY IN AGRICULTURE

CHAPTER I

CROPS AND THE SOIL

R. W. THATCHER

Director, New York State Agricultural Experiment Stations

The ancient Biblical writer recognized that "out of the dust of the earth" was man created; and from time immemorial funeral rites have declared that, "dust to dust, ashes to ashes, earth to earth," the human body is returned to the soil from which it came. These are figurative recognitions of the scientific fact that the ultimate source of the materials which compose the human body and the energy which keeps it going through life is the soil transformed through the medium of farm crops into human food. The ancients thought that the universe was composed of four elements; earth, air, fire and water. Modern chemists recognize many more elementary materials than this in the material universe. But the fact remains that the ultimate source of all human food is plants, generally cultivated as field crops, and these in turn are manufactured by Nature's processes exclusively from soil, air, sunshine and water. So that so far as the physical needs of the human race are concerned, the old philosophers were not so greatly wrong in their conception of the fundamental importance of these four units of universe material.

Unless one has this definite viewpoint as the background of his thinking, he cannot realize fully the

vital importance to human welfare of the inter-relation of crops and soils. Either directly or indirectly, all human food comes from the soil through field crops as the transforming medium. In some cases, human beings eat the plants just as they grow on the soil. This is quite generally true of fruits and vegetables. In others, commonly the forage crops and some of the cereals, the plant products are first consumed by animals, and then the animal products in the form of meat, eggs, milk, etc., are used as human food. In still others, the field crops are put through some process of mechanical or chemical treatment, such as milling, cooking, fermentation, etc., before being utilized as human food. But in every case, human food comes into being first as a plant or field crop, which in turn has its origin in the soil, with sunshine, air and moisture as accessory factors in growth.

There is little wonder then that from the earliest times of human intelligence the problem of how plants transform the lifeless, inert mineral material of soils into living tissues, which in turn become the source of material and energy for animal life, has been a fascinating field for study. The evolutionary sequence of these things was very early recognized, for the writer of the first chapter of Genesis records the order of creation as being; first soils ("dry land"), then plants, then animals, and finally man. Many of the very earliest of the classical writers devoted entire volumes to discussions of the practices of farming, particularly with reference to tillage and fertilization of the soil so as to make it produce more and better crops. Lacking any scientific knowledge of the chemistry and physics of plant nutrition, they often wrote statements which resulted from their field observa-

tions which are surprisingly in accord with modern knowledge and practice.

Thus, Varro (B. C. 116-28) wrote:

"A field is not sown entirely for the crop which is obtained the same year, but partly for the effect to be produced in the following; because there are many plants which, when cut down and left on the land, improve the soil. Thus lupines, for instance, are plowed into a poor soil in place of manure."

And:

"The land must rest every second year, or be sown with lighter kinds of seeds, which prove less exhausting to the soil."

Cato (B. C. 95-46) said:

"Plowing the land simply means rendering the earth porous and friable, which must tend to increase its productiveness."

"Wherein does a good system of agriculture exist? In the first place, in thorough plowing; in the second place, in thorough plowing; and in the third place, in manuring."

Virgil (B. C. 70-19) wrote:

"Linseed, poppy, and oats exhaust the soil."

And, in his GEORGICS:

"Still will the seeds, tho chosen with toilsome pains
 Degenerate, if man's industrious hand
 Cull not each year the largest and the best.
 'Tis thus by destiny, all things decay
 And retrograde, with motion unperceived."

Pliny (A. D. 23-79) wrote many treatises on agriculture which contain such statements as:

"The use of ash is viewed so favorably by farmers that they actually prefer it to manure furnished by their cattle."

"On large estates, fields are alternately allowed to lie fallow in order to save manure."

At about the same time, Columella (first century A. D.) wrote:

"Some of the leguminous plants manure the soil, and make it fruitful, whilst other crops exhaust it, and make it barren. Lupines, beans, peas, lentils, and vetches are reported to manure the land.

"The best forage plants are alfalfa, fenugreek, and vetches. Alfalfa may be placed in the foremost rank of such plants; for when once sown it lasts ten years, fattens lean cattle, and has a salutary action on sick cattle."

These quotations from ancient writers show how well observations of fact in all ages agree; but in spite of this agriculture in all nations and in all ages was on a constantly declining scale as the first virgin fertility of the soil was exhausted, until the science of chemistry was developed and an exact scientific knowledge of what are the principles of plant nutrition and of soil exhaustion was developed. Now, it appears that there is at least a scientific possibility for a "permanent agriculture."

The immense body of modern scientific knowledge of the chemistry of crop production may be best briefly summarized and discussed by approaching the problem from two different viewpoints; first, what the crop needs, and second, how the soil supplies these needs.

WHAT THE CROP NEEDS

It is one of the marvels of biology that various field crops, growing on the same land and with the same supplies of moisture, air, and sunshine, can transform the simple elements of nutrition which they receive into such varied forms of plant material as fruits, seeds, flowers, woody stems or tender foliage, etc. In any vegetable garden, there appears the amazing spectacle of such different crops as onions, corn, cabbage, beans, potatoes, lettuce, etc., etc.; all growing to full maturity from the same source of nutritional supply. But the chemist has helped to a partial understanding of this mysterious phenomenon. For his analyses have shown that although the outward *form* of these various field crop products may differ as widely as do a grain of wheat, a cabbage head, an onion bulb, a potato tuber, etc.; yet their *chemical composition* is fairly similar. Each component part

of any given plant contains certain amounts of definite chemical compounds of specific types which are known by the common names of simple carbohydrates (starches, sugars, etc.), celluloses (woody fibre), fats and oils, and proteins. To be sure, different plants, or different parts of the same plant, may contain different proportions of these constituent groups, or slightly different individual representatives of each group. Again, special crops may contain certain special kinds of compounds which give to them some unique color, odor or other characteristic property; such as nicotine in tobacco, oil of garlic in onions, certain aldehydes in horse radish roots, coloring matter in red beet roots, radishes, egg plant fruits, etc., etc. But these special characteristic components of certain plants are usually present in them in only small percentages of their total material; and, in general, all plants are made up chiefly of the general types of compounds mentioned above.

The mechanism or methods by which different plants build up such widely different *forms* as potato tubers, cereal grains, foliage leaves, etc., etc., out of the same simple *chemical compounds* is not known; but the actual chemical composition of the total structure, or that of any particular part, of any plant which is used for human food or animal feed has been repeatedly determined by analysis. Also, from the standpoint of the science of plant growth, studies of the chemical composition of plant tissues are constantly being made. These all confirm the statements made in the preceding paragraph concerning the similarity in chemical composition of the many diverse forms of plants which may grow on any given type of soil. While there are undoubtedly some preferences or adaptations of certain crops to particular types

of soils, it may be stated as a fact, that, in general, any and every kind of crop will grow successfully on any productive soil provided the climatic conditions are favorable to the crop in question. This is evidence that different crops have similar requirements of mineral nutrients which they obtain from the soil.

Hence, it may be accepted with assurance that all kinds of field crops, with their varied forms, colors, flavors, etc., take from the soil the same kind of mineral nutrient material and manufacture from it similar compounds out of which to build up their varied structures. Of course, the quantity and proportion of the several mineral nutrients which are taken from a given area of soil when different crops are grown on it varies, as has been known since Varro's time. But, in general, the relation of crops to the soil on which they grow is a definite one and is the same for all kinds of crops.

This relation may be expressed in the simple statement that crops must be able to obtain from the soil an adequate supply of each of a few simple mineral elements in order to make a satisfactory growth and come to complete maturity. We may consider first what these elements and their functions are, and later how the soil supplies them to crops growing on it.

Chemical analyses of dried plant tissues show that they contain usually from 90 to 98% of "organic" or combustible material which they have themselves manufactured from the gases of the atmosphere and moisture received from the soil, and from 2 to 10% of "ash" or incombustible mineral substances derived from the soil. Detailed analysis of this "ash" shows that it contains the same mineral elements as are found in the soil on which the plant grew, but in very

different proportions from those in which they occur in the soil. Silica, for example, which constitutes more than one-half of the mineral material of soil, is present in plant ash usually as less than 5 per cent of the total.

This is only another way of saying that crops take from the soil certain quantities of all the mineral plant food elements which are offered to the plant roots in suitable form for absorption; but that they can and do use only certain of these elements in the manufacture of their tissue material, so that the plants soon get saturated with the other or useless elements and can receive no more of these from the soil.

Hence of the twenty or more mineral elements which are present in the soil only a few are *essential* to plant growth and are, therefore, important from the standpoint of the vital interrelation of crops and soils. Those which are essential are potassium, phosphorus, sulfur, iron, calcium, magnesium and nitrogen. Of these all but nitrogen have been derived from the minerals of the soil. The nitrogen, however, is not of mineral origin as its ultimate source is the atmosphere, of which it constitutes four-fifths. Higher order plants such as the common field crops cannot, however, make any use of this atmospheric nitrogen, even though they are surrounded and enveloped by it during their entire period of growth. Atmospheric nitrogen must first be absorbed and utilized by lower order microorganisms. These decay in the soil and thereby supply nitrogen to the soil in suitable form for absorption by the rootlets of higher plants. All soils contain certain quantities of decaying or decayed original native vegetation, which has previously secured its nitrogen supplies through the agencies of preceding plants and microorganisms. It is commonly stated that the

source of nitrogen for crops is the soil; but this is true only because the debris of previous generations of plants is in soils and must be there if the soil is to be productive, and not because the nitrogen is present in any of the rocks or minerals from which most of the inorganic matter of the soil has been derived.

The so-called "essential" elements of plant food which crops obtain from the soil, are necessary to all crops because each of them is used in some definite way by plants in building up the compounds of which their tissues are composed. Briefly, these essential functions may be said to be as follows:

NITROGEN is a constituent element of all proteins, and these in turn are the all-important colloidal material of which the protoplasm, or active material, of every living cell is composed. Every plant cell is essentially a minute mass of protoplasm (composed chiefly of proteins) in which all of the vital manufacturing processes, by which the plant tissues are built up, take place. Protein materials are finally stored up largely in the seeds, but during the growing period they are actively at work in the foliage parts of the plant. Hence, the popular statement that "nitrogen makes foliage" is a fairly accurate expression of its function in crop growth. Nitrogen starvation produces very noticeable changes in the growth of any particular crop. The leaves are stunted in growth and yellowish instead of dark green in color. In fact, the whole crop takes on a stunted or starved appearance. Abundance of available nitrogen on the other hand gives a rank growth of foliage of rich deep green color. This difference is often to be seen in the "manure spots" in fields of growing grain.

Phosphorus is also an extremely important element in plant nutrition. Its exact function in the growth



“Manure Spots” in a wheat field, showing effects of increased available plant food in the soil

processes of plant cells is not definitely known and seems to be very difficult to discover. It is a constituent of most proteins, particularly of those which are found in the nucleus of cells and seems to have some definite relation to cell division and multiplication in growth. Phosphorus starvation does not show so markedly in the outward appearance of the plants as does lack of nitrogen. Abundance of phosphorus, especially in the early stages of plant growth, stimulates root development rather than foliage growth and later apparently hastens the ripening process. So that phosphorus may be said to be the balance or antithesis to nitrogen in crop growth. Popularly, it is often said that "phosphorus makes seeds."

Potassium is undoubtedly the third great essential for plant growth. The general tone and vigor of the plant are largely dependent upon an ample supply of potassium. The popular expression that "potash makes starches and sugars" is a fairly accurate statement of its function in plant tissues. While the element itself is not a constituent of any carbohydrate compound, it is in some unknown way connected with their manufacture in plant cells. The production of sugar, or starch, in such root crops as beets, potatoes, etc., diminishes with decreased supplies of available potassium in the soil. Potash-hungry plants do not exhibit any characteristic external change in form or color, but their vigor is much reduced and they have been found to be more susceptible to injury by disease than are well-nourished normal plants.

Calcium is also an essential element of plant nutrition. While its exact function is not yet definitely settled, it seems to have some connection with the formation of woody fibre or cell-wall material. It must have, also, some other important use, especially in

those plants known as "calciphiles," or "lime-loving plants," of which the various legumes are good examples, which use relatively large proportions of calcium in their tissues.

Magnesium, iron, and sulfur also each has specific functions to perform in promoting plant growth; but, since they are required in smaller amounts than the four elements just mentioned and are usually present in soils in ample amounts for all crop production requirements, they are not regarded as of such critical importance in agricultural practice as are the others. Magnesium and iron are in some way associated with the formation of chlorophyll, the green coloring matter of all higher-order plants. Since chlorophyll is the agent by which the radiant energy of the sun is absorbed and so determines the rate and amount of actual manufacture of chemical compounds which can go on in the plant cells, its importance is readily recognized. Magnesium is a constituent of chlorophyll, while iron is not; but on the other hand, plants which are artificially deprived of iron quickly lose their chlorophyll. Magnesium may also have some relation to the formation of fats and oils in certain plants, similar to that of potassium to carbohydrate-formation; but this has not yet been definitely established. Sulfur seems to serve a purpose similar to that of phosphorus, but its exact use is not yet known with certainty. It is used most largely by legumes and may have some relation to the development of microorganisms which utilize atmospheric nitrogen for their growth.

Briefly, then, it may be said that of the twenty or more chemical elements which are present in all soils, eight are *essential* to plant growth and any deficiency in the available supply of any of these in the soil limits

its possibilities for profitable crop production. Generally, however, all but three of these, namely, nitrogen, phosphorus, and potassium, are present in nearly all soils in available forms in ample amounts for the needs of all farm crops. These three, however, often become deficient either because of a limited original supply in the soil, or through improper agricultural practices (resulting in the so-called "worn-out soils"). They are therefore known as the "critical" elements of soil productivity.

The facts thus briefly reviewed illustrate some of the contributions which chemistry is making to agriculture. It has been known as a matter of common observation, since the time of the early Roman writers whose statements have been quoted above, that crops make certain drafts upon the soil for plant nutrients. But it was not until modern chemistry discovered the nature of chemical elements and compounds and the methods of analysis necessary to demonstrate their presence in any given plant tissue and to trace their transformations from the inert lifeless material of the soil through the process of manufacture in cell protoplasm and into their final storage forms, that any understanding of this interrelation of crops and soils was possible; or that the principles of successful agricultural practice which are discussed in other chapters of this book could be worked out.

HOW THE SOIL SUPPLIES THE ELEMENTS WHICH THE CROP NEEDS

In the preceding paragraphs, the expression "in available form" has been used frequently in connection with the discussions of the uses of soil elements by plants. A proper understanding of certain phys-

ical-chemical phenomena of plant nutrition which are involved in the term "availability" is necessary in order to promote the proper utilization of soil elements as plant food.

A complete chemical analysis of any agricultural soil will show that it contains many hundreds of times the quantity of each of the various essential elements of plant food which is necessary to produce a maximum yield of any of the common farm crops. Fortunately, most of this mineral material is present in the soil in forms which are not soluble in water. Otherwise it would be lost in drainage whenever an excess of soil water is present. But in order to be available to plants, or to be utilized by them, the soil elements must become soluble in water. This is because the only way in which these elements can enter the plant through its roots is by osmosis through the fine membranes which are the outer walls of the root hairs. To pass by osmosis through any such membrane, materials must first be in solution. Hence, only those portions of the mineral material which are in solution in the soil water, with which the root hairs of plants come in contact, can be absorbed into the plant. Thus, only the soluble forms of the potassium, calcium, phosphorus, etc., of the soil are available as plant foods.

This is, of course, only a very small proportion of the total mineral plant food elements of the soil at any one time. But the whole problem of soil productivity, from the standpoint of plant food supply, depends upon the presence in the soil during the growing season of a sufficient amount of each of the essential elements in soluble, or available, form.

Fortunately, the "weathering process," which is the effect of alternate freezing and thawing and of

moisture and air, supplemented by the action of the acids produced from decaying vegetation and that of soil microorganisms; is continually acting upon the mineral matter of the soil and gradually producing chemical changes whereby the complex insoluble compounds which compose the soil minerals are broken down into simpler and more easily soluble ones. With proper conditions of moisture and air, and an adequate supply of "humus," or decaying vegetation, in the soil, this process of changing the unavailable soil material into available plant food goes on continuously. There are many soils, particularly in the newer agricultural regions, in which this process provides ample available plant food for the production of profitable crops year after year in succession.

But in older soils, where the first virgin supply of some of the essential plant foods elements has been depleted by long-continued cropping, or where conditions unfavorable to some of the bacterial, or other, influences which tend to make plant food available, have developed, soluble plant foods in the form of commercial fertilizers must be added to insure maximum production. The chemical principles governing such practices are discussed in another chapter.

It sometimes happens that the processes which render soil materials soluble in water go on so rapidly, or under such favorable conditions, as to produce more soluble salts in the soil than can be utilized by the native or cultivated crops which are growing on that soil. If the soil receives surplus water and there is proper drainage, the extra soluble salts are washed away before they can cause any harmful effects. But if there is inadequate drainage to remove excessive soluble salts, or more particularly when seepage water from higher-lying lands brings soluble salts to lower

lands from which it cannot be properly drained, these soluble salts accumulate in such quantities as to be injurious to crops. They are then known as "alkali." "Alkali" soils are found only where drainage does not remove surplus soluble salts, and it is only necessary to establish proper drainage to remedy the condition. Unfortunately, however, much of the trouble from "alkali" in soils is in regions where there is not sufficient natural rainfall to produce any drainage water, and unless artificial flooding can be resorted to there is no possibility of establishing drainage conditions.

In every case, however, the proper supply of available plant food is determined by the nature and solubility of the chemical elements of the soil. Intelligent utilization of the soil for crop production is one of the triumphs of the application of chemistry in industry. The beginnings of intelligent agriculture date from the time when the chemist was first able to analyze correctly both plant tissues and the soils from which the crops secure the necessary elements to enable them to build up these tissues.

THE IMPORTANCE OF SOIL MOISTURE IN PLANT NUTRITION

From the preceding discussions, it is clear that an ample supply of water in both the soil and the plant is absolutely essential in order to permit the available plant food of the soil to enter the plant roots and to permit the manufacture and transportation of chemical compounds from cell to cell in the tissue of the plant.

Many actual measurements have been made of the quantity of water which is taken from the soil by



A fertile field ruined by excess of soluble salts, or "Alkali" in the soil



An "Alkali Spot" in an irrigated meadow.

plants during the process of growth and ripening. It has been found that this varies with different crops, and, to a lesser degree, with the same crop when grown under different climatic conditions. Certain plants, which grow in desert regions, use much less water in their growth processes than do the common cultivated crops. Among the cultivated crop plants, some (known as "dry-farming" or "semi-arid" crops) require less water for their growth and maturity than do others which can be successfully grown only in "humid" regions.

The actual quantity of water required by farm crops for their successful production has been found to vary from about 250 pounds of water for each pound of dry matter produced, in the case of some of the hardy "dry-land" cereals, to as much as 1200 pounds of water per pound of dry matter produced, in the case of some of the succulent forage crops of the humid regions. But in every case the minimum water-requirement of each particular crop must be available in the soil during the growing season if that crop is to develop to full maturity.

Fortunately, in most agricultural regions of the temperate zone, the natural normal rainfall during the growing season provides the soil with the required amounts of moisture to meet the water-requirements of most common farm crops. Under such conditions, the supply of available plant food, and the circumstances of insect or parasite attacks, or other injuries, are usually the limiting factors in crop production.

But in regions of limited total rainfall or of its unfavorable seasonal distribution, the soil moisture supply often comes to be the limiting factor in crop production. Proper methods of soil management, to conserve scanty supplies of soil moisture, become es-

sential practices in the so-called "dry-farming" areas and are aids to increased production in regions where droughts of varying duration may interfere with maximum crop growth. In other districts, natural rainfall is always insufficient for satisfactory crop growth even if the soil is amply supplied with available and reserve plant food. Here irrigation must be practiced to supplement natural soil moisture supplies, if successful crop production is to be secured.

Crop production with skillful use of irrigation water is a most satisfactory agricultural practice, since in such a case the limiting factor in crop yields is largely under the control of the farmer himself. But there are obvious dangers in unskillful use of irrigation water because of the chemical principles concerning available plant food supplies which have been presented in the preceding pages. The application of amounts of irrigation water in excess of those which can be held as capillary water in the soil inevitably leads to losses of available plant food through leaching, thus diminishing the potential productive capacity of the soil. On the other hand, the leach waters from over-irrigated lands, carrying their dissolved soil salts, are very likely to appear again at the surface on lower-lying lands elsewhere in the district, there to evaporate and leave their soluble salts in or on the soil as destructive "alkali." Thus, surplus soil water may be a factor very dangerous to successful agriculture.

SUMMARY

In brief, it may be said that the whole process by which crops absorb mineral nutrients from the soil and with their aid build up the carbohydrates, proteins, fats, etc., from which their own tissues are con-



Irrigating an Orchard to increase the water content of the soil.

structed and which later become human food, is a series of chemical changes. There is, first, the series of chemical changes whereby inert mineral material of the soil becomes soluble and hence available to the crop. Then comes the amazing chemical manufacturing process by which the plant cell manufactures from these mineral elements and the gases which it absorbs from the atmosphere the chemical compounds which are first its own structure-building materials, and later the foods from which all human beings build up and maintain their bodies. It is through this constructive chemical process that Man is continually being created from "the dust of the earth."

The knowledge of the nature of these chemical changes and the conditions under which they proceed most favorably is the contribution which chemistry makes to crop production. And since crop production is the primary function of agriculture, it may properly be said that chemistry offers the fundamental scientific basis upon which to build a sound and permanent agriculture.

CHAPTER II

THE WORLD'S FOOD FACTORY OR THE PLANT IN AIR AND LIGHT

JOHN M. ARTHUR and HENRY W. POPP

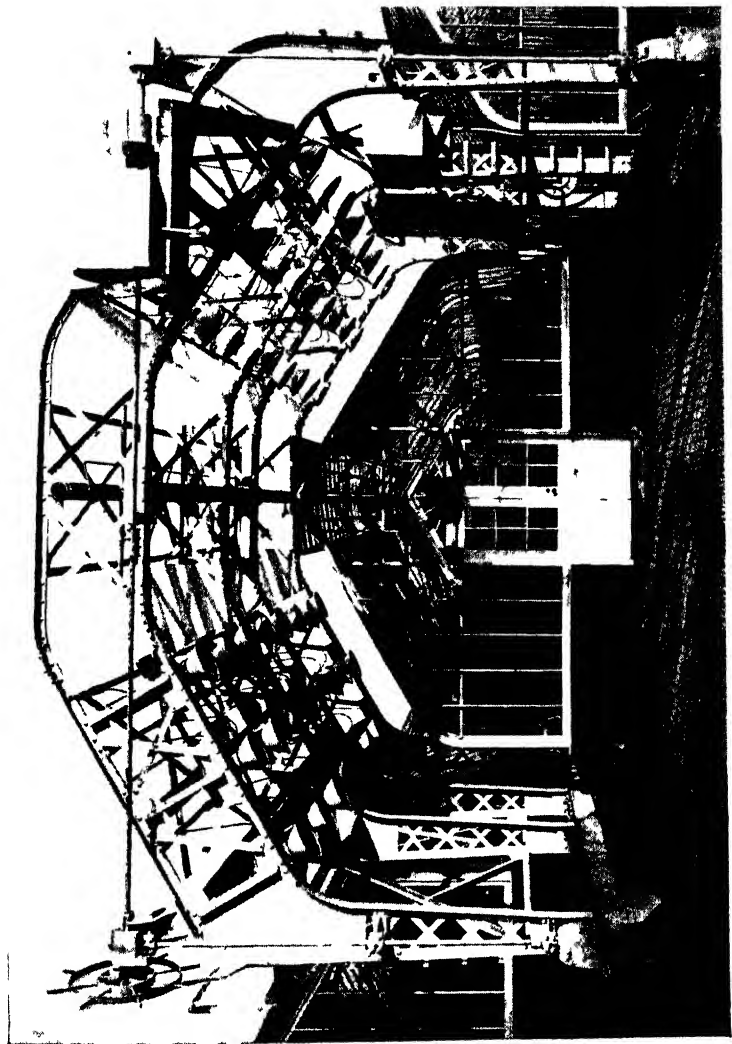
Biochemists, Boyce Thompson Institute for Plant Research.

“The first object which attracted Gulliver’s notice, when on his visit to the Academy of Logado, was a man of meager aspect, his eyes fixed on a cucumber sealed in a phial. On Gulliver’s questioning him, the strange personage explained that for more than eight years he had been absorbed in the contemplation of this bit of apparatus, trying in vain to solve the problem of the storage of the sun’s rays in this recipient and their possible utilization.”

The bibliography of our subject contains the names of some of the most noted chemists of all time who have studied figuratively the cucumber in the phial. The above quotation from Gulliver’s Travels was taken from a lecture delivered at a meeting of the Royal Society in 1903 by Timiriazeff after he had spent thirty-five years contemplating:

“If not a cucumber in a phial, still at what comes to the same thing at a green leaf in a glass tube, and breaking my head in vain endeavors to clear up the mystery of bottled sunshine.”

Why study the cucumber in the phial? Why worry our brains about the process by which the plant fixes the energy of sunlight in the form of carbon com-



Gantry Crane used at Boyce Thompson Institute for Plant Research for Illuminating Greenhouses.

pounds? The process was, no doubt, operating when human life appeared upon the earth. If the same conditions of light and air continue, the process will probably go on, even though we know nothing about it.

We might have applied the same process of reasoning to the great astronomer, Kepler, when he set out to study the motions of the planets. Why study their motions? The planets have been moving for a long time and will continue to move regardless of our knowledge or ignorance of their motions. There is no possibility of stopping them or changing their motions in the slightest degree. The reason for the study is plain. Such observations as Kepler's have brought civilization out of the ignorance and superstition of the past. Thanks to astronomy, we know several years in advance when eclipses will occur, how long they will last and where they can be observed. The sudden shadow which blots out the light of day has no longer any terror for us, for we know that the shadow will pass. How different it was before Kepler started his study of planetary motion. Astronomers are the pilots of space. Long before our planet collides with some celestial derelict, our pilots will have sighted it. From astronomy, therefore, comes the knowledge of our relations in space and of the probabilities of the continued existence of our planet. This is extremely important from the human point of view.

Of equal importance to our existence is our food and fuel supply. From a study of the relations of the plant to light and air comes the knowledge of the process by which our food and fuel are manufactured. Fortunately for us the conditions of light and air which affects the synthesis of carbon in the green plant offer some hope of control, which is not true of the conditions of planetary motion. The knowledge of the

former, therefore, has immediate, practical application. In the face of an ever increasing population to feed, on the one hand, and an ever decreasing acreage not yet under cultivation, on the other, the prospect of control of plant processes, so as to speed up food and fuel production, is indeed fortunate.

Rev. Joseph Priestly was a pioneer student of the cucumber in the phial. His work appeared in 1772. The phial which he used was a bell jar full of air which had become vitiated by the respiration of animals. The cucumber was a whole plant placed in the bell jar. The apparatus was sealed for a time, after which the inclosed gases were tested and found to be again fit for the respiration of animals. The gases would also support combustion, which was not true at the beginning of the experiment.

Unfortunately Priestly found that he could not always repeat this experiment. Sometimes the air would be purified by the plant; often the plant would have little effect. Ingen-Housz in 1779 showed that only the green parts of plants purified air and these only in sunlight. He discounted the importance of this process in the life history of the plant. Like a great many philosophers of the past, he regarded all nature, selfishly perhaps, as working to produce the climax of creation, man. The process, therefore, was designed primarily to purify air for the respiration of animals—more particularly for man himself. Ingen-Housz did not recognize the difference between marsh gas or methane, hydrogen and carbon dioxide, and thought that the plant would in time free air of all such foul gases. We can no doubt ascribe to Ingen-Housz and other early philosophers, the folklore which has been handed down even to our own generation that plants, especially those in flower, should not be

kept in the sick room, the most fragrant flowers being at the same time the most dangerous. Ingen-Housz wrote:

“If a few flowers of the honeysuckle which possess the most agreeable smell, are able to foul in three hours’ time a body of air equal to two pints, we may judge what dangerous effect might be expected from a large quantity in a close room. The air itself, which they have poisoned, is impregnated with the same fragrant smell as the flowers themselves; so that a person, not aware of the concealed poison which flowers spread round about them, might be easily induced by the sweetness of their scent to run the greatest hazard of losing his life without the smallest apprehension of danger.”

He thought it worth while to include a special warning which concerns the sick room, as follows:

“I acknowledge readily that a few flower pots can do neither good nor harm, but I remember to have found several orange trees in a room, by way of ornament, and, as I was told, to keep the air of the room wholesome; I think now such ornamental plants by no means indifferent, unless they were but small and the room ample; at any rate I should not suffer them to be kept in a room at night, where a sick person is.”

RESPIRATION

The “concealed poison,” which Ingen-Housz found to be spread about by flowers, is the gas, carbon dioxide. It arises from the process of respiration—a characteristic of all living cells whether plant or animal. Tashiro (1917) has called this liberation of carbon dioxide a “Chemical Sign of Life”—a test which identifies living tissue. Since other carbon compounds

may also give off carbon dioxide due to oxidation, the absolute value of the test in deciding whether cells are living or dead, is questionable. The fact still remains, however, so far as our knowledge goes, that all living plant organs give off carbon dioxide. The amount of gas given off by dry seeds and dormant plant organs is extremely small. It would require about 175 tons of air-dry shelled corn at room temperature to produce in an hour 1 ounce of carbon dioxide. Sixty sunflower plants averaging 15 leaves each would produce in 1 hour a little less than an ounce of the gas. Three men in the same length of time would produce more than twice as much carbon dioxide. It follows, therefore, that the sick man which gave Ingen-Housz so much concern would be in greater danger from the respiration of three friends than from a large bouquet of 60 sunflower plants.

Respiration in plants is usually measured by the amount of carbon dioxide given off by the plant sealed in a bell jar or other closed vessel. The gas is trapped by a wash bottle containing an alkaline solution with which it forms a carbonate. The amount of carbonate formed can be easily determined by titration. Oxygen is used during respiration. Some information concerning the substance oxidized may be gained by measuring the amount of oxygen used. If sugars are being used in respiration the ratio of carbon dioxide given off to oxygen used is one. If fats are burned, the ratio is less than one. In case of a shortage of oxygen for the process of respiration, the plants continue to give off carbon dioxide, obtaining their oxygen from the conversion of sugars to alcohol. This transfer of oxygen from one molecule to another is called intramolecular respiration. The mechanism furnishes the plant a very convenient means of tiding over periods of

oxygen shortage—a thing which occurs frequently when the plant closes its ventilating system.

PHOTOSYNTHESIS

Respiration of the green plant in sunlight, however, is masked by the opposite process, the absorption of carbon dioxide and the fixation of carbon. Oxygen is eliminated as a by-product. This process more than uses up all of the carbon released by respiration. As a net result, therefore, the green plant takes in carbon dioxide in sunlight and gives it off in darkness.

By the experiments of Senebier (1782) and DeSaussure (1804) it was established that green plants in light take in carbon dioxide, that this is a nutritive process, and that oxygen is given out in volumes approximately equal to the carbon dioxide taken in. Later work has shown that the volume of oxygen given off is usually greater than the volume of carbon dioxide used, as some water is decomposed in the process of photosynthesis and oxygen is given off from this decomposition. Boussingault (1860-1881) showed that the green plant started the decomposition of carbon dioxide as soon as it was illuminated and also that the plant could use the small concentration of the gas found in the atmosphere as a source of carbon.

This process of absorbing carbon dioxide gas and synthesizing carbon compounds from the carbon contained therein, has been called *photosynthesis*—a synthesis by light. Recent workers have preferred to call the process *carbon assimilation* to distinguish it from other synthesis which go on in the plant in the presence of light. This is reviving a term which was long ago rejected. The word *assimilation* connotes the transformation of foods into the living tissues of

organs and may apply to either plant or animal. Photosynthesis has been ordinarily applied to the great light synthesis of nature, that of the green plant, and the writers will retain the term in the text. The important thing, however, to hold in mind is not the name but the process itself.

THE INSIDE OF THE LEAF

Only green parts of plants are able to carry on the process of photosynthesis. We will, therefore, examine a leaf in some detail, as this is the organ which contains the greatest amount of the green coloring matter. Because of its thin character and great surface exposed to sunlight and air it is the organ primarily concerned with the process, although stems and other parts of plants often contain some pigment.

Before considering the inside of the leaf we should

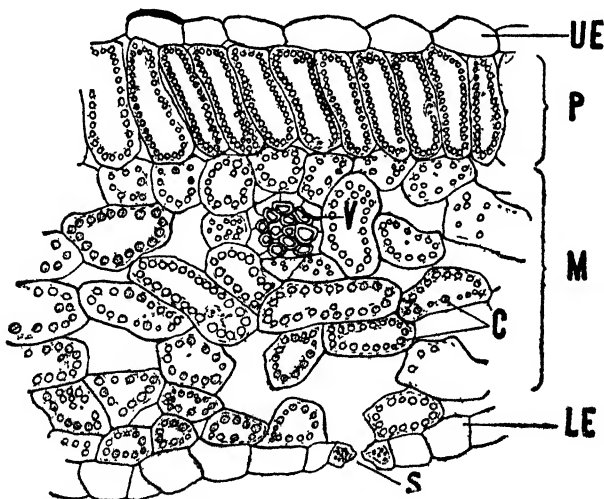


FIG. 1 Vertical Section of Barberry Leaf UE upper epidermis, P palisade layer, M mesophyll, LE lower epidermis, S stomata, V vein, C chloroplasts.

first find a unit suitable for measuring very small distances. The unit which the microscopist ordinarily employs in measuring distances under high magnification is the micron. It is 1/1000th of a millimeter. Figure 1 shows a vertical section through a barberry leaf magnified about 200 diameters. Any other leaf of a common seed plant would show a similar structure. If this figure is projected by a lantern so that the vertical distance between the upper and lower surfaces of the leaf is equal to 21 feet, an inch on the screen would be about equal to a micron.

The leaf is made up of units or cells of various shapes. On the upper surface is a layer of ovoid cells which contain no pigment, called the *upper epidermis*. Immediately below is a regular layer of elongated cells placed perpendicularly, which contain a great amount of green pigment. They have been named, from their shape and position, the *palisade cells*. On the screen mentioned above these cells are about $6 \frac{2}{3}$ by $1 \frac{1}{2}$ feet. Below the palisades is a layer of cells, the *mesophyll*, of many different shapes and sizes irregularly placed around air spaces. Disposed between the cells of the mesophyll are the veins of the leaf lamina. On the lower surface is the *lower epidermis*. This layer of cells is perforated at intervals by small openings, the *stomata*, which communicate with the air spaces of the mesophyll and palisade tissues. The area of the opening is regulated by two guard cells which operate through turgor changes within the cells. When the cells lose water faster than it can be replaced the stomata close. The plant's ventilating system is closed. The brakes are at once applied to the process of photosynthesis due to the shortage of raw material, carbon dioxide, and the factory slows down. Respiration continues as the plant needs energy for its metabolic

processes. Growth must go on, and therefore new compounds must be built up and energy used. The energy is furnished by respiration. If the oxygen supply is low, intramolecular respiration begins.

THE WORLD'S FIRST FACTORY

If we examine closely under high magnification the green pigment in the cells of the palisade and mesophyll layers of the leaf, we can see that it is localized in globoid bodies about 2 microns in diameter. As projected on the screen this body would appear not more than 2 inches in diameter in a palisade cell 2 by 7 feet. An extremely small body compared with its importance to our continued existence! The body is the chloroplast. It is so small that its structure is not definitely known. With certain methods of staining, the presence of starch grains can be demonstrated. We shall see later that we have some evidence of the nature of the solution which contains the green pigments. The chloroplast is probably the smallest and certainly the most important factory in the world. If this factory should suddenly close down permanently, due to lack of raw material or energy for the process, practically all plant and animal life would soon disappear from the earth. The carbon fuels which we burn to heat our homes were once built up in this small factory. Even the clothes which we wear had the same origin. Cotton is principally cellulose, one of the factory's main products. Woolens came indirectly from the plant. The sheep which produced them consumed large quantities of the products of the chloroplast. The food which we eat is a product of the factory. Our meats were produced by animals which lived either directly on plants or on other herbivorous animals.

Ultimately the chloroplast is the earthly source of our energy of life, for this small factory transforms the energy of sunlight into the potential energy of carbon compounds.

THE PROCESS

The Master Chemist of nature thus far holds the key to the world's first factory. In spite of the work of some of the best chemists of all times, we do not know the details of the process. The facts which we know might be summed up briefly:

1. Carbon dioxide gas enters the leaf from the outside air by way of the stomata. Meeting water which is being carried up from the soil through the conductive system, it forms carbonic acid.

2. Oxygen is released.

3. Light energy is absorbed.

4. Sugars and starch appear.

The amount of carbon dioxide used by the plant in a given time, minus the amount produced during that time by the process of respiration, is a measure of the amount of photosynthesis. The amount of gas used is ordinarily determined by sealing the plant in a chamber and analyzing the entering and issuing gases for carbon dioxide. The amount of photosynthesis has also been determined by weighing leaves, by making heat of combustion determinations and by analysis for carbohydrates before and after exposure to light. The amount of oxygen released also gives some information as to the nature of the products of photosynthesis. The fact that gas enters the leaf mainly through the stomata may be easily shown by painting regions of the leaf surface containing stomata with vaseline or wax and measuring the amount of photosynthesis both

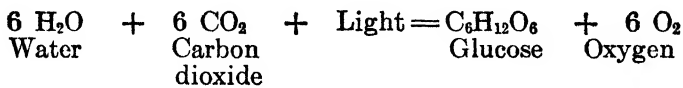
before and after closing the pores. There is little or no photosynthesis when the stomata are closed in this way.

The third fact listed above, the absorption of light energy, can be shown by measuring the amount of light transmitted by the leaf. That the leaf gains energy, can be shown directly by making a heat of combustion determination both before and after exposure to light. This may be accomplished by choosing leaves which are bilaterally symmetrical, burning one-half before and the remaining half after exposure. The amount of energy gained plus the amount lost in respiration, evaporation of water, and radiation to the surrounding air, is equal to the amount of energy absorbed. The unit of energy is the Calorie which is the amount of heat required to raise one thousand grams of water one degree centigrade, or approximately four pounds of water one degree Fahrenheit. Burning one gram of glucose yields 3.75 Calories of heat. The heat of formation of one gram of glucose is assumed to be the same as its heat of combustion—about 3.75 Calories. This amount of energy is supplied by sunlight. It may also be supplied by artificial illumination. The process is not efficient from the energy standpoint. Under natural conditions, probably not more than one per cent of the total radiant energy falling upon the leaf is utilized, over a period of 12 hours illumination. About 27% of this total energy is used in evaporating water. The evaporation of water from the leaf serves the double purpose of cooling the leaf and keeping a supply of mineral salts moving through the plant from the roots toward the leaves. Blackman and Matthaei (1905) using a thermo couple inserted into the body of a cherry laurel leaf, found that the internal temperature

of the leaf increased about 18 degrees Fahrenheit when placed normal to the solar radiation. If the leaf were completely inclosed in glass the increase would be doubled. In the latter case, all evaporation is cut off, and the leaf soon reaches its thermal death point. Lundegardh (1923), using a similar method of measuring the internal temperature of the leaf, found that in a stream of moving air the leaf seldom showed a rise of more than 4 degrees Fahrenheit on account of the effective regulatory action of the amount of water evaporated. On a cloudy day the leaf temperature is usually lower than air temperature.

The fact that sugars and starches appear is the fourth point which we have listed. Starch grains can be seen in the chloroplast after exposure to light by staining the tissue with iodine in chloral hydrate solution. The presence of sugars can also be shown by adding another chemical, phenyl hydrazine, to a section of the plant organ and observing, under high magnification, the development of characteristic crystals, of the phenyl osazone.

The first product of the process of photosynthesis which exists in the plant in quantity is sugar. The general equation for its synthesis is:



The simplest carbohydrate which can be formed by the interaction of single molecules of water and carbon dioxide is formaldehyde. From a chemical point of view, therefore, we would expect to find this substance present in plant tissues, as it is a logical step in the synthesis of sugar. Formaldehyde has been found in plant tissues and in chlorophyl extracts which

have been exposed to oxygen and light. In these cases it has been shown to arise as a decomposition product due to the oxidation of plant alcohols. Jorgensen and Kidd (1916) found that even grain alcohol under illumination by ultra violet light would yield formaldehyde and that a higher alcohol, a phytol group in chlorophyll, was no exception to this. In fact, carbon dioxide and water can be converted directly into formaldehyde by exposures to short waves of light in the ultra violet region (Baly, 1924). With slightly alkaline solutions a syrup is produced containing sugars very similar to those found in plants. It does not follow, however, that the short rays of light which are effective in synthesizing a syrup in a test tube are the same rays which the plant uses in the process of photosynthesis. Plants grow well under green-house glass which does not transmit these short rays of light. We will reserve for a later discussion the formative effects on growth produced by screening out the blue region, as well as violet and ultra violet, from sunlight.

CHEMISTRY OF THE PIGMENT

We have found from a study of the leaf under the microscope that the green pigment is restricted to small bodies called chloroplasts. The chloroplasts are distributed through the living protoplasm of the cell. The manufactured products are transferred through the protoplasm to the conductive tissue and thence to all parts of the plant.

The green pigment in the chloroplasts of the fresh leaf can be extracted with solvents such as alcohol and acetone. From solutions obtained in this way four pigments have been isolated:

Chlorophyll A ($C_{55}H_{72}O_5N_4Mg$) and Chlorophyll B

($C_{55}H_{70}O_6N_4Mg$) the two green pigments of plants; carotin ($C_{40}H_{56}$) a substance identical with the orange yellow pigment of carrots; and xanthophyl ($C_{40}H_{56}O_2$) a yellow pigment. Willstätter (1913) has made the greatest contribution to the chemistry of the pigments associated with photosynthesis. Chlorophyl is soluble in acetone when pure, but it cannot be dissolved readily from dried leaves until about 15% of water is added. The absorption bands in the spectrum of extracted chlorophyl are shifted slightly toward the blue end of the spectrum as compared with similar bands in the living leaf. When a leaf is plunged into hot water its color changes to a bright green. Spectroscopically, this change is represented by a shifting of the absorption bands toward the blue end of the spectrum. The foregoing evidence leads us to think that chlorophyl is present in the leaf as a colloidal solution with fats, waxlike substances and mineral salts.

The pigments are, so far as known, always present in seed plants which carry on the process of photosynthesis. The amount of carotin and xanthophyl varies with the plant. It may also vary with the season of the year. The two chlorophyl pigments are present in green leaves in a fairly definite ratio of about 3 chlorophyl A to 1 chlorophyl B. In a total of ten analyses of three non-related species, Willstätter found the following percentages of the pigments on a dry weight basis:

Chlorophyl A	.61%	Carotin	.059%
Chlorophyl B	.22%	Xanthophyl	.10%

The amount of chlorophyl increases as the leaf matures in the spring. Its power to carry on photosynthesis also increases, but the rate of increase in the latter falls behind the increase in amount of chlorophyl.

Leaves grown in the shade have more chlorophyl than those grown in the sun. It is interesting to note that the chlorophyl pigments yield derivatives which are related to haematin, a derivative of haemoglobin found in blood. Haematin has the metal iron, placed very similarly in the molecule to that of magnesium in chlorophyl. Iron is necessary to the formation of chlorophyl, but is not a part of its molecule. Plants grown without this metal develop a nutritional trouble called chlorosis. The leaves are pale green, or yellow, due to lack of chlorophyl. The disease can be cured by adding iron to the soil or by spraying the leaves with iron salts. The function of both iron and magnesium in the processes of photosynthesis and respiration is not clearly understood. Since they are metals and are necessary only in small amount, they may operate as catalysts; iron playing a major rôle in respiration in both plants and animals, and magnesium being intimately linked with the process of photosynthesis in the plant.

The chemistry of the two yellow pigments, carotin and xanthophyl, as well as their function in photosynthesis, is little known. They no doubt play a very important rôle in the process, since they are always associated with chlorophyl and are very reactive substances. Both take up oxygen from the air, carotin often increasing in weight by 40%. Several theories have been advanced to show the function of all four of the pigments. None are entirely satisfactory, however, in explaining the mechanics of photosynthesis, and space does not permit our entering into a description of them. When some young chemist of the future has gained the key to the process from the Master Chemist of nature, we will, without doubt, be able to see clearly the function of the four pigments in the world's first factory.

EFFECT OF EXTERNAL CONDITIONS IN GENERAL
ON PLANT GROWTH

The pioneer chemist, Liebig, stated that the yield of a crop is limited by the minimum essential constituent which is present in a soil, whether it be nitrogen, potassium, phosphorus, calcium, water or other ingredient. Blackman (1905) applied this "Law of the Minimum," as Liebig called it, to the effects of carbon dioxide supply, temperature, water supply, intensity of illumination and quantity of chlorophyl, on the rate of photosynthesis and indirectly on the growth of plants. These factors he called "limiting factors," as any one of them may inhibit the rate of development of the plant. If the limiting factor is increased toward its optimum the rate of the plant processes increases until another factor limits. It may be truly said that a plant in nature never has a chance to carry on its life processes at a maximum rate, as at least one of these factors is limiting. In the winter the temperature is too low. If this is regulated by placing the plant in a greenhouse the rate will increase until light intensity is the next limiting factor. If light intensity or duration be increased by artificial illumination, the rate will again increase until a third factor such as carbon dioxide supply is limiting. In the summer when light intensity is high and length of day is maximum it is often too hot or too dry for the maximum rate of the plant's life processes. If these factors are corrected the plant is finally limited by the small percentage of carbon dioxide in the atmosphere. In the following pages we will deal in some detail with the effects of environmental factors on plant life processes, paying particular attention to those effects when a factor is limiting.

TEMPERATURE AND HUMIDITY

A great many plants grow best in the tropics, where both temperature and humidity are high. Other plants thrive best at a moderate temperature and humidity, as those found in the temperate zones. There is a smaller list of plants which grow only in the hot, dry climate of the desert. From geographical considerations, therefore, we conclude that plants have an optimum temperature and humidity which varies with species, or which may even vary with variety. The fact that a plant is found growing abundantly in an extreme climate like the desert may not mean that it grows best there, but that it has less competition there from other plants. It also indicates that it can carry on its life processes, photosynthesis and respiration, either within a wide range of temperatures and humidity or at least within a range which is beyond that of most plants.

Blackman and Matthaei (1905) have made some measurements of the rate of photosynthesis of several leaves, including those of both aquatic and land plants. They found that leaves in general have the same coefficient of economy in the photosynthetic process. Their differences lay in the difference in the rate of acceleration with rise in temperature. In the case of the cherry laurel leaf the rise in the rate of photosynthesis for 18° Fahrenheit rise in temperature was 2.1. The corresponding rise in a sunflower leaf was 2.5. The sunflower, therefore, is a high temperature plant as compared with cherry laurel. Both respiration and photosynthesis increase with temperature up to a certain maximum, which is near the thermal death point. Lundegardh (1924) showed that in the case of the potato leaf the rate of increase for respiration

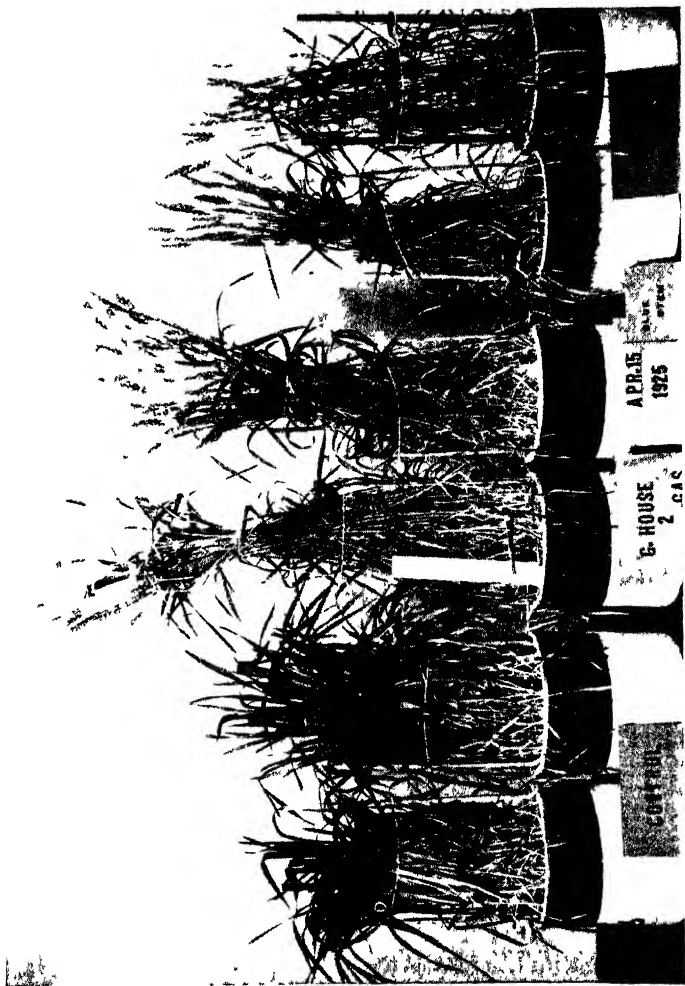
at temperatures between 77° and 95° was about 1.8. At lower temperatures the rate was higher. Photosynthesis at 59° Fahrenheit goes on at about 5.6 times the rate at 41°. The rate of increase falls off to about 2, however, at temperatures between 68° and 86°. He also found that the optimum temperature, or temperature at which the process is most rapid for photosynthesis, increases with light intensity and concentration of carbon dioxide. With about 1/25th the intensity of bright sunlight and normal concentration of carbon dioxide the optimum temperature is about 64° Fahrenheit. With full sunlight and 1.22% carbon dioxide in the air the optimum was 86°. That is, with higher light intensity and higher carbon dioxide concentration the plant can make use of a high temperature, at least for a short time. Whether this initial rate can be maintained during the entire life history of the plant is yet to be determined.

LIGHT

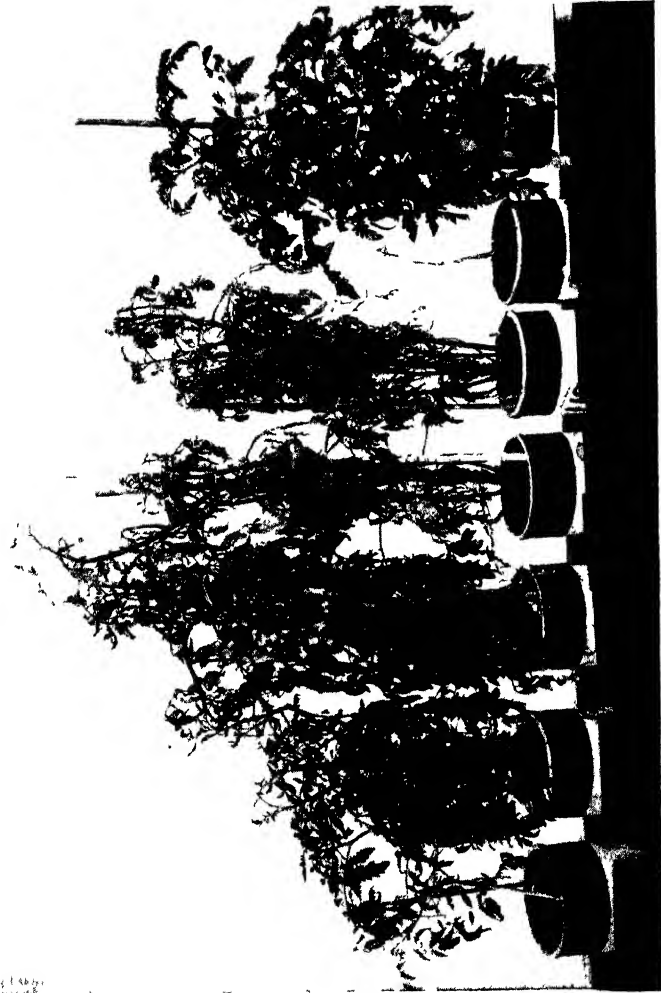
The great source of light and energy for plants is the sun. Moonlight has been thought to exert some influence on the growth of plants, but on account of its exceedingly low intensity it has little or no effect on the process of photosynthesis. Sunlight is one of the great variables of nature. It varies both as to intensity and quality. As regards intensity, some data on solar illumination furnished by the New York Meteorological Observatory for the year 1925 is of interest. The average daily illumination for the hour 11-12 during the month of May was about 5,440 foot candles. This same figure for the month of January was about 2310 foot candles. January had 5 days during which the illumination was at no time greater than

880 foot candles. The four most cloudy days in May had an illumination which did not exceed 3,680 foot candles. The darkest days of May, therefore, exceeded in brightness the average of the brightest hours (11-12) of January, and the average illumination for the hour 11-12 during the month of May was more than twice that of January.

Summer sunlight intensity is more than sufficient to carry on maximum amount of photosynthesis with the normal amount of CO_2 in air. Blackman and Matthaei found that in England during the month of August maximum sunlight intensity could be decreased to .36 and still get maximal photosynthesis with cherry laurel leaves. In the winter sunlight intensity often limits the process. Many of our common garden vegetables and crop plants grow very slowly in greenhouses during December and January even though temperature and humidity are optimum. With a few additional hours of illumination at night the growth rate can be greatly increased. Red clover has been grown in this way from seed to flower in a short period of thirty-eight days. A good crop of clover hay has been grown in two months from seed. In ordinary agricultural practice this would require two seasons to produce. Plate II shows the effect on growth and time of heading of supplementing the short days of March and April with six hours per day of artificial light. The two plots of wheat at the left were grown with no additional light or carbon dioxide gas. The two in the center received six hours artificial light from a battery of forty-eight 1,000 watt lamps plus natural daylight, with carbon dioxide gas held at about .3%. The two at the extreme right received the same illumination but no additional carbon dioxide. All were grown from seed planted February 28th and all held at the same tem-



Blue Stem—a Spring Wheat Two pots at left received normal day of spring and normal concentration of carbon dioxide. Two pots at center received six hours additional light and additional carbon dioxide. Two pots at right received additional light only. Plate II.



Tomatoes Grown Under Artificial Light, Except Control and 24 hours of artificial light in each 24-hour period and temperature and humidity. Plate III.

From left to right, 5, 7, 12, 17, 19
Control grown in greenhouse at same

perature. The plants were, therefore, forty-four days old when the picture was taken. Extra light caused the plants to head earlier. Both extra light and extra gas caused the plants to head early and gave better yield of grain and straw.

LABOR UNIONS AMONG PLANTS

Since there is a progressive increase in the length of day from December to June in our latitude, and a corresponding decrease from June to December, it is not surprising to find many temperate zone plants attuned to day length. Certain plants flower during the early summer months; others not until late summer or autumn. Garner and Allard (1923) working at the Bureau of Plant Industry found that certain plants, like the late blooming Cosmos or the Salvia, would flower only on short days, which they would receive in nature in the autumn. These plants can be made to flower at any time during the summer by shortening their working day. Other plants like the radish and lettuce flower only on a long day, that is only during the early summer. A group of intermediates, of which the sunflower is an example, flower on an equatorial day. Plants of these three groups are like a labor union in that they have very definite working hours. The common tomato belongs to a more temperate sort of a union. It will not live on a twenty-four hour day, while it continues to grow on a nineteen hour day. Plate III shows a series of tomatoes grown under all artificial light except the plant marked "control." From left to right the plants received respectively 5, 7, 12, 17, 19 and 24 hours of illumination in every twenty-four hour period from a battery of twenty-five 1,500 watt lamps. The plant marked "con-

trol" was grown in the greenhouse at the same temperature and humidity but with the sunlight of Spring. All plants are the same age. The tomato rapidly loses all of its leaves during two months continuous illumination and finally dies. With 5 hours rest in every 24 hour period it lives but does not fruit. With 7 hours rest it will fruit. Intensities of light which are too low to produce any appreciable amount of photosynthesis in plants sometimes initiate flowering. The effect, therefore, may be a direct stimulus of light or the production of substances by light, which even in low concentrations are effective in stimulating the plant to flower.

QUALITY OF LIGHT

White light, as we get it from the sun, consists of a definite series of rays of different wave-lengths. When a beam of this light is passed through a prism, each of the different rays suffers a different amount of refraction or bending, the longer (red) rays being least refracted and the shorter (blue-violet) rays most. The result is that a spectrum is formed, part of which is visible to the eye and appears as a band of colors consisting of red, orange, yellow, green, blue and violet. Beyond the visible portion of this spectrum, at the red end, is a series of longer, invisible rays called the infra red. Similarly, beyond the violet there is a series of shorter, invisible rays called the ultra-violet.

Ordinary daylight is made up of direct sunlight and skylight and since these two differ considerably in the relative proportions of the different wave-lengths present, the quality of daylight will vary with the position of the sun. Weather conditions also affect the quality considerably but in general the greatest amount of

energy is in the red end of the spectrum. A curve showing the distribution of the total energy in the different parts of the spectrum of the combined light from sun and sky will always have its highest point in the visible region, but a large percentage of the energy is in the infra red, and since this is readily converted, by absorption, into heat, these infra red rays are sometimes referred to as radiant heat. The ultra violet rays, on the other hand, are relatively low in energy value but are effective in bringing about certain chemical reactions, especially with silver salts, and therefore, are sometimes called chemical rays.

Since daylight is made up of different wave-lengths or colors it is natural to inquire whether the different parts of the spectrum affect plants differently. This question in fact has attracted the attention of scientists for many years. Many investigations have been made in which different kinds of light were obtained by the use of colored screens of glass or of chemical solutions. In other cases sunlight was passed through a prism and plants exposed to the various regions of the resulting spectrum. Many artificial sources of light have also been used. Arc lights in general, and especially the mercury vapor arc, are much richer in ultra-violet rays than is sunlight. The light from incandescent lamps, however, such as our common electric light bulbs, is deficient in blue violet and ultra violet rays as compared with sunlight and therefore appears yellow in daylight. In general, artificial light sources become whiter, or more nearly like sunlight in quality, the more blue violet rays they contain. No artificial light source has yet been found that compares with daylight in both intensity and quality and this fact has made it difficult to compare light experiments with plants using artificial light sources with those

using sunlight. The desirability of using artificial light for such investigations lies in the fact that all the variables of light; intensity, duration, quality and direction, can be controlled, whereas these factors are constantly changing in daylight. By controlling all factors except one the effect of a single variable on plants may be tested.

QUALITY OF LIGHT AND PHOTOSYNTHESIS

If we pass a ray of sunlight through a solution of chlorophyl and then through a prism we find that we no longer obtain a continuous band of colors but that certain parts of the spectrum have been absorbed. These parts appear as dark bands which are called absorption bands. The heaviest of the bands will be in the visible red. Others appear in the yellow and in the blue and violet. Green is least absorbed and hence chlorophyl has a green color. If the light absorbed by chlorophyl is the principal light utilized in photosynthesis we should expect red light to be more effective than any other, and actual experimentation by many different investigators has demonstrated that such is the case. When sunlight is used as the source of light, it is always found that the greatest rate of photosynthesis occurs in the red part of the spectrum, corresponding in general with the absorption by chlorophyl in that region. Thus Timiriazeff (1903) found that by dividing the whole visible spectrum at 550 millimicrons (the middle point) and recombining each half through another prism and lens, the red half had a value of 100 and the blue 54 in photosynthesis, or roughly half that of the red. The red end of the spectrum of sunlight is higher in energy value than the blue violet. However, it is not wholly a matter of the amount

of energy in the incident rays, for a curve showing the rate of photosynthesis at different wave-lengths does not correspond to a curve showing the distribution of energy of the incident light at these same wave-lengths. If this were true we should expect considerable photosynthesis in the infra red because of its high energy value, but such is not the case. Neither does the curve of photosynthesis follow exactly the absorption bands of chlorophyl, as we might expect, although as stated, the highest point in the photosynthetic curve does correspond to the strongest absorption band of chlorophyl. Repeated investigations have shown that photosynthesis may take place in all parts of the visible spectrum and in the ultra violet. Ursprung (1917) found that photosynthesis took place in wave-lengths as short as 330 millimicrons. He also found it to occur in the infra red, but only after many hours of illumination.

EFFECT OF QUALITY OF LIGHT ON GROWTH AND DEVELOPMENT

Besides photosynthesis, other physiological processes within the plant are influenced by the kind of light under which plants are grown. These collectively manifest themselves in the kind and amount of growth the plant makes and in other ways. Early work on this subject is inaccurate. With regard to light used, for instance, the only statement given in many cases is that glass of a certain color was used. Very often this color was not spectroscopically pure. In fact, many colored glasses, besides cutting down light intensity considerably, transmit the entire visible spectrum. It is obvious, therefore, that a mere statement of the

color of the glass used tells us little about the actual quality and intensity of the light.

In recent years improvements in the making of glass to transmit very definite regions of the spectrum has made it possible to conduct more exact experiments in this field. In 1919 Fritz Schanz, a German oculist, reported the results of his experiments with plants grown under very definite conditions of light as regards quality. He arranged his plants in eight beds which were covered with various kinds of glass. In the first five beds the range of wave-lengths of light transmitted was gradually decreased from the violet end of the spectrum toward the red, thus enabling him to study the effect on plants of light from which greater and greater regions of the spectrum were eliminated in the blue violet end. In the last three beds he used combinations of colored glasses which gave predominating colors of yellow, green and blue violet respectively. Schanz's work was superior to that of many of his predecessors in that he knew fairly accurately the quality of light used. He did not, however, make any measurements of light intensity and therefore again left us in doubt as to whether all of his results were really caused by quality of light. Schanz found that plants became taller the more the short rays of sunlight were cut off from them. Maximum height was obtained under red light and minimum under blue violet. This was true for cucumbers, Fuchsia, chrysanthemums, lobelia, begonia and oxalis. Potatoes and red beets were weakest in yellow light, a little stronger in green and still larger and healthier in blue violet light. The red pigment in the epidermis of colored leaves of certain plants failed to develop under any of the glasses that eliminated ultra violet rays. Flowers also became paler in color, the more the short rays



Soy Beans Grown Under Different Qualities of Light House 1, window glass; House 2, a glass which transmits more ultra violet, House 3, filters out ultra violet, Houses 4 and 5, show the effects of screening out the blue region of the spectrum Plate IV.

were removed, although fundamentally their colors were not changed. With such plants as Fuchsia, beans and tomatoes, the time of flowering was hastened and the number of flowers and fruits increased as the short rays were eliminated. As a general result of his work, Schanz concluded that the short wave lengths of light, and particularly ultra violet rays, were detrimental to the growth of plants. He therefore recommended the use of Euphos glass, a yellow glass which cuts off ultra violet rays, for greenhouses.

The work of Schanz was repeated recently under better controlled conditions. Plate IV shows a series of soy beans grown in 5 colored glass houses in which all growth conditions were kept practically the same except the quality of light falling on the plants. House 1 was covered with ordinary greenhouse glass and was used as a control. House 2 was covered with a clear glass which transmits the entire spectrum of sunlight and has an especially high transmission of the blue violet end of the spectrum; this house was shaded with tobacco shading cloth on the inside so as to reduce the light intensity to that of the houses having a limited spectrum (houses 4 and 5) and thereby to eliminate light intensity as a factor in the results. House 3 was covered with a lemon yellow glass which removed only the ultra violet part of sunlight. House 4, also covered with a yellow glass, cut out all of the ultra violet and violet and half of the blue. The glass over house 5 was orange-yellow in color and eliminated all ultra violet, violet and blue and half of the green. Other plants used in this experiment were tomatoes, buckwheat, petunia, sudan grass, soy beans, tobacco, four o'clocks, sunflowers, radish, lettuce and Coleus.

The most striking results were obtained in house 5, which transmitted only red, orange, yellow and a small

amount of green light. In this house the plants in general were taller but showed a decrease in weight as compared with the other houses. Soy beans, in addition to growing unusually tall, became twiners as shown in plate IV. There was less differentiation of stem and leaf tissues, less compact and thinner walled cells, and a reduction in strengthening tissue, resulting in weak plants. Leaves of many plants showed a tendency to curl or roll. Flowers were considerably delayed in appearing and there was a reduction in the number produced. Fruiting and development of storage organs was poor. Potatoes developed no tubers, and carrots, radishes and beets had very small storage roots. Chemical analysis showed a decrease in total carbohydrates and starch in most plants and an increase in soluble nitrogen.

In house 4, in which the plants received the red, orange, yellow, green, and part of the blue of sunlight, similar results were obtained but to a lesser degree. When only the ultra violet part of sunlight was removed, (house 3) none of the above results were obtained with any of the plants used, although there was a slight increase in height in some cases. Some of the plants (tomatoes, petunia, sudan grass and sunflower) bloomed earlier when the ultra violet rays were removed than they did under any other conditions. In general, these plants were little different from controls in full sunlight. This is of particular interest because it illustrates the fact that these rays are not essential for normal plant growth and development. Plants apparently differ from animals in this respect as it has been shown that ultra violet rays are beneficial to animals, especially in preventing rickets.

Some of the characteristics of the plants grown in houses 4 and 5, as enumerated above, are similar to

those obtained when plants are grown under greatly reduced light intensity. That light intensity was not the important factor in these experiments is indicated by the fact that normal growth was obtained when the plants received the full sun's spectrum at an intensity that was at all times lower than that of the house in which all ultra violet, violet and part of the blue was removed, and only slightly greater than that of the house which eliminated all rays down to the green. It was thus clearly shown that quality of light as such, aside from its intensity, has a considerable effect on the general growth and development of the plant and that the earlier contention, that the blue violet part of the spectrum is necessary for normal growth was correct.

EFFECT OF ULTRA VIOLET RAYS ON PLANTS

Biological studies with ultra violet rays have attracted so much attention in recent years that a few statements regarding the influence of these rays on plants are of interest.

The intensity of the ultra violet part of sunlight, as received on the surface of the earth, is comparatively low, and none of the shortest rays are present. For this reason studies in this part of the spectrum are usually made with artificial light sources, and among these, mercury vapor lamps with quartz tubes have been most frequently used.

The earliest biological work with ultra violet rays was done with single-celled, microscopic organisms and especially with bacteria. Such organisms are very rapidly killed by these rays. This fact has been made use of in the sterilization of potable water and other liquids and in phototherapy. The work with lower

organisms showed that the destructive action of ultra violet rays increases as the wave length decreases and that this action is independent of temperature.

We have already seen in the foregoing paragraphs that ultra violet rays are probably not necessary for normal plant growth and development. When plants are placed under a source of light rich in these rays, it is found that the rays are not only not useful, but decidedly destructive. A two to three hour exposure is often enough to kill leaves. Examination of the internal structure of leaves killed in this way has shown that the rays seldom penetrate beneath the outer layers of cells. For this reason, parts of plants having a thin epidermis are killed most rapidly. Ultra violet rays also cut down the rate and amount of germination of many seeds and rapidly kill young seedlings.

It has been found that ultra violet rays cause a decomposition of sugars, starch, inulin, cellulose, organic acids and other substances found in plant cells. Many enzymes are also inactivated while in other cases an action somewhat similar to enzyme action has been induced by ultra violet rays. If such reactions take place within the plant cell it is conceivable that the protoplasm might be completely disintegrated or that, at least, reactive chemical compounds may arise that would prove inimical to the plant.

Schanz, in discussing the fact that plants grown at high altitudes are usually dwarfed and have structural characteristics different from those of plants grown in lowland regions, attributes these differences largely to a greater intensity of ultra violet rays in high altitudes. He calls attention to the Swiss Edelweiss, which in high altitudes is definitely dwarfed but when removed to lowlands becomes a tall plant, and states that

the same effect is produced by artificial elimination of ultra violet rays.

Leaves and flowers grown in high altitudes have greater amounts of red and yellow pigments than those grown in lowlands. This increased production of color has been explained as a protective measure of the plant against a greater intensity of ultra violet rays in high altitudes. It is doubtful, however, whether the characteristics of such plants can be attributed mainly to ultra violet rays. The French botanist, Bonnier, whose researches in this field covered a period of almost 50 years, has shown that temperature and moisture relations in high altitudes are also very potent factors. Furthermore, it is only the shorter rays of ultra violet, which are not present in any quantity in sunlight even at high altitudes, that are destructive to plants. It has been shown elsewhere that removing only the ultra violet rays of sunlight was almost without effect on plants. If the whole blue violet end of the spectrum is considered, however, most of the changed characteristics of plants attributed by Schanz to ultra violet rays could be accounted for in so far as light is concerned.

CARBON DIOXIDE

The amount of carbon dioxide in the air varies, according to Lundegardh's compilation (1923) of a great number of determinations made on land in various parts of the world, from .0256 to .0329 volumes per cent. The average is approximately .03%. The plant is dependent upon this small amount of gas in the air for the carbon which it fixes. The amount depends on the proximity of the observer to sources of carbon dioxide such as the burning of coal in great cities, breathing of animals, etc., and his relation to the places

where the gas is being used or absorbed. Air over sea water or winds coming from the sea contain less carbon dioxide, according to Lundegardh. Samples of air from the cold antarctic ocean region contained only .0190 volumes per cent. Schloesing in 1880 advanced the theory that the ocean is the regulator of carbon dioxide. It absorbs the gas as bicarbonate of the common alkali metals, and releases it again depending on the concentration and relative temperature of the air so that equilibrium is always maintained. When we consider that approximately three-fourths of the earth's surface is water we can see how effective is such a regulator. Higher temperatures of the past ages, no doubt, operated toward increasing the amount of carbon dioxide in air, and the fossil remains of palms and other tropical plants in Greenland give evidence that even the Arctic circle once had a tropical climate.

Since the atmosphere contains approximately only .03%, or three parts of carbon dioxide in 10,000 of air, let us examine in greater detail the effects of increasing this concentration. We have already seen in the discussion of the effects of light on plant growth that when extra light is added to the ordinary spring day wheat will head much earlier, and, further, when carbon dioxide concentration is also increased to .3%, or ten times the normal concentration, a much greater yield of both grain and straw is obtained. This applies similarly to barley, oats, red clover and a great many of our common agricultural plants. A luxuriant crop of clover hay has been grown in the greenhouse from seed in the brief time of two months with additional light and carbon dioxide; a crop which takes two seasons' growth to produce under our present system of agriculture.

PRACTICAL APPLICATION

The forcing of plants with artificial light has no immediate practical application in the field on account of its excessive cost, but with the advent of more efficient electric lighting and cheaper current rates, science of the future may find a way of effectually illuminating whole fields of growing crops. The first application of such intensive agriculture, if there is an application, will no doubt be to plants growing in greenhouses. This affords an opportunity of increasing the amount of carbon dioxide in air at a reasonable cost and holding it without interference from winds and other climatic conditions. The largest problem in this connection is to provide light at a low cost which does not diminish in intensity with the age of the lamp, and which requires little or no attention during operation. Increasing carbon dioxide concentration of the air has already been carried to the field. Riedel (about 1918), at Essen, Germany, purified flue gases which he obtained from a steel factory, and piped the carbon dioxide produced in this way into adjoining fields of sugar beets. He reported greater growth and yield of beets treated. The gas is heavier than air, and where there is little wind will remain among growing plants long enough to be partially absorbed by them. This is another way in which chemistry is able to utilize the waste of great industries and at the same time get rid of a problem of all population centers, the smoke nuisance. It also furnishes nature with a short cut in the carbon cycle, whereby the carbon which was fixed from the air in the form of wood or coal can be burned and given back directly to the plant to be fixed again.

PROBLEMS OF THE FUTURE

It can be safely stated that no man, were he given

the opportunity, could choose an illumination, a carbon dioxide concentration, temperature, humidity and a soil which would produce a single mature plant in the shortest possible time. After considerable study of the effects of various external factors on the growth and metabolism of plants, Blackman wrote:

“It will be generally conceded, I think, that the way of those who set out to evaluate exactly the effects of changes in a single factor upon a multi-conditioned metabolic process is hard, and especially so when the process is being pushed towards the upper limits of its activity.”

The literature of plant science contains many articles setting forth attempts at evaluating approximately the effects of single factors. Leaves, stem terminals, and even whole plants, have been studied over short periods of time under different concentrations of carbon dioxide with different intensities and qualities of light and at many temperatures. The metabolic processes have been pushed toward their upper limits of activity in this way for a short time. Men have studied the effects of growing plants throughout their life cycle in increased concentrations of carbon dioxide, but have neglected entirely the other factors limiting the rates of plant metabolism. Plants have also been grown under continuous artificial illumination from seed to seed with no additional carbon dioxide, and temperature controlled only within wide ranges. Up to the present time, however, either apparatus was not available or funds were insufficient for purchasing equipment to control all of the main factors of the plants' environment and to hold these factors constant over long periods of time. With standard air conditioning machinery it is now possible to control both temperature and humidity of the air within narrow

limits throughout the growing season of the plant. Artificial illumination is available also, the intensity and quality of which can be held far more constant than sunlight during the growing season.

With this excellent equipment which modern science has produced, the plant scientist of the future has before him the difficult problem of determining the effects of single environmental factors and all combinations of factors on plant metabolism. The solution of this problem will yield facts of most fundamental importance to world agriculture. Application of these facts we will leave to the Edisons of the future.

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CHAPTER III

SOIL LIFE

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In the history of the earth there came a time when the temperature of the ocean was low enough to permit the existence of living things. There appeared then lowly forms of life, among them organisms that could subsist on very simple chemical compounds. Bacteria, capable of deriving the energy necessary for growth and multiplication from the oxidation of sulfur, hydrogen, ammonia, methane, carbon monoxide, iron and of other elements and simple compounds, were thus the forerunner of more complex and more specialized forms of life. The emergence from the ocean of areas of rock, the weathering and disintegration of the rock surfaces, the migration of microorganisms and primitive plants into the firm medium, the accumulation of a mantle of soil and the further adaptation and specialization of the soil microorganic life are all a part of the story of the genesis of the land, of plants, animals and of man himself.

THE HISTORY OF SOIL MICROBIOLOGY

Soil microbiology finds its beginnings in the growth of scientific inquiry. A Dutch lens grinder, Antonina

van Leeuwenhoek, confirmed the suspicions of older students when he demonstrated (1683) the existence of very minute organisms in water, saliva and other substances. The gradual improvement in the construction of microscopes, as well as in the technique of the study of microorganisms, slowly but surely broadened the knowledge of microorganisms. During a portion of the eighteenth century much was said and written about spontaneous generation. The minute forms of life revealed by the microscope were thought to be capable of arising spontaneously out of dead matter. While it was subsequently shown that bacteria and other microorganisms cannot arise in a sterile medium, the theory of spontaneous generation helped to bring about a better understanding of the nature of microorganisms and of their activities.

During the first half of the nineteenth century much attention was given by chemists to the processes of decay, putrefaction and fermentation. Liebig and his followers believed that the decomposition of organic matter was purely a chemical process. Pasteur and his school maintained that decay and fermentation are largely the work of living organisms. The biologists and biochemists finally made good their claim. Meanwhile our understanding of the factors involved in plant growth was broadened and clarified and an important place was assigned to soil microorganisms as a primary factor in the providing of food for plants.

To men like Koch, Hansen, Beijerinck and Winogradsky we owe much of the technique and methods used by the soil microbiologist. It was indicated already by Pasteur in the 60's of the last century that the formation of nitrates might be due to the activities of microorganisms. The actual demonstration that nitrification is a biological process was furnished by

Schloessing and Müntz in 1877. In a similar way it was shown in the early 80's that the reduction of nitrates in the soil, frequently referred to as denitrification, is largely the work of microorganisms. It was also shown by Berthelot, Winogradsky, Beijerinck and others that bacteria living in the soil are capable of making nitrogen compounds out of free nitrogen. The symbiotic relations of bacteria and plants of the legume family was shown to be a factor of great economic importance by French, German, English and American investigators. The work of Wollny and others helped us to see more clearly how microorganisms influence the circulation of carbon between the atmosphere and the soil. In brief, it had been clearly established before the end of the nineteenth century that microorganisms are directly concerned in the migrations of carbon, hydrogen, nitrogen, sulfur and of a number of mineral ingredients of the earth's surface. It had also been demonstrated that soil microorganisms are a major factor in the maintenance of vegetation on the earth's surface.

THE SOIL AS A CULTURE MEDIUM

Soil formation is a gradual process. Rock material, under the influence of weathering, gradually crumbles into fragments of varying size. Temperature changes, the leaching action of rain, oxidation and reduction, all contribute to the disintegration of the rock fragments into smaller particles. Microorganisms and higher plants gain a foothold in this partly disintegrated material. The rock residues are enriched by the additions of the remains of plants and animals, and the resulting product is then recognized as soil. The depth of the soil itself, as well as its texture and

chemical composition, are determined by the element of time, the amount and distribution of rainfall, seasonal and climatic changes and the nature and extent of vegetation, as well as by the character of the original rock material. It is apparent, therefore, that the soil is in a dynamic condition and that the age of the soil and its history have a direct relation to its ability to support plant life.

It is easy to conceive of a soil as a mass of particles of varying degrees of fineness. These particles are separated by spaces filled partly with air and partly with water. Each particle is surrounded by a film of moisture of varying thickness. Within this film soil microorganisms are active. They multiply rapidly or slowly, in accordance with the concentration of salts in the moisture film, the oxygen pressure, temperature, the presence or absence of toxic substances and the growth of higher plants. But since the soil particles differ both as to size and chemical composition, it may be said truly that the soil is a mixture of culture media rather than a single culture medium. Since particles of granite, limestone, feldspar and silica all differ in their composition, the concentration and quality of the films surrounding these particles would also vary. In the same way, moisture films surrounding particles of plant or animal residues would show marked differences in composition. The microorganic flora found in the film surrounding a particle of limestone would be expected to differ from that in a film surrounding a minute fragment of plant root or of insect wing. The more or less intimate contact of the moisture films enveloping individual particles tends to work toward an equilibrium in the character of the soil solution as a whole. The equilibrium is very seldom if ever reached, for the activities of living organisms and the

variations due to unequal distribution of moisture and oxygen tend constantly to disturb this equilibrium.

Bacteria are numerically the most important constituent of the soil micro-flora. Fungi, protozoa, yeasts and algae are present in varying numbers, depending on the chemical nature of the soil material and the environment in which it finds itself. Aside from these, nematodes, earth worms and soil-infesting insects are more or less common and more or less important. By far the larger proportion of the soil microorganisms may be found within the upper five to six inches of soil. The largest number per gram of material is usually found between two and four inches from the surface. This, however, will vary as between humid, semi-arid or arid regions. The number of soil microorganisms tends to decrease with the increasing distance from the surface, until at a depth of three or four feet very few bacteria are found in humid soils. In semi-arid and arid soils, especially those receiving the benefits of irrigation, relatively large numbers of microorganisms may be found at greater depths. There is a direct relation between the amount and quality of the organic matter in the soil and the numbers and distribution of microorganisms. Since a relatively large proportion of the organic matter is present in the upper six inches of soil, one should expect a corresponding proportion of microorganisms to be found in the surface soil. Aside from the organic matter, the factors that tend to influence the distribution of soil microorganisms are those of oxygen supply and plant root distribution. Indeed, it has already been demonstrated that root hairs are colonized by microorganisms and that presumably root hairs of different plants will carry relatively different numbers and species of microorganisms. In a general way, it may be said that the number of micro-

organisms in any given soil will vary from season to season. The drying out of the soil will cause the death of many of the soil bacteria. The lowering of the soil temperature will slow down their activities and lead to a reduction in their numbers. It is for this reason that soil samples taken at regular intervals in any particular area will show variations both as to numbers and species. There is a gradual increase in the numbers of microorganisms from early spring to summer and a decrease from late summer to mid-winter. Aside from seasonal variations, the differences in total numbers and the prevalence of one or more species are brought about by cultural methods, such as tillage and irrigation, liming and manuring and the use of chemical fertilizers. It should be evident from what has been said above that the activities of soil microorganisms must be influenced by soil treatment, and by the extent and character of the crops growing on the land.

THE WORK OF SOIL MICROORGANISMS

The average acre of cultivated land contains in the humid regions about twenty tons of organic matter. This is made up of recent, or more or less ancient, remains of plants, microorganisms, insects and animals. The organic matter is constantly under attack by microorganisms, most of which depend on it for food. Being largely of plant origin, the organic matter is made up of carbohydrates, proteins, fats, organic acids and other compounds more or less commonly found in plants. The breaking down of these substances leads ultimately to the formation of carbon dioxide, water, nitrates, sulfates, phosphates, carbonates and chlorides. Ultimately, therefore, organic residues in the

soil may become entirely mineralized and the carbon, representing approximately one-half of the total dry matter of plant substances, returned to the air. The rate of decomposition will obviously be determined by the soil environment as well as by the nature and origin of the organic matter. In soils of open texture, plant residues are decomposed very rapidly. Indeed, these very open, well-aerated soils are often the despair of the farmer. They are notorious for their inability to retain, for any considerable length of time, the organic matter incorporated in them. In extreme cases the decomposition of the organic matter is so rapid as to make profitable cultivation impracticable. Much land of this character is found along the Atlantic seaboard. Because of their open textures, the exchange of gases in them is rapid, and aerobic organisms are able to mineralize plant and animal remains in a relatively short time. On the other hand, in the fine-grained soils there is a tendency, under the same circumstances, toward the accumulation of organic matter. The supply of oxygen, particularly in the upper layers of the soil, is not sufficiently great to allow intense activity by aerobic organisms. On the other hand, anaerobic organisms are relatively more prominent in such places. We must recognize, thus, that in the average soil there are factors which make for the accumulation of organic matter; on the other hand, there are other factors which make for the disappearance of the organic matter. The relative prominence of these factors will determine whether a soil will lose organic matter faster than it accumulates it.

Any condition which will tend to intensify bacterial activities will hasten also the decomposition of organic matter. Tillage, liming, the use of fertilizer salts, higher temperatures and an optimum supply of water

will speed up the chemical changes produced by microorganisms. On the other hand, lessened aeration due to excessive rainfall, the seeding down of grass, sub-optimum temperatures and the dispersion of soil colloids will favor the accumulation of organic matter. In such less well-aerated soils intermediate products will tend to accumulate. In the older treatises on soils the more or less dark colored organic residues in the soils are referred to as humus. This consists of vegetable material in various stages of decomposition. It has been shown that the carbon-nitrogen ratio of the organic matter in the surface soil is much wider than is that of the organic matter in the subsoil. It is usual to find ten to twelve parts of carbon for every part of nitrogen in the surface soil, whereas in the subsoil there are often no more than five to seven parts of carbon for every part of nitrogen.

When vegetable and animal substances are attacked by microorganisms, carbon dioxide and ammonia appear almost at once. The ammonia does not accumulate in the soil, but is further oxidized to nitrous and nitric acids. The final product in the soil solution is some form of nitrate, usually calcium nitrate. The process of nitrate formation from organic matter is known as nitrification. The microorganic activities entering into this process are in part highly specialized. The number of bacteria and fungi which can produce ammonia from proteins and from their cleavage products is very large. On the other hand, the ability to oxidize ammonia to nitrous acid is limited to only one or two species. The same is true also of the oxidation of nitrous to nitric acid. In the ordinary cultivated soil nitrate formation goes on rather rapidly. Where the supply of organic matter is limited, twenty-five to fifty pounds of nitrogen per acre is

transformed into nitrates in the course of a single growing season. In soils more amply supplied with organic matter and nitrogen, as much as 100 to 150 pounds of this element may be changed into nitrates. The reaction of the soil, the amount and distribution of rainfall and the range of soil temperature are important contributing factors.

The sulfur contained in the organic matter is oxidized to sulfuric acid, and the phosphorus to phosphoric acid. We thus have carbonic, nitric, sulfuric and phosphoric acids derived from vegetable residues and capable of reacting with the mineral portion of the soil. A part of the calcium, magnesium, potassium, sodium, iron and aluminum present in the soil silicates will combine with these acids, giving rise to carbonates, nitrates, sulfates and phosphates. It is to be expected that, under such conditions, the surface soil would lose substantial amounts of basic material. An analysis of drainage waters will substantiate this assumption. The study of the composition of surface waters will furnish additional evidence that the land is giving up to the sea very large amounts of calcium, magnesium, sodium, potassium, etc. Directly or indirectly, soil microorganisms are the factor responsible for the migration of a very considerable part of this material from the land to the sea. The significance of these changes for the nutrition of plants will be noted later.

As has been pointed out, it is the function of soil microorganisms to restore to circulation the elements locked up in plant and animal residues. We should, therefore, recognize that soil microorganisms play an essential part in making possible the continuance of life on the earth. They not only help to maintain dynamic conditions in the soil, but they also help to improve

the soil as a culture medium for higher plants. Moreover, soil microorganisms are not alone concerned with the transformation of organic and mineral substances in the soil. They are directly or indirectly responsible also for increasing the store of combined nitrogen.

One of the most interesting chapters in the history of soil and plant chemistry is that which has to do with the source of nitrogen for vegetation. In an empirical way, farmers recognized centuries ago that certain crops had the ability not only to grow in soils where other crops do not thrive, but also to improve the land to a point where the following crops seemed to be decidedly larger and better. When, at the beginning of the nineteenth century, general and analytical chemistry had advanced to a point where fairly accurate analyses could be made of soils and plants, the question became more insistent as to the source of nitrogen supply for vegetation. The French chemist, De Saussure, demonstrated to his satisfaction, at the beginning of the century, that plants could not utilize elementary nitrogen. In accepting his claim, it was therefore necessary to assume that crops derive their nitrogen supply from compounds furnished by the air, the soil, or both. Analyses of samples of air raised the question as to the adequacy of the ammonia or nitrates present in it for meeting the nitrogen needs of wild and cultivated plants. Similar analytical work on samples of soil indicated that the nitrogen supply of the latter was rather limited. This led to a far-reaching inquiry by chemists into the question of the nitrogen supply of plants. Various theories were advanced to account in a purely chemical way for the supply of combined nitrogen in nature. One after another, these explanations were found to be far from convincing. Liebig himself believed that the ammonia

content of the atmosphere was sufficiently great to supply the needs of at least all broad-leaf plants.

The scientific as well as the economic significance of this question forced much investigation and was productive of much controversy. The French investigator, Boussingault, was apparently able to show that he could maintain a satisfactory nitrogen balance in his soils when legumes were included in his rotations. He thus confirmed the belief existing among farmers that clover and other leguminous plants could in some way add to the nitrogen supply of the soil. Carefully planned experiments at the Rothamsted Station, carried out under the direction of Gilbert, seemed to furnish absolute proof that clover, like other plants, was unable to utilize elementary nitrogen. Thus, the second half of the nineteenth century brought out the striking contrast between empirical practice and the findings of the agricultural chemists.

At the beginning of the last quarter of the century microbiology had made sufficient progress, both as to the body of knowledge and technique, to offer helpful methods for reconciling the apparently hopeless contradiction between theory and practice. The presence of minute cells in the nodules of leguminous plants had been demonstrated repeatedly by botanists. Some of them came to believe that there might be some connection between these bodies and the ability of legumes to enrich the soil in combined nitrogen. Atwater and Woods, in the United States, developed certain experimental data which offered a basis for the satisfactory accounting of the ability of legumes to utilize atmospheric nitrogen. A definite and satisfactory explanation was given by Hellriegel and Wilfarth. They showed that the so-called nodules of legumes are produced by the entrance of certain microorganisms into

the root hairs. They demonstrated, likewise, that in the absence of these organisms nodules are not formed and legumes are not able to utilize elementary nitrogen. In 1889 the Dutch botanist, Beijerinck, isolated pure cultures of this organism and called it *Bacillus radicicola*. Since that time a large mass of conclusive evidence has been developed to show that the circulation of nitrogen between the soil and the atmosphere depends in large measure on the bacteria capable of associating themselves with legumes in the utilization of atmospheric nitrogen and the formation of nitrogen compounds. The story of the biological fixation of nitrogen would not be complete without reference to the work of the French chemist, Berthelot, who seems to have proved that the quantity of combined nitrogen in the soil may be increased in the presence of soil microorganisms capable of carrying on their processes directly in the soil. Toward the end of the century it was definitely established by Winogradsky that certain species of butyric acid bacteria are able to fix atmospheric nitrogen under anaerobic conditions. At the beginning of the present century Beijerinck showed that organisms of the azotobacter group are able to fix atmospheric nitrogen under aerobic conditions. Since that time it has been established that, aside from the organisms already mentioned, there are others which in a greater or lesser degree have the ability to make nitrogen compounds out of elementary nitrogen.

BACTERIA AND THE NITROGEN CYCLE

Very considerable quantities of combined nitrogen are found in the earth's surface. These nitrogen compounds are of air origin. Soils of fair quality usually contain about .1 per cent of nitrogen. Assuming that

the surface soil of each acre will weigh, when dried, approximately two million pounds, we find an equivalent of one ton of nitrogen per acre. Poor soils will contain less; and productive soils, considerably more. Good loam soils are usually expected to contain at least two tons of nitrogen per acre. This is present in organic residues. When the latter are attacked by microorganisms, ammonia and nitrates are formed, as has already been noted. The ammonia and nitrates are in part taken up by vegetation and in part leached out of the soil. The nitrogen content of the land is thereby diminished. The loss may be offset by the growing of legumes, by creating conditions in the soil favorable for the fixation of nitrogen by bacteria living directly in the soil, and by the application of manures and fertilizers. In dealing with cultivated soils we must, therefore, so adjust our practice as to allow, on the one hand, the most effective and economical transformation of nitrogen compounds in the soil, and, on the other, the most effective and economical utilization of atmospheric nitrogen. When organic matter begins to undergo decomposition, a part of the ammonia formed is changed back into protein compounds by bacteria, fungi and other microorganisms. This portion thus withdrawn from circulation may amount to only one or two per cent of the total, or it may be equivalent to more than half of the total nitrogen appearing as ammonia. The ammonia not otherwise used is changed by nitrous and nitric bacteria into nitrous and nitric acid, respectively. These acids combine with basic material in the soil, giving rise to nitrites and nitrates. The nitrates are likewise used in part by bacteria and other microorganisms and the supply of combined nitrogen for use by higher plants is thus still further reduced. Evidently, therefore, our meth-

ods of soil treatment should be such as to prevent the competition for nitrogen compounds between microorganisms and higher plants. The processes of ammonification and nitrification may be controlled in such manner as to reserve a maximum supply of ammonia and nitrates for the crop. For example, when excessive quantities of manure or straw are applied to the land, the carbohydrates contained in these materials would stimulate the activities of certain bacteria to a point where most, if not all, of the ammonia and nitrates would be readily changed back into the bacterial cell substances and thus made unavailable to crops. It is, therefore, one of the problems of the farmer to see to it that the energy material available to soil microorganisms be kept down to a point where there would be no interference with the obtaining of a satisfactory supply of nitrogen by the crop. It may also be noted here that where the oxygen supply in the soil is decreased beyond a certain point the nitrates may be reduced to nitrites, to ammonia, and even to elementary nitrogen. Also in this case, the supply of combined nitrogen for the crop may become less adequate. In a word, then, bacteria are a vital factor in the transformation of nitrogen compounds in the soil. The process of transformation itself is capable of modification, and such modification may be favorable or inimical to the crop.

The process of nitrogen fixation, like that of nitrogen transformation, can also be controlled more or less effectively. In the first place, it should be remembered that the bacteria which enter the roots of legumes, as well as those which are able to fix atmospheric nitrogen but do not associate themselves with higher plants, persist in the soil whether legumes are being grown on it or not. It is well known among

farmers that, when land is once inoculated for alfalfa, subsequent inoculations are usually unnecessary, even though there may be an interval of many years between two crops of alfalfa. This means that *Bacillus radicumicola* can survive in the soil indefinitely, even though its host plant may not be present. In fact, it has been demonstrated that the organism can not only survive in the soil, but actually multiply there, and that it can fix at least small quantities of elementary nitrogen when living outside of the plant roots. In the case of azotobacter and other nitrogen-fixing organisms not entering into association with legumes, the soil is the primary medium. In the case of all of these organisms, it is, therefore, necessary to make the medium a favorable one in order that biological nitrogen fixation may be maintained at its best. More recent investigations have demonstrated that there is an optimum soil reaction for these organisms. It has also been shown that the amount and quality of the organic matter, the nature of the soil colloids and the rate of gas exchange between the soil and the air influence more or less materially the activities of nitrogen-fixing organisms and, therefore, the rate of nitrogen fixation.

Among the legumes themselves there is a wide range of effectiveness from the point of view of nitrogen fixation. In the case of cowpeas, the amount of nitrogen fixed during the growing season may be no more than 10 to 15 pounds per acre. In the case of alfalfa or sweet clover, it may be as much as 200 to 300 pounds per acre. But even for any given plant there seems to be the best adjustment between the bacteria and the host. Individuals and strains, both of plants and bacteria, seem to differ in their effectiveness. The farmer has learned that the intelligent use of lime, of phosphate and potassium fertilizers, and of suitable tillage

methods, will create more favorable conditions for the accumulation of nitrogen with the aid of leguminous crops. In some regions the supply of sulfur is also a factor of significance in this connection. Since sulfur is an indispensable constituent of protein, there is a more or less definite relation between the sulfur supply and the amount of nitrogen fixed by legumes. Where a sufficient quantity of sulfur in combined form is not furnished by the soil, the use of sulfur carrying materials becomes necessary, as has been found to be the case in certain localities in Oregon, Washington, Idaho and California. Indeed, in any locality where commercial fertilizers are not used, a deficiency of sulfur for legumes may now and then arise. All told, therefore, bacteria bear a peculiar relation to the nitrogen cycle in Nature, and for this, if for no other reason, they are an essential part of our soil fertility structure.

THE MOBILIZATION OF OTHER INGREDIENTS OF PLANT-FOOD

The amount of carbon assimilated by a crop growing on an acre of land often amounts to one ton. Under exceptional conditions, as much as eight to ten tons of carbon per acre may be assimilated in the course of a single growing season. Such extremely favorable conditions for the assimilation of large quantities of carbon are found in the tropics. A striking illustration of this sort is found in the enormous tonnages of sugar cane per acre produced in Hawaii. It is obvious that an abundant supply of carbon dioxide must be available if vigorous growth is to occur. In view of the fact that the atmosphere contains only .03 to .04 per cent of carbon dioxide, there must be some

effective agency or agencies for renewing the supply of carbon dioxide in the air as it is being depleted by the rapidly growing vegetation. Processes of combustion, the metabolism of plants and animals and the activities of microorganisms serve to maintain the necessary supply of carbon dioxide. The last-named factor is particularly important. Microorganisms are able to use carbohydrates, organic acids, alcohols, proteins and other organic compounds as a source of energy. The metabolic processes of microorganisms are, therefore, a potent means in the mobilization of carbon. Under some conditions, the supply of carbon dioxide in the atmosphere may not be adequate. In greenhouses and in gardens, where the most intensive methods of plant culture are followed, the artificial addition of carbon dioxide to the air serves to stimulate plant development, as has been repeatedly shown by a number of investigators.

A part of the carbon dioxide produced by microorganisms is used up in the formation of carbonates and bicarbonates. It has already been noted that large quantities of calcium, magnesium and of other constituents of rocks are removed from the land and carried to the sea. It may, therefore, be said with propriety that microorganisms are geological factors of very considerable significance. They not only play a part in the disintegration of rocks, but also in the gradual depletion from the land of basic substances.

A very considerable degree of specialization is found among microorganisms in respect to their ability to use different carbon compounds as a source of energy. It has been shown that specific types of bacteria are able to oxidize hydrogen, methane and carbon monoxide. The existence of such species of bacteria will serve to account for the practical absence of these

substances in the atmosphere, even though very considerable quantities of methane and hydrogen are produced in anaerobic fermentation which occurs in swamps, mud flats, the bottom of lakes and seas and in manure piles. The existence of such microorganisms will also account for the disappearance of these gases emitted from volcanoes and fissures in the earth's surface.

The mobilization of sulfur is also due largely to microorganisms. Species have been isolated that are capable of oxidizing sulfur to sulfuric acid. Other species are known to have the ability to oxidize hydrogen sulfide, carbon bisulfide and other sulfides. The growing plants obtain their sulfur from the soil largely in the form of sulfates. These are built into proteins and other sulfur compounds. When plant tissues are attacked by microorganisms sulfur dioxide, hydrogen sulfide, or both, may be formed. The types of microorganisms concerned in the decomposition processes will determine the nature of the changes which sulfur-containing substances will undergo. Ultimately, however, the sulfur will appear in the form of sulfates provided the supply of oxygen is adequate. The sulfates appearing in the soil solution are in part absorbed by plant roots and in part removed in the drainage waters. Some of the sulfur escapes into the air as hydrogen sulfide or as sulfur dioxide. These are later returned to the soil by atmospheric precipitation, and may then pass through the usual cycle in which bacteria play so important a part.

The mineral portion of all soils undergoes progressive changes, which ultimately involve the more or less complete removal of basic materials. The acids produced by microorganisms (particularly carbonic,

nitric and sulfuric acids) react with basic substances to form the corresponding salts. Thus, calcium, magnesium, potassium, sodium, iron and aluminum are more or less effectively removed from the soil silicates. In the so-called mature soils, silica becomes a prominent residue.

RELATION OF MICROORGANISMS TO HIGHER PLANTS

Plants find a large portion of their food in the soil solution. Indeed, it is only in so far as the substances found in soils become water-soluble that they are able to contribute to the growth of plants. Materials removed from the soil solution by plant roots are gradually replenished from the soil reserve of inorganic and organic compounds. The rate at which these pass into solution is determined by the effectiveness of the microbiological machinery found in soils. The microorganisms, in their turn, are affected by environmental conditions, such as temperature, the supply of oxygen, the hydrogen ion concentration of the soil solution, the presence or absence of toxic substances, and particularly the quantity and quality of the organic matter. Everything being equal, the higher the proportion of nitrogen in organic matter, the more effectively is it attacked by microorganisms and the greater the supply of nitrogen for the plants growing on the land. The factor of competition and associative action among the microorganisms themselves is of direct significance to vegetation. It has been shown that soil bacteria are the prey of flagellates, amoebae and other protozoa. Indeed, it is claimed by some investigators that, by controlling the number of bacteria protozoa become a rather important soil fertility factor. It has been shown, likewise, that there is com-

petition between bacteria and fungi as well as competition among different species of bacteria. On the other hand, the activities of some species of microorganisms are markedly stimulated by the presence in the medium of other species. These relations directly influence the efficiency of the soil microbiological machinery in creating an adequate supply of available plant food.

In a certain sense, there is competition between higher plants and microorganisms. A part of the soil nitrogen in the form of ammonia or nitrates is used up by microorganisms, and, to that extent, placed beyond the immediate reach of plants. In a lesser way, phosphorus, sulfur and calcium are withdrawn from the soil solution for the building of cell substances by microorganisms.

In the processes of decomposition of organic matter, substances may be produced which tend to depress plant growth. Organic compounds toxic to plants have been isolated from soils. Aluminum nitrate, and other soluble aluminum compounds, have been shown to be toxic to plants. Hence, in soils of high hydrogen ion concentration, the activities of microorganisms may cause more or less serious interference with plant growth.

The phenomenon of parasitism must also be reckoned with when the relations between higher plants and microorganisms are considered. The mycologist and plant pathologist have described a large number of so-called plant diseases. They have demonstrated that the pathogens may persist in the soil for longer or shorter periods of time, and that the success of the farmer may depend on the presence or absence of these organisms. The losses to agriculture caused by these parasites are truly enormous. They have given rise

to investigations of the organisms themselves as well as of soil conditions affecting their survival and activities. Methods of soil treatment have been developed which aim to lessen the damage done by this portion of the soil microorganic flora. Crop rotations and the use of disinfectants, on the one hand, and selection and breeding of resistant or immune varieties of plants have been the direct outcome of such investigations.

CONTROL OF SOIL LIFE

Within the past twenty-five years, much progress has been made in the discovery and application of methods for the effective control of soil microorganisms. Since the supply of oxygen in the soil is of direct importance in this connection, drainage and tillage are resorted to. Where the supply of water is inadequate for establishing optimum conditions for microorganisms as well as for higher plants, irrigation water is applied. By changing the hydrogen ion concentration of the soil solution, the farmer is able to increase or decrease the numbers of soil bacteria and to modify the relations among the different species of microorganisms. The use of lime and of other basic materials is widely recognized as a means of decreasing the acidity of soils. On the other hand, the use of ammonium sulphate, of sulfur and of other substances is recommended for increasing the hydrogen ion concentration of the soil solution where this may seem desirable from the standpoint of plant food supply and the control of pathogenic organisms.

Chemical fertilizers, being largely water-soluble, readily affect the concentration of the soil solution. Nitrates, ammonium salts, soluble phosphates and salts of potassium become thus an effective means for influ-

encing in a more or less far-reaching way the activities of soil microorganisms. Small quantities of nitrates or of phosphates are often used for raising the efficiency of the biological machinery of the soil and for increasing the degree of change in the soil constituents. In a sense, therefore, certain fertilizer practices affect the microorganisms directly and growing crops indirectly.

Animal manures, by supplying organic matter, furnish a source of energy to microorganisms. They also affect the soil reaction and thereby modify the supply of plant food. It is recognized, moreover, that the enormous numbers of bacteria present in manure are a factor of importance. An application of manure may be regarded as a means of inoculating the soil and of intensifying for a time the decomposition of soil organic matter. In the case of clovers, vetches, soy beans and of other plants used as green manures, bacterial activities are stimulated because of the relatively large amounts of organic matter introduced into the soil. All told, therefore, practices of drainage, irrigation, tillage, liming, fertilization and manuring modify more or less directly the effectiveness of the soil microflora as a soil fertility factor.

Another practice which serves to disturb soil microbiological activities is that designated as partial soil sterilization. Carbon bisulfide, formaldehyde, sulfate of copper and mercury compounds are now and then used for ridding the soil or seed of a large part of their microorganisms, including species that may be inimical to cultivated plants. The use of carbon bisulfide and formaldehyde for the disinfection of greenhouse soils is now fairly common. Also, steam under pressure is not infrequently used for the partial sterilization of greenhouse soils and of hotbeds. Under

natural conditions, there is partial sterilization of the soil where it is exposed to long periods of drought and of abnormally high temperatures. Such conditions occur in arid and semi-arid regions.

Soil inoculation, that is, the introduction of large numbers of specific organisms, is also a fairly common practice. Where alfalfa, soy beans, vetches and other legumes are grown for the first time, cultures of the proper legume bacteria are employed. Where applications of compost or manure are made, the soil is inoculated with a mixture of microorganisms rather than with specific bacteria. Where sulfur is employed for the control of the microorganisms causing scab of potatoes or soil stain of sweet potatoes, efficient sulfur-oxidizing bacteria are now and then used to hasten the oxidation of the sulfur and the formation of sulfuric acid. In newly reclaimed marsh areas, fertile loam soil is occasionally scattered on the surface. The purpose of this is to introduce large numbers of nitrifying and other bacteria likely to be deficient in such soils.

Finally, it may be noted that activities of soil microorganisms may be stimulated by the use of very small amounts of compounds of copper, zinc, mercury, manganese, arsenic and of other substances. This phase of soil research is still in its infancy, but enough has already been done to prove that the use of these stimulants may be a direct means of modifying the soil microorganic flora in the direction desired by the farmer. Still other soil practices are already in vogue or will be developed in the future for the purpose of exploiting soil microbiological activities in behalf of the rational and effective utilization of soils for the growing of economic plants.

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CHAPTER IV

WHERE THE NITROGEN COMES FROM

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MAIN SOURCES OF NITROGEN SUPPLY

Growing plants take up from the soil certain so-called mineral foods which are as essential to their growth as sunlight, air and water. A fertile soil must contain a reserve of these substances adequate to the plants' demand, and where crops are removed from the land year after year it is obvious that the soil is being slowly depleted of essential plant foods. Fortunately there is an almost inexhaustible supply of most mineral foods already in the soil, and for practical purposes attention need be turned only to those few substances likely to be lacking. Of such, nitrogen holds first place, followed by phosphorus and then potassium. In relatively rare instances, iron, calcium, magnesium, sulphur, or some other mineral plant food may be deficient.

It may seem curious that there should be anywhere a shortage of nitrogen for agricultural use, for the earth's atmosphere weighs roughly 5333 million million tons and about three-fourths of it is nitrogen. The surface of the earth is bathed in nitrogen continuously, and the soil is in perpetual contact with atmospheric nitrogen. The difficulty lies in the fact that the nitrogen of the air is "free," i. e. not combined chemically



Courtesy of the Anglo-Chilean Consolidated Nitrate Corp

Shipping Mole of the Tocopilla Nitrate Company, Tocopilla, Chile.

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with any other element, whereas plants can assimilate nitrogen only when it is chemically combined, or, as chemists say, "fixed." The problem of nitrogen supply is, therefore, not to find nitrogen but to find "fixed" nitrogen or to find methods of "fixing" atmospheric nitrogen.

There are at least seven sources from which agricultural soil is today securing nitrogen. These may be listed as follows:

1. Nitrogen compounds carried down by rain and snow.
2. Nitrogen captured from the air and "fixed" by bacteria living in the soil or on the roots of legumes.
3. Animal manure, both that produced by domestic animals and that secured from deposits such as the guano found particularly on islands off the coast of Peru.
4. Nitrogenous waste materials such as cottonseed meal, meat packers' scrap, fish scrap, etc.
5. Sodium nitrate from the natural nitrate beds of Chile.
6. Ammonium sulphate produced in the coking of coal.
7. Nitrogen captured from the air and "fixed" by chemical processes.

In the last analysis, probably all of the nitrogen in the above listed sources came from the air, for nitrogen is an element which easily escapes from chemical combination. Once free, its chief characteristic is chemical inertness; only with difficulty can it be made to combine with anything else. Very early in the earth's history the nitrogen must have accumulated in the atmosphere as free gaseous nitrogen, from which source relatively small amounts have since been withdrawn by natural processes to account for the reserve of fixed nitrogen in the soil, in coal, and in such deposits as the Chilean nitrate beds, etc.

NITROGEN COMPOUNDS CARRIED DOWN BY RAIN AND SNOW

Many attempts have been made to measure the amount of fixed nitrogen carried into the soil annually

by rainfall. Most of these measurements have naturally been made in agricultural areas and, as is to be expected, the results vary considerably, but the amount is evidently somewhere around five pounds per acre per year. Since a good wheat crop of, say, 25 bushels per acre, will remove annually nearly 50 pounds of nitrogen per acre, it may be seen that the amount carried down in rainfall is insufficient to keep up the supply. Further, some of the fixed nitrogen found in rain and snow is not nitrogen fixed by electric or other processes in the air but nitrogen which once escaped from the soil as ammonia, later to be dissolved and brought down again. Over this source of nitrogen supply man exercises no control and in any event the amount is not large compared to crop demands.

BACTERIAL FIXATION OF NITROGEN

In the case of most of the mineral plant foods it is a fairly simple matter to determine by chemical methods the amounts in the soil and the amounts removed annually by crops. In the matter of nitrogen supply, however, the problem is complicated by a number of factors. The soil is in contact with air, and while ordinary plants cannot capture free nitrogen from the air and make it available as a mineral food, there are certain bacteria which can do this. On the other hand, natural chemical reactions are always going on in the soil which liberate nitrogen or gaseous ammonia which escapes into air. There comes about in this way a perpetual interchange of nitrogen between the air and the soil, so that the matter of nitrogen supply to crops is a much more complex problem than in the case of other plant foods.

Certain kinds of bacteria can "fix" nitrogen, i. e.

convert free nitrogen into nitrogen compounds. Of these, one kind makes its home on the roots of legumes such as clover, peas, etc. This gives the farmer an opportunity to "grow" his nitrogen, for by simply plowing under a legume crop occasionally or even the non-marketable residues of such crops, the nitrogen content of a soil can be replenished. Of course, this method of getting nitrogen into the soil may involve the substitution of a less remunerative crop than could otherwise be produced and the question then becomes one of deciding whether it is cheaper to "grow" nitrogen or to secure it in fertilizer which can be applied to the soil.

Just how bacteria "fix" nitrogen is not known. Certain it is that they do not use any of the drastic chemical processes by which man has learned to do the same thing. In the early days of chemistry the matter would have been dismissed by the assertion that here was another example of the operation of those "vital forces" by which all organic processes of nature are accomplished. This was really no explanation but merely a removing of the problem from the realm of chemistry. Experience with a wide range of such problems, however, has taught us that there is no difference in kind between the chemical reactions of the laboratory and those of nature. There is still plenty of mystery in the behavior of matter, but it is the mystery of the yet unknown and not of the forever unknowable.

The amount of nitrogen fixed annually by bacteria is enormous compared with that which enters the soil by any other means. We may almost say that nitrogen-fixing bacteria have made agriculture, and indeed all plant life, possible. It is not unlikely that the time may come when the farmer can so completely control

the bacterial life of his soil as to assure an abundant nitrogen supply for crops. But that time is apparently not yet near. The growing of legume crops does give a limited measure of control over the bacterial method of securing agricultural nitrogen and it is possible to encourage bacterial activity in the soil by other means, but it is still highly important for agriculture to have other sources of cheap nitrogen supply.

ANIMAL MANURES AS A SOURCE OF AGRICULTURAL NITROGEN

From time immemorial agriculturists have used animal manures as fertilizer. These contain not only nitrogen, but also the other desirable mineral plant foods—phosphorus, potash, etc., as might be guessed from the fact that the plants used as food by the animals originally drew from the soil the minerals necessary for their growth. It must be remembered, therefore, that using the manure of domestic animals is only a means of returning to the soil a part of the nitrogen taken out of the soil by crops, and such a process can never increase the reserve of nitrogen in the soil. Of some importance is the fact that the farmer has a degree of control over nitrogen distribution on his farm through manuring; for example, the nitrogen fixed in a clover meadow used as pasture may be in part utilized later on a corn field.

Although it is true that the use of animal manures does not build up the nitrogen reserve of the soil, but only decreases the rate of depletion by returning part of the nitrogen removed by crops, nevertheless the importance of the common practice of manuring agricultural land can scarcely be over estimated. Aside from bacterial supply, more nitrogen is returned to the soil in animal manures than through any other agency,

and there are in the aggregate vast agricultural areas where no other form of fertilizer is used. Taken the world over, however, there is far too little of this form of fertilizer available. The supply, moreover, must necessarily decrease as the increasing food demand of the world drives agriculture more and more toward direct production of human foodstuffs.

NITROGENOUS WASTE MATERIALS USED AS FERTILIZER

A number of nitrogenous waste materials have long been used as fertilizer. The early settlers in America noted the Indian custom of putting a little fish in each hill of corn planted. Along the St. Lawrence River many Canadian farmers still follow the practice of using fish as fertilizer, while fish scrap from the sardine industry and from the fish oil plants is a common ingredient of the mixed fertilizers on the market. Cottonseed meal is another common fertilizer ingredient, along with meat packers' scrap, tobacco stems, dried blood, and a wide variety of such materials, known to the trade under the general term "organic ammoniates." All such materials are of value as fertilizer primarily for their nitrogen content, which, unfortunately, is low, only a few percent in most cases. Many of them are now finding more profitable use in stock food and their importance as fertilizers is diminishing. For a long time to come, however, some of these nitrogenous waste materials will find use as fertilizer and this class of substances must be considered as one of the sources of agricultural nitrogen.

CHILEAN NITRATE

For nearly one hundred years, Chilean nitrate has been used as a source of agricultural nitrogen. Begin-

ning with a few thousand tons in 1830, shipments of nitrate from South America reached 50,000 tons per year by the middle of the 19th century. After 1880, when Chile secured possession of the nitrate fields, exploitation of this product for agricultural purposes expanded fairly rapidly, and by 1913 had reached over 2,000,000 tons per year.

The nitrate deposits are located in a long narrow strip of territory on the eastern slope of the coastal range of Chile, in the desert country lying between the coastal range and the Andes. Just how these nitrate deposits came to be there is not definitely known; that is, there has been no theory advanced for their origin which accounts for all the known facts concerning the deposits. The nitrate occurs in patchy deposits or beds, four to twelve feet thick, usually overlain by several feet of sedimentary deposits. The nitrate bearing ore, known as "caliche," is dug up and transported to plants located near the deposits, where the sodium nitrate is extracted by leaching with water. The water solution is evaporated and the nitrate salt dried and transported to the coast for shipment to all parts of the world.

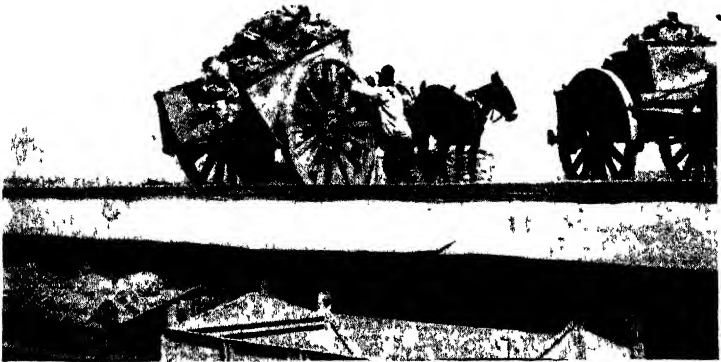
There has been much speculation as to the amount of nitrate contained in the deposits. Many of the estimates have been little more than guesses, due to lack of accurate information as to the extent of the nitrate area, thickness of the beds, etc. On the basis of information now available, however, it is safe to say that the supply will last for more than 100 years at the present rate of consumption and it is probable that the life of the beds will be much longer than this.

The companies producing nitrate in Chile are organized as the "Chilean Nitrate Producers Association" and the price of nitrate is fixed from year to



Courtesy of the Anglo-Chilean Consolidated Nitrate Corp.

Loading "caliche" (nitrate ore) from a pile into a wagon for delivery to the trams which haul it to the plant



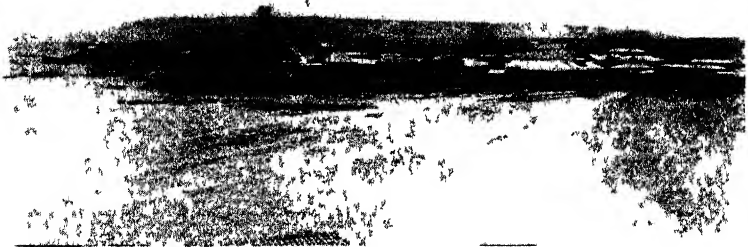
Courtesy of the Anglo-Chilean Consolidated Nitrate Corp.

Loading "caliche" from wagon to railway car for transportation to plant.



Courtesy of the Anglo-Chilean Consolidated Nitrate Corp

Workmen bagging nitrate from the storage pile for shipment



Courtesy of the Anglo-Chilean Consolidated Nitrate Corp

A typical nitrate plant or "oficina" in Chile.

year by this Association. Due to the fact that the Chilean deposits of nitrate are the only ones in the world which can be worked profitably, Chile has had practically a monopoly in the field, and the nitrate business has yielded large profits to the producing companies. The Chilean Government has also shared in the benefits of the monopoly through the export tax of about \$11.20 per short ton, and this income has been one of the chief supports of the Chilean Government since Chile acquired the nitrate fields in 1880. The Chilean Nitrate Producers Association and its predecessors have long maintained agents in a number of agricultural countries of the world, whose business is to promote the use of Chilean nitrate in agriculture.

During the past two decades, the development of the air nitrogen industry in various countries of the world has modified the monopoly which Chile enjoyed for so long. In recent years, the production of nitrogen compounds from the air has actually exceeded the amount shipped from Chile. Competition between the air nitrogen products and Chilean nitrate is every year becoming keener, forcing technical improvements in methods of production in Chile, and will perhaps in time also force the Chilean Government to reduce the export tax. On the other hand, it must be remembered that the use of chemical fertilizers in the world is growing at a rapid pace and it is not likely that Chilean nitrate will be driven from the market by the synthetic products.

AGRICULTURAL NITROGEN AS A BY-PRODUCT FROM COAL DISTILLATION

When coal is distilled for the purpose of making coal gas and coke, a part of the fixed nitrogen in the

coal is recovered as ammonia and the ammonia can be converted by simple chemical means into ammonium sulfate, a material which now finds very wide use as a source of agricultural nitrogen. Since, however, ammonium sulfate produced in this way is a by-product, the amount produced will increase only as coke and coal gas industries expand. During the last twenty years there has been a very rapid expansion in these industries, with the result that ammonium sulfate has become one of the largest sources of agricultural nitrogen. In fact, the United States now produces so much ammonium sulfate that agriculture does not absorb all the output. We find ourselves, therefore, in the curious position of exporting about 150,000 tons of ammonium sulfate yearly and at the same time importing about 800,000 tons of Chilean nitrate, both salts being of value to agriculture solely because of the fixed nitrogen they contain. The reason for this anomaly lies in the fact that the two materials are not entirely interchangeable for agricultural purposes, and there is a large specific demand for Chilean nitrate which prevents all of the ammonium sulfate from being used to meet the agricultural demand for nitrogen.

THE AIR NITROGEN INDUSTRIES

As indicated above, the earth's atmosphere constitutes an almost inexhaustible supply of nitrogen, the difficulty being that this nitrogen is in a free or uncombined condition, whereas agricultural nitrogen must be chemically combined. The problem of "fixing" the atmospheric nitrogen in chemical form has proved to be a problem of considerable difficulty. At present, however, there are four methods which have

been brought to commercial success and others which are still in the experimental stage. These methods differ rather widely in the materials used and in mechanical equipment, and the cost of obtaining fixed nitrogen by any of them depends somewhat on local conditions.

The first method to be brought to commercial success is known as the Arc Process. It consists, essentially, of passing air through an electric arc and dissolving the small amounts of nitrogen oxides thus formed in water to produce dilute nitric acid. This process enjoys the advantages of using raw materials, namely, air and water, and the labor cost in production is low. On the other hand, the amount of power required for operating the electric arcs is so large that the process has not been successfully applied except in those locations where electric power has been developed cheaply and where such power has found no other market. The only large arc plants now operating are in Norway where the conditions outlined above prevail.

It is a curious fact that because this first chemical process of producing nitrogen compounds from the air was one which required cheap electric power for its successful application, the association of cheap power and nitrogen fixation has become so rooted in the public mind that it seems impossible to eradicate it. In the voluminous discussions which have taken place concerning Muscle Shoals, this idea crops up again and again, despite the fact that there are processes now available for fixing nitrogen which do not depend upon cheap power for their success.

Following the installation of the arc plants in Norway during the first decade of the present century, the Cyanamide Process of Frank and Caro was installed,

first in Italy and soon thereafter in Germany. This process requires only about one quarter as much power as does the arc process, but requires more in the way of raw materials and labor. In the period between 1905 and 1913, cyanamide plants were put up in various countries of the world and the product is now widely used as agricultural fertilizer. In the United States it is utilized in mixed fertilizers principally. Cyanamide has a number of undesirable qualities as a fertilizer and of late there have been many attempts, some of them partially successful, to convert the material into a more desirable product.

Just previous to the outbreak of the World War in 1914, the Badische Anilin-und Sodafabrik had put in operation a pilot plant at Oppau, using what is now known as the Synthetic Ammonia Process. Naturally not much was known about the process or the plant outside of Germany, and after 1914 it was very difficult to get any information regarding this plant. When, therefore, in 1917, the United States Government was faced with the problem of building nitrogen plants to safeguard our nitrogen supply for military purposes, the choice lay between the two known processes, the Arc and the Cyanamide. The Arc Process, on account of its enormous power requirements, was out of question. The United States Government, therefore, built at Muscle Shoals, Alabama, the largest cyanamide plant in the world, and began the construction of two other plants of this sort. It also constructed at Sheffield, Alabama, near Muscle Shoals, an experimental synthetic ammonia plant. This smaller plant was never brought to successful operation, but the large cyanamide plant is one of the best of its kind in the world, although, unfortunately, the eco-

conomic situation in the United States since the War has not permitted its operation.

The Synthetic Ammonia Process mentioned above, represents a new type of commercial chemical process, a type which is evidently destined to be of great importance in the chemical industry of the future. If hydrogen and nitrogen are brought together under ordinary conditions of temperature and pressure, there is no measurable quantity of ammonia formed, but if these gases be brought together at somewhat elevated temperatures and pressures, they will react to form ammonia and the rate of this reaction can be enormously accelerated by bringing the hot compressed gases in contact with the surface of certain solid materials known as catalysts. One of the best catalysts so far discovered for the ammonia reaction is composed of pure iron to which small amounts of aluminum and potassium oxides have been added.

When Germany was cut off from the supply of Chilean nitrate for military purposes in 1914, the problem which faced her was one which no other nation had ever before encountered. Modern explosives are all of them nitrogen compounds and the problem facing Germany was to prepare the necessary nitrogen compounds on a very large scale for military use while at the same time she was faced with an agricultural demand for nitrogen, accentuated by the food requirements of the war. As a result, not only were a number of her cyanamide plants enlarged and new ones built, but the plant at Oppau was enlarged to gigantic dimensions, and finally one of the largest of its kind in the world was built at Merseburg, in the brown coal fields of northern Germany. This huge plant was finally completed with a capacity of about 200,000 tons of fixed nitrogen per year, which alone is equivalent

in nitrogen to about two-thirds of the whole annual shipment of Chilean nitrate.

The fact that Germany was building these huge synthetic ammonia plants was, of course, known to other countries and experiments were undertaken to develop similar processes. As a result of such experiments, begun during the war and continued ever since, there are now available a number of synthetic ammonia processes, such as the Casale developed in Italy, the Claude developed in France and the American process developed by the Fixed Nitrogen Research Laboratory, all of these in addition to the original Haber-Bosch used by the Germans. At Syracuse, New York, the Atmospheric Nitrogen Corporation has been for a number of years successfully operating a modification of the Haber-Bosch process, while at Niagara Falls, the Casale process has recently been installed. The Claude process is represented by a plant at Charleston, West Virginia, owned by DuPont interests. The Arc Process is also represented by a small plant at LaGrande, Washington, owned by the American Nitrogen Products Company. This little plant produces sodium nitrite, a salt which is used primarily in making dyes.

None of the products turned out by American nitrogen plants goes for agricultural use. However, the production of synthetic nitrogen compounds from the air has forced a proportionally larger amount of by-product nitrogen from the coke and coal gas industries into the fertilizer market. The air nitrogen industry in this country is now approaching the point where it will have saturated all of the higher priced markets for nitrogen compounds and further expansion will compel them to enter the fertilizer fields.

WHERE THE NITROGEN COMES FROM 89

RELATIVE IMPORTANCE OF THE VARIOUS SOURCES OF NITROGEN FOR AGRICULTURE

Seven sources from which agricultural soil secures its nitrogen have been considered above. These are widely different in importance. Taken the world over, bacterial fixation of nitrogen accounts for vastly more of the agricultural supply than any other one agency. The conditions favorable to this sort of bacterial activity in the soil are fairly well known, but the bacterial fixation of nitrogen, while of enormous importance to agriculture, is yet a natural process over which man can exercise only indirect control. To the chemist the bacterial fixation of nitrogen is of greater interest because of the fact that, whatever the chemical process the bacteria use, it is certainly carried out at ordinary temperature, whereas all known methods for chemical fixation of nitrogen involve elevated temperatures.

Rain and snow bring to the soil a few pounds of fixed nitrogen yearly, an amount of little significance in view of crop demands, and the supply is, of course, quite beyond man's control.

Of the nitrogenous materials purposely applied to the soil as fertilizer, animal manure accounts for the largest amount of nitrogen, and, where available, represents the cheapest kind of fertilizer. The supply is altogether too limited, however, and is destined to decrease relative to the population as the expanding population of the earth calls for greater and ever greater production of human foodstuffs.

Nitrogenous waste materials will always form a relatively small source of nitrogen for agriculture. In the past there have been rather large amounts of such materials available in the United States as compared

to other countries, but the situation is changing, and eventually only such relatively small amounts of nitrogenous waste materials will be used for fertilizer as cannot be sold in the more profitable markets. Chemical processing has been used to some extent in preparing nitrogenous waste material for fertilizer use. For the most part this has been directed toward making the nitrogen content more readily available for plant food.

Of the more strictly chemical fertilizers, Chilean nitrate held first place until a few years ago, followed by ammonium sulfate, with the synthetic air-nitrogen products holding last place. Today this order is exactly reversed. The air-nitrogen products supply most nitrogen to agriculture, by-product ammonia sulfate comes second, and Chilean nitrate falls into third place.

The significance of this change is profound, for it means that the chemical processes for fixing nitrogen have reached such a stage of development that agriculture can never be cut off from a nitrogen supply. The Chilean nitrate beds will eventually be exhausted, by-product nitrogen is strictly limited in production, but the earth's atmosphere contains literally millions of millions of tons of nitrogen which now, through chemical processes, can be utilized to whatever extent agriculture demands. Improved technology in the manufacture of air-nitrogen products will continually cheapen nitrogenous fertilizers, and be it remembered that fixed nitrogen has long been the most costly of plant foods lacking in the soil.

FUTURE SOURCES OF AGRICULTURAL NITROGEN

Aside from the natural restoration of nitrogen to the soil through bacteria and through rainfall, the

whole situation with regard to agricultural nitrogen is changing rapidly and no one can foresee what new factors the application of chemistry and engineering to problems of fertilizer production may bring into effect. There are certain current trends to be recognized, however, and these give us some grounds for prediction.

It seems clear that the so-called organic ammoniates, the nitrogenous waste materials, will be largely replaced by synthetic nitrogenous salts. Animal manure will be used where available, but will supply relatively less and less of the total agricultural nitrogen. The rapidly increasing demand for nitrogen compounds must be met chiefly by expanding the air-nitrogen industry. Chilean nitrate will continue to be an important source as long as the supply in Chile lasts or until driven from the market by cheaper air-nitrogen competitors. By-product nitrogen from coal carbonizing will increase in amount only as the coal processing industries expand, but this source of agricultural nitrogen is already large and the coal processing industries are growing rapidly.

Eventually by-product nitrogen and the synthetic air-nitrogen products must probably supply the great bulk of agricultural nitrogen. But after all, it must be emphasized that no one can say what new things chemistry may bring to light with regard to nitrogen-fixing bacteria, or with regard to yet undreamed of methods of getting nitrogen into the soil. One thing does appear certain, and that is that the problem of agricultural nitrogen supply is becoming more and more completely a chemical problem.

CHAPTER V

MAINTAINING SOIL FERTILITY

G. S. FRAPS

Chief, Division of Chemistry, Texas Experiment Station

The problem of maintaining soil fertility was early attacked by chemists beginning with Sir Humphrey Davy and Thaer, but the most significant progress was made in 1840 when the German chemist Justus von Liebig, proposed his theory of soil fertility. Discarding the old theory that plants feed upon the organic matter of manure or of the soil, Liebig maintained that in the soil the mineral part alone was necessary for plants, and that they build their organic matter from the carbon dioxide and nitrogen of the air. He proceeded to test the correctness of his theory on a notoriously barren spot of land near Giessen and a successful demonstration resulted. The worthless field was converted into a fertile tract and sold for a good sum of money. Liebig's theory was merely the starting point, the incentive, to ascertain the fundamentals of soil fertility. Which mineral constituents are necessary for plant life and which are absent from the soil or not present in sufficient amount, remained to be determined. Other chemists took up the work, and practical men, who knew of the demonstration field at Giessen, were impressed with the possible utility of the theory.



SIR JOHN LAWES

Founder of Rothamsted Experiment Station (England)

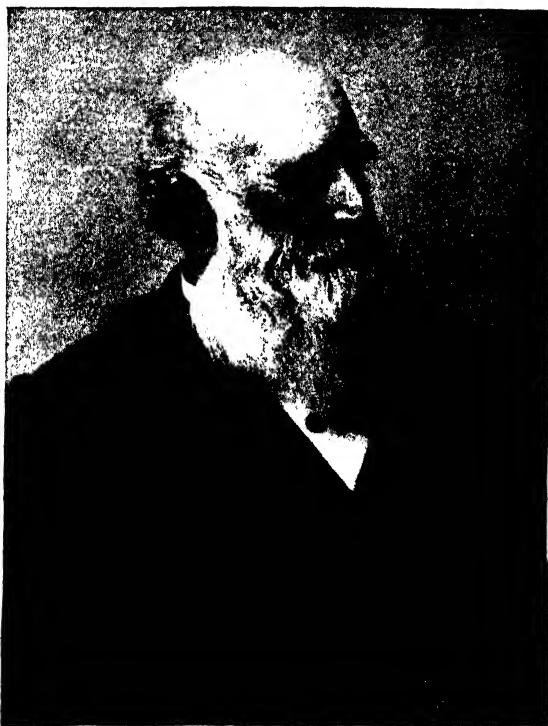
About the same time, John Lawes, an Englishman, later and better known as Sir John Lawes, discovered that bone meal treated with sulfuric acid was much more effective than untreated bone meal in its action on plants. It had been known for a long time that bones were beneficial to plant growth, but why they were beneficial was not known. As soon as chemists had discovered that bones, and bones treated with sulfuric acid were beneficial on account of the phosphoric acid they contained a search was begun for other sources of phosphoric acid to supplement the limited supply of bones. Sir John Lawes found that mineral phosphates such as apatite rock, when treated with sulfuric acid, similarly had the phosphoric acid which they contained converted into forms available to plants. The product which he obtained, and which he tested as a fertilizer, is known as super-phosphate or acid phosphate. In 1842, he took out a patent for the manufacture of this super-phosphate, his patent being based on this new process of converting phosphate rock into plant fertilizer material. His factory, one of the first of its kind, together with his process, became the foundation of the present enormous fertilizer industry. Immense deposits of phosphate rock were discovered in various parts of the world. Treatment of this rock with sulfuric acid made the phosphoric acid available to plants, and the production of ample supplies of acid phosphate has placed the farmer in a position to increase the yield of his crops.

It did not take farmers long to find out that acid phosphate gave profitable returns on many crops and many soils, and its manufacture increased by leaps and bounds. Sir John Lawes began field experiments with fertilizers at Rothamsted, England, in 1843, and from this beginning there has developed the most fa-

mous experiment station in the world. Associated with the chemist, Dr. Henry Gilbert, he conducted and encouraged agricultural investigations of a wide scope. Experiments with acid phosphate, nitrogenous fertilizers, lime, rotations of crops, and other soil treatments have now been conducted at Rothamsted for over sixty years, and on some of the plots the same plan has been followed continuously. The experiments were carried on by Sir John Lawes at his own expense and, at his death, the work was endowed by him. It is now continued and has been expanded by the British Government. The Rothamsted Experiment Station has been followed by the establishment of experiment stations in Germany, France, and other countries, including one or more in every State of the United States. At these Experiment Stations chemists are among the chief workers and their investigations have contributed much to the building up of agricultural science.

Liebig's theory of the mineral nutrition of plants was faulty so far as it related to nitrogen, for ordinary cultivated plants cannot take nitrogen from the air as he supposed. Yet clovers and other legumes were known, from ancient times, to aid in maintaining soil fertility. This mystery was not explained until 1882, when Hellriegel, a German chemist, and Atwater, an American chemist, showed that legumes by the aid of bacteria could assimilate or fix the free nitrogen of the air, causing it to form chemical compounds; while other plants, or legumes without bacteria, could not do so. This discovery revealed a cheap and practical method of maintaining the nitrogen supply of the soil, at least in part, as is shown elsewhere.

The investigations of chemists stimulated by Liebig's theories showed that nitrogen is essential to



SIR HENRY GILBERT
Chemist of Rothamsted Experiment Station.

plant growth and that it is deficient in many soils. Search was made for cheap materials containing nitrogen which could be used for application to the soil to promote the growth of crops. The droppings of sea birds were found in immense quantities on many islands of light rainfall, and were marketed under the name of "guano" and for some time were an important fertilizer. The guano deposits were almost all used up many years ago, and the supply of guano is now very limited but the name "guano" still persists. As the supplies of guano declined, search was made and other nitrogenous materials were found, such as nitrate of soda, sulphate of ammonia, tankage, cottonseed meal and various products containing nitrogen.

Another important discovery of the chemists was the use of potash as a fertilizer. Common salt has been mined in Germany a long time. Other salts originally of no value were associated with it, and were used to stop up abandoned mine galleries or disposed of elsewhere as waste. Chemists found that this waste material contained potash. It was also found that plants could not grow without potash, and that many soils do not contain enough potash to give heavy crops. Thus these potash salts, which were waste products, became more valuable than the common salt, and they are now used extensively as fertilizers, to aid in increasing crop yields in many parts of the earth.

These discoveries relating to phosphoric acid, nitrogen and potash are outstanding ones concerning soil fertility, but great as they are, they represent only a small part of what chemists have done to aid in the maintenance and increase of soil fertility. Many chemists in various countries of the world have made numbers of discoveries and collected a great mass of de-

tailed information, so that entire books are published dealing with soils, or with fertilizers.

The important plant food materials deficient in soils were found to be phosphoric acid, nitrogen, and potash. Lime is also needed by some soils, but not to supply plant food. Many experiments were made before these conclusions were reached, because it was necessary to consider everything found in the plant, and to examine many kinds of soil. The work still goes on, for it appears that under special conditions, or with peculiar soils, other things may be of fundamental importance. For example, in Oregon and Washington, soils occur which are deficient in sulphur, for it has been found that sulphur, or gypsum which carries sulphur, added to these soils will markedly increase the yield of alfalfa. Then again there are some soils which do not seem at times to furnish plants with enough iron, so that the leaves become yellow instead of the normal green.

Spraying the leaves with sulphate of iron changes the color from yellow to green with a quickness which is astonishing. Some soils appear to need magnesia, and possibly others need lime as a plant food. Yet these are special cases, and for the great majority of soils, phosphoric acid, nitrogen, potash, and lime remain of fundamental importance.

Knowledge of the important plant foods shows the way to maintain or increase the fertility of soils. As Liebig pointed out, crops take up certain mineral materials of the soil, and when the crop is removed, the mineral material is removed with it. This results in a decrease in fertility. The maintenance of soil fertility is largely dependent upon restoring the necessary elements removed by the crops and, as already stated, these have been reduced to phosphoric acid.

nitrogen, and potash, together with lime, which, however, is used to correct acidity and not often as a plant food.

Conversely, soils naturally poor can be increased in fertility, a process which can be seen in any locality where good farmers use fertilizers. A most striking example of this is found in some pineapple soils of Florida. Some of these soils are almost entirely devoid of plant food, and would be utterly worthless except for the work of the chemist. After treatment with chemical fertilizers these soils produce splendid crops of pineapples of the highest quality, and are worth several hundred dollars an acre.

Manure has for ages been highly esteemed for its favorable action on the soil. The agricultural chemist has estimated the phosphoric acid, nitrogen, potash and other constituents of manure, and has studied the best methods of saving and applying it. He has found that manure must be kept moist to reduce losses by fermentation and protected from leaching by rain, so that the plant food may not be washed out. While manure contains only about 6 pounds phosphoric acid, 8 pounds nitrogen and 6 pounds potash to the ton, it is justly esteemed, not only on account of the plant food which it carries, but on account of the lasting action it has, and its favorable effect on the properties of soils. Plants, like animals, need not only food, but a suitable amount of water and a favorable place in which to live and develop. Favorable soil conditions are equally as important as plant food, and indeed are more important in many instances, now that the chemist has rendered it so easy to secure and apply the necessary plant food. Manure or its substitute, green crops turned under, still has an important part to play in maintaining soil fertility. The

quality of manure depends on the plant food in the feed eaten by the animal, as well as on the kind of animal, and other conditions, such as the litter used to absorb the liquid excrement.

The restoration of the fertilizing constituents of animal foods to the soil by utilization of the manure is of great agricultural importance and is most completely realized when animals are fed directly upon the farm to be manured. Serious economic losses of plant food occur in the United States by the exportation of cottonseed meal and other crop materials to foreign nations, who, in addition to securing the nutritive value of these products, derive an additional benefit from the fertilizing ingredients of the manure of the animals that consume the imported feeds.

The development of commercial fertilizers brought many problems to the agricultural chemist. A most important one is that of the relative value or availability of the same plant food in different forms. Phosphoric acid, nitrogen and potash occur in different forms of combination. Some of these act quickly and are of high value, some are of no practical value, while others are intermediate in value. Potash is found in salts soluble in water, which have a high value, but potash is also found as silicates from which the potash can be extracted only by intense chemical treatment, and only very slightly by plants. Attempts are still sometimes made to market minerals containing potash, or other so-called fertilizers, of no value as fertilizers. Nitrogen in nitrate or sulphate of ammonia has a high value, while in peat or untreated leather it has a very low value. The chemist has learned to treat leather, hair, or other nitrogenous materials of low availability, with acid and heat, so as to convert the nitrogen into forms that are easily

taken up by plants. Phosphoric acid may be applied as bone, acid phosphate, phosphate rock, dicalcium phosphate, or other substances. The phosphoric acid in acid phosphate is partly soluble in water, in the form of mono-calcium phosphate; partly soluble in ammonium citrate, as di-calcium phosphate, and partly insoluble, as tri-calcium phosphate or unaltered rock phosphate. The water-soluble phosphoric acid and the citrate-soluble phosphoric acid together form the available phosphoric acid.

Chemists are called on to ascertain the availability of plant food in different forms of combination with different values and to give information regarding the utilization and value of all these various materials under varied conditions of soil, climate and crops. Enormous progress has been made in the solution of such problems but much more must be done before any final solution can be reached. Sulphate of ammonia and nitrate of soda, for example, both have a high value, but, on an acid soil, nitrate of soda should give better results; on a neutral soil they may be of equal value, while on a soil tending to alkalinity, sulphate of ammonia would probably be better.

The chemist is being called to assist in determining the formulas of fertilizers which should be used for different crops under varying conditions of soil and climate. Fertilizer experiments in fields and pots and chemical analyses of soils and crops are some of the means by which this information is obtained. The matter has been complicated by the multitude of formulas of mixed fertilizers put out by the various manufacturers. These have developed partly from economic conditions, partly to meet the demands of dealers, partly to suit the needs of the farm and farmer. Out of this multitude of formulas it was difficult

to choose those to be studied or to recommend any one without recommending the goods of some particular manufacturer.

Recently this question has been partly solved by chemists, agronomists, manufacturers, and others, in various states or sections of the country, agreeing on a relatively small number of standard formulas to be recommended by all the cooperating agricultural agencies. This important step aids greatly in simplifying and solving the problems of fertilization. In some of the southern States, manufactures have gone still further by agreeing to limit the number of formulas which they will market. For example, in Texas only twenty formulas for mixed fertilizers will be used in place of one hundred and eighty as formerly. The ratio of the plant food constituents determines the formula of the fertilizer. For example, the ratio 4:1:1 occurs in a 8-2-2 fertilizer, or a 12-3-3 fertilizer or a 16-4-4 fertilizer.

There is still some confusion, for, in some states, a 12-3-3 fertilizer means one containing 12 per cent available phosphoric acid, 3 per cent. *nitrogen*, and 3 per cent. potash, while, in other states, it means 2.47 per cent. nitrogen corresponding to 3 per cent. *ammonia*. That is to say, in some states the figure refers to *nitrogen*, in others to *ammonia*, which is a larger figure for the same thing. All fertilizers should be described on a uniform basis.

It would take too much space to discuss fertilizer formulas, suitable to various crops and soils but the Agricultural Experiment Station or Extension Service of any State will furnish information applying to local conditions. In general, crops of low value to the acre are fertilized sparingly while those of high value to

the acre receive more generous applications of fertilizer.

The chief essentials as discovered by the chemist for the maintenance of soil fertility are briefly as follows: First, to maintain the supply of nitrogen and humus of the soil by growing legumes in a proper rotation and turning them under or grazing them off, and to supplement this rotation by the use of manure as far as available, together with such fertilizers as may be found profitable.

Second, maintenance of the phosphoric acid content of the soil, or correction for deficiency in phosphoric acid, by the use of phosphatic fertilizers, supplemented by the saving of all possible plant food in manure and crop residues.

Third, correction of the acidity of the soil, if there is any acidity injurious to the crops being grown, by the use of ground limestone or lime. Lime, limestone, and marl are also used for the improvement of the physical character of some heavy soils low in lime, or for supplying lime to certain crops which need a quantity of lime, when grown on soils low in lime. Lime should be used only in connection with a systematic crop rotation.

Fourth, if there is a deficiency of potash in the soil, potash fertilizers should be used to correct this deficiency.

Fifth, all possible losses of plant food should be prevented. Manure should be saved carefully, or the animals fed as much as possible on the land to be manured. Leaves and stubble should be made into manure or turned under, and not burned, unless necessary on account of insect pests or plant diseases. The land should be covered by a green crop, so far as possible, especially during the open, rainy seasons, to

prevent the plant food from being washed out of the soil. This is much more important in the South than in the North.

Maintaining the nitrogen supply of the soil is probably the most important problem which the chemist has to face. Phosphoric acid, potash, and lime are relatively cheap and abundant, not easily lost from the soil, and not readily lost from manure or crop by-products. Nitrogen is expensive, easily lost from the soil, and easily lost from manure by fermentation, heating, or leaching.

The high cost of nitrogen in fertilizers renders it impossible to purchase enough nitrogen to maintain soil fertility when crops of low acre value are grown. If it takes a pound and one half of nitrogen for a bushel of corn (including leaves and stalk) and the nitrogen costs 25 cents per pound, the cost of 37 1/2 cents a bushel would prohibit the use of nitrogen sufficient to grow an entire corn crop, or to maintain the fertility of a corn soil. The expense would be too great. This also applies to similar crops, such as wheat or oats. On the other hand, the use of a small amount of nitrogenous fertilizer to supplement that in the soil might be profitable for wheat or oats or corn, as the increased gain in yield of the crops may be much greater than the cost of the fertilizer.

In his search for new nitrogenous fertilizers the chemist has succeeded in causing the free nitrogen of the air to combine with other elements to form calcium cyanimide, nitrate of lime, or soda, and salts of ammonia, all of which are useful in agriculture and the industries, a fact which has directed so much attention to Muscle Shoals. While these processes reduce the cost of fertilizer nitrogen, they do not solve the problem of maintaining the nitrogen supply of the soil. The

fuel or power cost of causing nitrogen to combine is high, so it is not yet possible to produce fertilizer nitrogen as cheap as phosphoric acid or potash.

The impracticability of using nitrogenous fertilizers alone to maintain the nitrogen fertility of the soil, leaves, as the only alternative, the use of a legume crop in a rotation. Chemists have shown that legumes have the power of taking nitrogen from the air, where there is an inexhaustible store. Crimson clover may take up 200 pounds to the acre, velvet beans, 141 to 213 pounds, and other legume crops take similar amounts. The legume may be grazed off or turned under, supplying other crops with nitrogen and adding humus so much needed by many soils. Crop rotation reduces damage from pests and plant diseases, utilizes the soil to better advantage, helps keep it in better physical condition, and adds to the nitrogen of the soil by means of the legume crop. Experiments in Maryland have resulted in yields of 102 bushels potatoes per acre in rotation with common clover compared with 68 bushels when potatoes were grown continuously. Corn in rotation with red clover in Illinois has produced 55 bushels per acre compared with 35 bushels without rotation; while cotton in rotation with cowpeas, in Alabama, gave 1533 pounds seed cotton compared with 837 pounds when cotton was grown continuously. Similar results have been obtained in many other experiments.

Some soils turn blue litmus paper red, and have other acid properties. The acidity may be removed or decreased by applying limestone, oyster shell, marl, quick lime, or hydrated lime. Soil acidity has received much deserved attention from agricultural chemists. The Rhode Island Experiment Station, and others, have observed great variations in the behavior of crops

to acid soils. While watermelons, cowpeas, cranberries, and some other crops do best on acid soils, and are injured by applications of lime to correct the acidity, and plants vary in their tolerance to acidity. Onions, peanuts, and tobacco are injured by an acid condition of the soil. There are various degrees of acidity, and plants vary in their tolerance to acidity. Crimson clover is not dependent on lime, and even alfalfa will do well on soils with a slight degree of acidity. The question of soil acidity is a perplexing one, and while chemists have worked a great deal on it, the problem seems far from solution. The determination of the *hydrogen ion* concentration or "pH" has been of some assistance, but the whole matter is undoubtedly more complex than many have supposed.

Acidity appears to be caused by several substances or conditions, such as: aluminum salts, acid silicates, organic acids, absorption by colloids, etc. Also, the behavior of crops depends on the cause of the acidity as well as on the quantity or degree. Well rotted manure or green manures seem to take the place of lime on some soils. Many acid soils must be corrected by lime before legumes can be grown successfully. On the other hand, over-liming a soil will cause the leaves of plants to turn yellow (chlorosis). Liming sandy soils will cause loss of plant food, especially nitrogen, which probably originated the adage "Lime makes the father rich and the son poor." Lime has other desirable effects on some clay soils, making them less sticky and more easily cultivated. The chemist has the problem of showing when, where, and how to lime successfully, and this information, suitable for local conditions, may be secured, so far as it is available, from the various Experiment Stations.

The question may be asked, will the chemical analy-

sis of the soil give information to aid in maintaining or increasing soil fertility? Determinations of the active phosphoric acid, the active potash, the total nitrogen, the basicity and the acidity, are of great help. This information is best utilized, however, when the soil analyses are made systematically upon typical soil samples representing large known areas. Systematic work of this kind enables the chemist to secure general information for many farmers. It would be an impossible task to analyze every kind of soil on every farm in the United States, but it is not necessary to do so. It is not necessary to analyze each lot of corn, in order to tell how to feed corn, even though there may be some variation in composition. In the same way, it is not necessary to analyze every soil on every farm to tell the farmer how to keep it fertile. When chemists have secured systematic information regarding soil types, information can be given individual farmers regarding the general needs of each type of soil for plant food.

A full discussion of the contribution of the chemist to the maintenance of soil fertility would take too much space. The writer can only hope that the brief discussion here made regarding fertilizers, manure, lime, acidity and legumes will induce many readers to study the matter more thoroughly in text books and Bulletins of the various Experiment Stations. The maintenance of the fertility of our soils is based largely upon the work of the chemist.

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CHAPTER VI

CEREALS

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MAN, THE GRAIN-GRINDER

No further evidence of the consumption of grains as food by primitive man is required other than that to be found in the characteristics of the teeth in the human jaw. "Molar" means grinder, and the broad, flat molar teeth constituted the grain-grinding apparatus of our prehistoric ancestors. It is easy to picture the old man of the tribe and his family squatting on a stone near the bank of a stream, munching the grains of the wild grasses of the region. When Lamb related the discovery of a process of roasting pigs, he failed to tell us of the origin of a method of parching grain over the fire. We may well imagine however that the conquest and control of fire by man was speedily followed by the development of a procedure for roasting grains and thus rendering them more palatable.

Then some thinker of the tribe conceived the idea of grinding the grains by rubbing them between stones, and so in the new stone age a simple mill was developed. With a meal prepared from roasted grain, it required only one more stage in the sequence of processes to result in the production of a flat cake, baked

on a heated stone. From these beginnings we may trace, through the succeeding centuries, the additions of refinements in methods and machines which have resulted in the sanitary and automatic processes of the present day that yield such appetizing and nutritious cereal products.

WHEAT, THE EMPEROR OF GRASSES

Some enthusiast once referred to Indian corn or maize as the king of cereals. If corn is king, then wheat is emperor. Wheat is grown on every continent, and in every clime from the tropics to the edges of the Arctic circle. It is consumed to a greater or less extent by every civilized race. Its use by man can be traced back to the beginnings of human history.

There are several species of wheat grown and handled in commerce. No less than five such species can be distinguished among the modern wheats, all of which are classified in the genus *Triticum*. These are common wheat (*T. vulgare*), club wheat (*T. compactum*), durum or macaroni wheat (*T. durum*), the poulard wheats (*T. turgidum*), and the polish wheats (*T. polonicum*). The last two named are not grown in quantity in America. The common or vulgar wheats are the most widely grown. In regions of mild climates, the varieties chiefly cultivated are fall-sown or winter wheats, while in the northern United States, and in parts of Canada spring sown varieties must be grown. Club wheats are grown in certain districts in the western states. Flours produced from them are not regarded as well suited to baking yeast-leavened bread. Durum wheats are grown in certain areas in the Dakotas and western Minnesota. They are not used extensively in milling bread flour, but are em-

ployed in the production of macaroni and other edible pastes.

The services of the chemist have been utilized in the breeding of bread wheats. Plant breeders recognize certain deficiencies in some of the well-known wheat varieties, as, for example, a lack of resistance to such diseases as black stem rust. In an effort to breed rust-resistant varieties, it appears necessary at times to cross these choice milling wheats with varieties that possess the desired disease resistance but which have inferior baking qualities. Among the resulting hybrids, the desired combination of high disease resistance, and excellent baking qualities may be found. The chemist aids in classifying these hybrids on the basis of milling quality, and in selecting the acceptable strains for cultivation on an extended scale.

Chemists have also collaborated in the selection of the varieties of durum wheat which are best adapted to the manufacture of macaroni.

In the development of standards for grading wheat, chemical analysis and baking tests have played an important role. At the time this article is written, a large fraction of the hard wheat crop in America is being bought and sold on the basis of protein content. Substantial premiums are paid in the terminal markets for those lots of hard wheat which contain more than the normal percentage of protein and are otherwise sound and of good quality.

Biochemical studies of grain in storage have yielded facts of interest concerning its keeping qualities as related to other properties of the kernels. Stored grain respire or breathes like other living things, and this rate of breathing can be determined in terms of the carbon dioxide respired. In general, dry, plump, sound, hard grain has a lower rate of respiration, and

hence keeps better in storage than damp, or shriveled, or unsound, or soft grain.

FLOUR MILLING

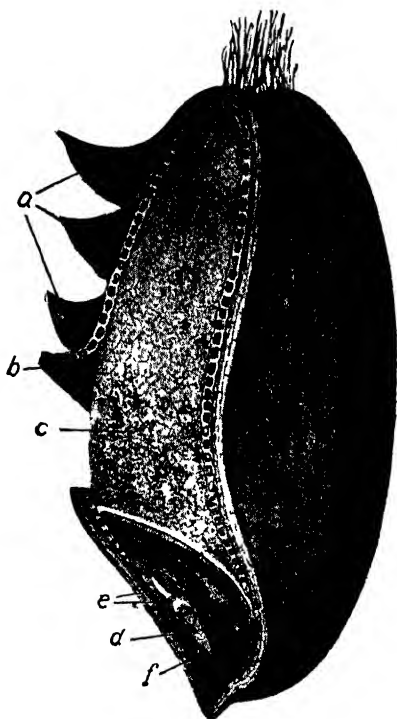
In the operation of the modern roller mill the chemist has come of late years to occupy an increasingly important position. When we admit at the outset that flour milling (aside from bleaching) is a mechanical process, in which no important chemical reactions ordinarily occur, it may be difficult to understand why a chemist is essential. Let us, therefore, endeavor to trace certain of his activities, to determine wherein he is of service to the miller.

In the first place, the parcels of wheat which are offered to the miller may be exceedingly variable in their characteristics, and consequently in their milling and baking properties. The different varieties of wheat vary more or less in these particulars. Again, the wheat plant responds readily to variations in its environment. Climatic conditions, including temperature, rainfall, sunshine, and winds; irrigation; plant diseases; methods of harvesting and treatment of the grain subsequent to harvest; and other factors are reflected in the composition and properties of the wheat crop. Certain of the differences in the several lots of wheat may be detected by the skillful grain buyer. The chemist can frequently measure these differences in a more definite manner, however, and apply numerical values to the results of his observations. In this manner he can aid the buyer and the elevator operator in the selection and classification of the various parcels of wheat. This also puts the miller in possession of information for use in making up the

blend of wheat as used in grinding, and thus insure a greater uniformity in the flour.

Similarly, in flour milling, the chemist is rarely in direct charge of grinding operations. The man in the laboratory, however, can apply certain tests to the intermediate and finished products, as a measure of their properties. Protein determinations afford a measure of the gluten content of flour, since the protein of flour is largely gluten. Ash determinations indicate the degree of refinement of the white flours. Patent, or high grade flours, are usually low in their content of ash. This constituent occurs chiefly in the bran or fibrous covering of the wheat kernel, which is largely separated from the choice flours in the process of milling. The lower grade or clear flours contain more ash than the high grade or patent flours in consequence of the inclusion of more bran particles in the former. Since the presence of bran fragments, and of the dirt and foreign matter adhering to them serves to render the flour darker in color, it follows that, in general, the ash content is related to the color of the flour and of the crumb of bread baked therefrom. Other chemical tests are occasionally used to determine the degree of refinement, and the strength of flour. Such chemical determinations are commonly supplemented by experimental baking tests made under carefully controlled conditions. In consequence of these several tests, the mill chemist can report the measured properties of the flour in fairly definite terms.

In addition to the flour tests, the mill chemist analyses the mill by-products or feeds. On the basis of these findings, the miller can brand on the sack or label the guaranteed composition of the feed, in order to advise feeders as to how to use it intelligently and



Courtesy of F B Morrison

Fig. 1

Diagram of Wheat Kernel

A, three bran coats; b, aleurone layer; c, cells filled with starch grains; d, embryo, or germ; e embryo leaves; f, embryo root. (Partially after Neumann.

also to conform with the state and federal laws and regulations. The minimum percentage of fat, and protein, and the maximum percentage of fiber are commonly included in the guarantee of composition of mill feeds.

It is difficult in a limited space to more than outline the processes of flour milling. Those interested in the details should consult the book entitled "Practical Milling" recently written by Professor B. W. Dedrick.* The diagram of the wheat kernel in Fig. 1 aids in following the brief description of the milling process. This illustration and also Fig. 2 were prepared by Professor F. B. Morrison of the University of Wisconsin and were kindly loaned by him for use in this volume. Wheat, as it comes to the miller, is usually mixed with weed seeds and impurities which are removed as completely as possible by cleaning machinery. Frequently the cleaned wheat is then washed with water, and scoured to remove the surface dirt. A small quantity of water is always used in wetting dry, plump, hard wheat to toughen the bran. In fact, the control of the moisture content of wheat and intermediate products in milling, is an important duty of the chemist and may be a source of profit to the mill, both in terms of yield and quality of products.

Conditioned or tempered wheat is first ground between corrugated iron rollers which crack the grain. Several such grindings or breaks, usually five in number, followed in each instance by bolting the ground material in a sifter, effects the removal of the coarse bran. Granular particles midway in size between the grain and flour, and known to the miller as semolinas or flour middlings, are separated in the process of sifting the break chop. These are classified,

*Published by the National Miller, Chicago, Illinois, 1925.

as to size of granules, and are treated with air currents to remove flaky, fibrous particles in a machine known as a purifier. The purified middlings are then pulverized or reduced by grinding them between smooth and highly polished iron rollers. The fine particles sifted from the reduced middlings by bolting them through silk sieves having about 110 to 125 meshes per inch, constitute the most highly refined or choicest flour of the mill. Particles too coarse to pass through the flour silks are reground, but each successive grinding results in progressively inferior flour of darker color and lower baking strength until finally the residue is spouted to the shorts bin.

Semolinas made from durum wheat are sifted so as to classify the particles as to size. These granular semolinas are mixed into a simple stiff paste with water, and the paste forced under high pressure through openings in a die so designed as to yield the familiar sticks of macaroni and spaghetti. These are carefully cured or dried, in which form they are marketed. Other and more complex pastes in which eggs are incorporated yield noodles and the like. Semolinas from ordinary hard wheat are used in making breakfast porridge under the name of farinas.

From what has been said about flour milling, it is evident that a number of flour streams are to be found in each roller mill. One such stream results from each grinding operation in the gradual reduction process. Each stream possesses distinctive properties which may be measured by chemical and experimental baking tests. Maintaining uniformity in each stream, and determining which of the streams are suited to inclusion in the several grades of flour is the combined task of the miller and the chemist.

Combinations of the various flour streams result in

producing the several grades of flour which are marketed by the mill. In order of the degree of refinement and usual market value these are known as fancy patent, standard patent, straight grade, first clear, and second clear. Graham flour is made by merely pulverizing the entire grain after it is carefully cleaned. The removal of the coarser bran particles results in a product generally known in the trade as "whole wheat flour." There are no well-defined standards for the several grades (except graham flour) promulgated by any governmental agency, so trade practices or private understandings and contracts determine the meaning of these various terms. Occasionally flours are sold on the basis of chemical composition as stipulated in contract specifications.

BREAD PRODUCTION

Modern, large scale baking has come to be a highly-organized business. The process of handling the dough and bread is largely mechanical. Bread doughs are mixed in motor-driven mixing machines. Milk, or milk solids are often included in the dough batch to impart flavor and added nutritional value to the bread. These doughs ordinarily are leavened with compressed yeast, which produces alcohol, and the gaseous carbon dioxide that "raises" the batch. Since yeast is a living organism or simple plant, its activities are controlled in part by the temperature of the dough. Provision is accordingly made for the careful and automatic control of the temperature of the chamber in which the dough is raised. The degree of acidity of the dough is regarded as of importance, and is controlled in many bakeries. At the conclusion of the fermentation period the dough is divided and made

up into loaves automatically in a series of three machines. The dough in the baking pan is then raised by placing the pan for a definite length of time in another and somewhat warmer chamber. In many bakeries the dough is baked in a long, narrow oven which has a moving hearth like an endless belt. The raw dough in pans is fed into one end of the oven, and the baked loaves are discharged at the other end. Several important chemical changes occur in fermenting and baking bread dough, and a lack of control over these processes results in inferior bread. In selecting and blending flours, and other ingredients of the dough batch, and in controlling the baking process, a knowledge of the chemical changes involved is of considerable value to the bakery superintendent.

SODA-CRACKER PRODUCTION

A cracker sponge is handled quite differently from a bread dough. Soft wheat flour is generally used in cracker sponges. The quantity of yeast used is small, and the sponge stands several times as long as a bread-dough, or from 16 to 20 hours. During this time the gluten of the flour is broken down to a considerable extent, and the sponge becomes decidedly acid. This acidity is then neutralized by adding cooking soda (sodium bicarbonate) in the proper proportion and remixing the dough. A nice adjustment of this soda dosage must be made to produce ideal crackers. The quantity of shortening or fat used in soda-crackers is rather large (about 16 to 20 pounds per barrel of flour) as contrasted with bread and this shortening must be choice and of good quality to impart the desired flavor and keeping qualities to the crackers. Under proper control the resulting cracker

is not only palatable and nutritious but can be kept without danger of deterioration, in a tight package for an extended period.

CAKES, PASTRIES AND BISCUIT

Flours and other cereal products are extensively used in making an almost infinite variety of cakes, pastries, and biscuit. Generally a flour milled from soft wheat, and having a relatively low gluten content, is best adapted to baking such products. Not infrequently the proportion of shortening used is relatively large and the cakes possess a high caloric value in consequence.

GLUTEN FLOURS AND BISCUIT

In planning the ration of diabetics, it is necessary that the sugar and starch content of the diet be kept as low as possible. To this end, gluten flours, and bread or biscuit prepared therefrom, are commonly used. Considerable secrecy attends the preparation of certain brands of gluten flour and gluten biscuit. When a wheat flour dough is kneaded in a stream of running water, the starch and soluble materials are largely washed away, leaving a tough elastic mass of "crude gluten." About four-fifths of the dry matter of such gluten is made up of the two proteins, gliadin and glutenin, which the chemist regards as constituting true gluten. The remainder is starch, fat, fiber, and mineral matter. This wet crude gluten, if carefully dried, pulverized, and bolted, would yield a gluten flour. The federal standards of purity for food products permit the branding of such a product as gluten flour providing it does not contain more than 44% of starch.

When the wet crude gluten, or a paste made with gluten flour, is baked in an oven, the evolution of steam puffs the wet material, which, on further baking yields a form of gluten biscuit.

CEREAL BREAKFAST FOOD FROM WHEAT

Farinas are usually taken from one or more of the granular middlings or semolina streams of a flour mill. Sometimes the highly refined middlings are used as in Cream of Wheat. In other instances, streams containing more of the branny particles and germ are included in the mixture. Again, malted or sprouted grains are dried, and milled, and the resulting farinas incorporated in the cereal. The malted material is sweeter than the normal grain, and possesses a typical flavor. A coarse farina may also be made by merely cracking or granulating the entire wheat kernel.

Care is taken in packaging these farinas to insure the destruction of insects and insect eggs. This is usually accomplished by heating the material to a sufficiently high temperature. In this manner the keeping qualities of the contents of the packages can be improved.

Shredded wheat products are made by steaming the entire grain, and then forcing the softened material through dies in such a manner that it emerges in long, thread-like shreds. These are laid down in tiers to the desired thickness, cut into appropriate lengths, and then baked. The result is the familiar biscuit ready for the breakfast table.

Another ready-to-serve breakfast cereal is puffed wheat. This cereal is made by first scouring off the surface branny layers in large part, and then "puffing" the grain. The puffing process involves im-

pregnating the grain with the requisite amount of moisture, heating the grain in a tightly-closed iron cylinder or drum, and then releasing the material from the drum by suddenly removing the head or cap. When the pressure is thus suddenly reduced the grain "puffs" in somewhat the same manner as pop-corn "pops." Puffed rice is made in essentially the same manner, starting with hulled and polished rice grains.

A dough made from a coarse or entire-wheat flour, and barley flour, fermented, slowly baked in loaf form, granulated, and re-baked or toasted, yields another type of crisp, palatable, ready-to-eat breakfast cereal.

Bran flakes are prepared by flaking and toasting a preparation of wheat bran together with some of the endosperm or floury portion of the wheat.

CEREAL BEVERAGES FROM WHEAT

Roasted wheat kernels, treated with molasses, may be ground and brewed with hot water in preparing a hot beverage. In certain instances, the brew or infusion is made in the factory on a large scale, filtered, and then dried. A fine powder made from the dried residue is soluble in hot water and yields the "instant" beverage without recourse to the pot or percolator.

ANIMAL FEEDS FROM WHEAT

In this discussion of wheat products, particular attention has been given to those products used as human food. Roller milling yields not only flour but several types of by-products or offals used as animal feeds. Bran is the coarsest, most fibrous product, and is highly prized as a feed for dairy cows. Shorts, and standard middlings are next in order of diminishing

fineness, and are used in the ration of certain of the domestic animals, particularly swine. They contain less fiber, more fat, and, usually, somewhat more protein than bran. Red dog, or low grade flours, are the finest, least fibrous of the mill by-products. They are used not only in the feeding of certain farm animals including swine, but find some use in the industries. Thus the cores used in making iron castings in foundries not uncommonly are made with red dog as the binder.

RYE PRODUCTS

Rye flour is made by a roller milling process not unlike that followed in grinding wheat. Owing to the comparative softness of the floury portion or endosperm of the rye kernel, the rye semolinas are not separated in as granular or pure a condition as is the case in milling wheat. In consequence, rye flour is generally less highly refined and free from cellulose or fiber than the corresponding grades of wheat flour. Such flours are accordingly darker in color and yield a bread with a gray or brown tint.

The refined, or patent flours milled from rye find a use in the baking of rye bread. Pumperknickel is usually baked with a pure rye flour. A less highly flavored loaf may be made using some wheat flour. Thus the Federal standards for rye bread permit of labeling the loaf "rye" in the event that the flour mixture consists of not less than one-third rye, the remainder to be wheat flour.

Rye graham made by grinding the entire rye grain, is used in certain breads, including the flat bread or rye crisp that is so much relished by the Scandinavian peoples. Such flat-breads contain a low percentage of moisture and hence keep well.

Eye was formerly used in America in the production of certain distilled alcoholic beverages, but this industry has been legislated out of existence.

BARLEY PRODUCTS

Considerable barley is consumed on the farms of the United States as an animal feed. In a coarsely ground meal it can be utilized in the ration of several of the domestic animals.

In the industries barley finds fairly wide applications. Pearl barley is milled by rubbing the kernels between rotating stone disks until the outer portion, including the hull of the grain, has been removed. With a little polishing, and blowing with an air current to remove the dust and chaff, the pearl barley is ready for soups, stews, or porridge. By-products of the barley-pearling plant are suitable for use in feeding farm animals.

A carefully refined, and bolted barley flour is available for household use, particularly in the preparation of barley water infusions for diluting cow's milk in feeding young infants.

Barley malt has been prepared in quantity for use in several connections including: (1) distilleries, in converting starch from other cereals into fermentable sugars; (2) breweries, where it was used in a like manner; (3) malt-extract manufacture, such extracts being used in the baking industries, and in the textile industries; (4) milling of malt flour, used in baking and other connections where an active diastase is required. The first two uses enumerated are no longer of large magnitude, although barley-malt is still used in the manufacture of non-alcoholic malt beverages or ale, and "near-beer."

Chemists have had a particular interest in barley malt because of the very active diastase which can be obtained from it. When the normal barley kernel is wetted, and allowed to sprout or germinate, this diastase appears in an active form and proceeds to break down the insoluble starch of the grain into malt sugar. If the sprouting grain is dried, ground, and then extracted with water, the resulting extract contains much of this diastase, which can then be put to work in converting more starch into sugar. Barley malt constitutes the cheapest, and most convenient source of such a diastase preparation.

Varieties and types of barley differ in the character of malt which they yield. In general, the small-kernelled varieties, grown in the northern great plains region, including western Minnesota and the Dakotas, yield malt with the most active diastase. Large-berried barley from the western states, containing more starch and less protein than the great plains barley, yields more extract, which, however, is lower in diastatic activity.

OATS AND OAT PRODUCTS

It is recorded that the witty Ben Jonson was once twitted by an Englishman about the use of oat meal in the diet of the Scotch. "Why," said his English friend, "in England we feed oats only to horses." Jonson retorted, "Yes, and in England you raise the best of horses, while in Scotland we raise the best of men."

As a matter of fact, the products consumed by man and beast are quite unlike, and oat meal for the table is the result of a rather complicated treatment of the original oats. The question is frequently asked, "How can we prepare oat meal in the farm home from our

own oats?" It is impossible to make rolled oats without recourse to facilities which can not be included in a domestic outfit. This will be evident from a brief description of the process used in a rolled oat mill.

The first task is to completely remove the hull of the oat. Cleaned and carefully graded white oats are roasted or parched in a kiln, the treatment with heated air rendering the hull crisp and brittle. In this condition it can be detached from the grain by rubbing the parched kernels between large, flat stones, one of which rotates in a horizontal plane. The hulls after several such grinding operations are separated from the meat of the kernel by aspiration, or treatment with a current of air. The air current lifts out the hulls and dust which are recovered in a dust collector. Aspirated oats are again carefully graded on a sifter to remove any small oats which have escaped hulling.

When the resulting hulled oats are cut into angular fragments in a special grinder, *steel-cut oats* are produced. Rolled oats are made by steaming the hulled oats, and then flattening them between heavy iron rollers. Such oats are already partially cooked due to the parching treatment in the kiln, and the steaming before rolling.

Smaller, or more finely ground rolled oats cook somewhat more rapidly than the large flake, and constitute the *rapid oats*, which can be made into a porridge with a few minutes of cooking.

This process of oat meal production serves to refine certain parts of the oat kernel, thus producing a food for human consumption which is free from the fibrous hull of the grain. The hull is both unpalatable, and of no value as a source of food for man. By-products of the oat-mill, such as oat shorts and oat feeds, par-

ticularly when combined with other feeding stuffs may be used as mixed animal feeds.

Chemical manipulation of oat-hulls, as involved in digesting them with strong mineral acid solutions, yields a product known as furfural. Furfural is used in a variety of ways, including the production of plastic resins having properties somewhat like that of Bakelite.

CORN AND MAIZE PRODUCTS

Indian corn or maize is the distinctively American cereal. Several kinds or species of maize were found growing in America when the early European settlers arrived. These included pod-corn, soft corn, pop-corn, sweet corn, flint corn, and dent corn. The latter is the most common type handled in commerce. The first two species named, pod-corn and soft corn, are raised only to a very limited extent. Pop-corn is well known to the American boy and girl because of the delicious products which can be made from the popped grain. Sweet corn yields roasting ears rich in sugar, and "what we can't eat we can." Flint corn is grown in the northern portions of the corn belt, although even there it is gradually being replaced by the hardy varieties of dent corn.

Breeding strains of dent corn rich in fat or oil, and rich in protein has been attempted at the Illinois Agricultural Experiment Station. While the strains selected did not yield as much grain per acre as the ordinary corn from which they were selected, it appears that after a quarter century of effort the quantity of protein, or oil produced per acre can be substantially increased by growing the high protein and high oil strains. Corresponding reductions in the yield per

acre of these constituents can be effected by growing the low protein and low oil strains.

Recently an effort to increase the average protein content of certain varieties of dent corn has been attended with a considerable degree of success at the Minnesota Agricultural Experiment Station. These experiments have not yet resulted in any substantial modification of agricultural practice in the corn belt. They demonstrate forcefully that such crop plants lend themselves to manipulation in the hands of the plant breeder, however, and that a modification of the chemical composition of the grain of maize or corn can be effected by breeding.

In preparing corn for human food a great variety of products have been manufactured. Possibly the simplest process involves merely parching the entire grain which may then be munched or pulverized into meal. Meals of all degrees of fineness may be milled from corn. A coarse, fibrous meal made by grinding the entire kernel requires the least machinery. If the grain be ground by a gradual reduction process, including the use of a machine known as the degerminator, grits may be produced which, on reduction, yield a flour, or a degerminated meal. Such meals possess much better keeping qualities than the whole corn meals.

Hominy grits made in this gradual reduction process have been utilized in a number of ways. They were formerly used, in connection with barley malt, in the brewing of beers and ales. Hominy feed, which includes corn bran, and much of the starchy portion of the kernel and the germ, is a by-product of dry milling of corn and finds a use in stock feeding.

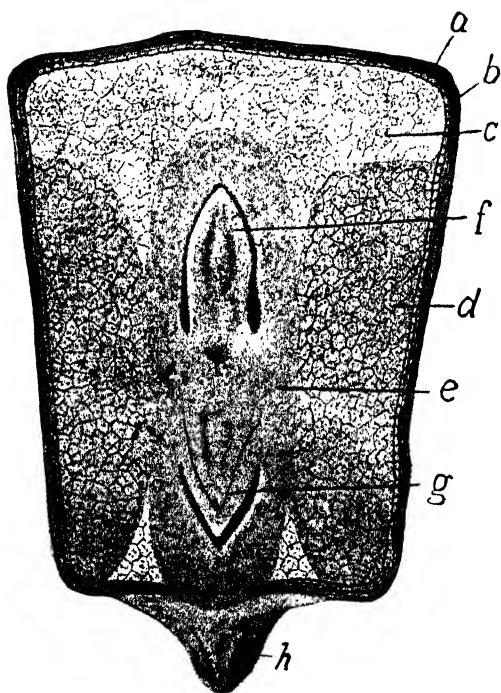
Another type of "hominy" sometimes known as hulled corn has long been made in American homes by

soaking whole corn kernels in a dilute lye solution and then rubbing off the loosened hull under water. Such hominy constitutes a very delicious porridge and is now made on a large scale and sold in cans.

Wet milling of corn effects a more exact separation of the various parts of the kernel from one another than can be accomplished by the dry milling process. These kernel structures are shown in Fig 2. In wet milling the corn is soaked in water acidulated with sulphurous acid, and the soaked kernels are torn apart in a grinding machine. This loosens the germ which can then be floated off with water, thus separating it from the remainder of the kernel. The separated germ is ground, partially dried, and the oil which it contains can be squeezed out in a special press made for this purpose. This oil is then refined and used as an edible oil in salads, for cooking purposes, and in various other ways where a refined vegetable oil is required. The residue of the germ after the oil is expressed, known as corn oil cake, is very rich in protein and constitutes a valued addition to mixed cattle feeds. In the ground state it is sold as corn germ meal.

After the germ has been removed from the cracked grain, the residue is finally ground in a wet condition and is then filtered through sieves which hold back the bran but allow the dissolved or suspended particles of corn "gluten," and the starch granules to pass through. The starch is recovered by allowing it to settle out in long troughs while the "gluten" flows out of the troughs and is then recovered. The wet "gluten" and bran can then be mixed, dried, and ground yielding a gluten feed useful in cattle feeding.

A great variety of products can be made from the crude starch recovered from the settling tables or



Courtesy of F. B. Morrison.

Fig. 2

Diagram of a Kernel of Dent Corn

A, hull; b, hornlike gluten; c, floury starch; d, horny starch; e, embryo, or germ; f, embryo stem; g, embryo root; h, tip cap.

troughs. When treated with water containing a little lye to remove traces of materials other than starch, followed by washing and drying, a purified starch results which is known as pearl starch, in the lumpy condition, and as powdered and table starch when finally pulverized. Thin boiling starch is made by warming ordinary starch with water containing a small amount of acid followed by drying of the resulting paste. Such starch penetrates fabrics better than an ordinary thick starch paste and gives body to the fabric without an extreme stiffness. Thin boiling starches are also used in the manufacture of certain confections.

Dry powdered starch when roasted yields a series of products known as dextrins the characteristics of which depend upon the conditions of heating. Spraying the starch with acid before roasting hastens the dextrinizing process. A variety of dextrins are available for various purposes, particularly in sizing cloth and as an adhesive for use on labels, gummed tape, and the like.

An interesting chemical change in corn starch can be effected by heating it in the presence of water and a small quantity of hydrochloric acid. Under these conditions the starch reacts with water to form maltose or malt sugar which, in turn, is further split yielding a sugar known to the chemist as glucose or dextrose and to the trade as corn sugar. The familiar corn sirup is prepared by concentrating the thin liquor in a vacuum pan. Ordinary corn sirup consists of about 20 per cent of water and about one half of the remaining 80 per cent is glucose, the other half being a mixture of non-sugar substances, chiefly dextrins. Such a sirup is sometimes mixed with cane sirup for table purposes. The cane sirup is distinctly sweeter

than the glucose sirup thus rendering the mixture more palatable for use in certain connections.

Several types of corn sugar can be prepared from the thin liquor which results from the treatment of corn starch with water and hydrochloric acid. If the starch has been treated so that about 85 to 95 per cent of it has been converted into sugar, and the sirup evaporated and cooled, a cake or solid mass is formed. This contains a small amount of material which does not crystallize, and this non-crystalline material can be squeezed out in a hydraulic press. Varying degrees of purity in the resulting product can thus be obtained, depending upon the extent of hydrolysis of the starch, and the care with which the non-crystalline material is pressed out. The more refined products have been used in brewing and in bread making.

A fairly pure crystalline glucose is now being manufactured on a large scale by almost completely hydrolyzing the starch, carefully clarifying the sirup, evaporating, seeding with sugar crystals, and then allowing the sugar to crystallize out. Cerelose is a familiar example of such a product which is almost pure glucose. The bright glistening crystals of this product are suitable for use in a variety of connections as in bread making, ice cream, and various confections.

The various stages in the wet milling and processing of corn are illustrated diagrammatically in Figure 3. These come under rather exact chemical control. The regulation of the acidity of the steep water, the adjustment of the acidity of the hydrolyzed corn sirup at the time of precipitating out the remaining traces of corn gluten, the control of the digesting and evaporating processes in making corn sirup and corn sugar, all fall to the lot of the chemist in the corn products factory. The various grades of starch and types of

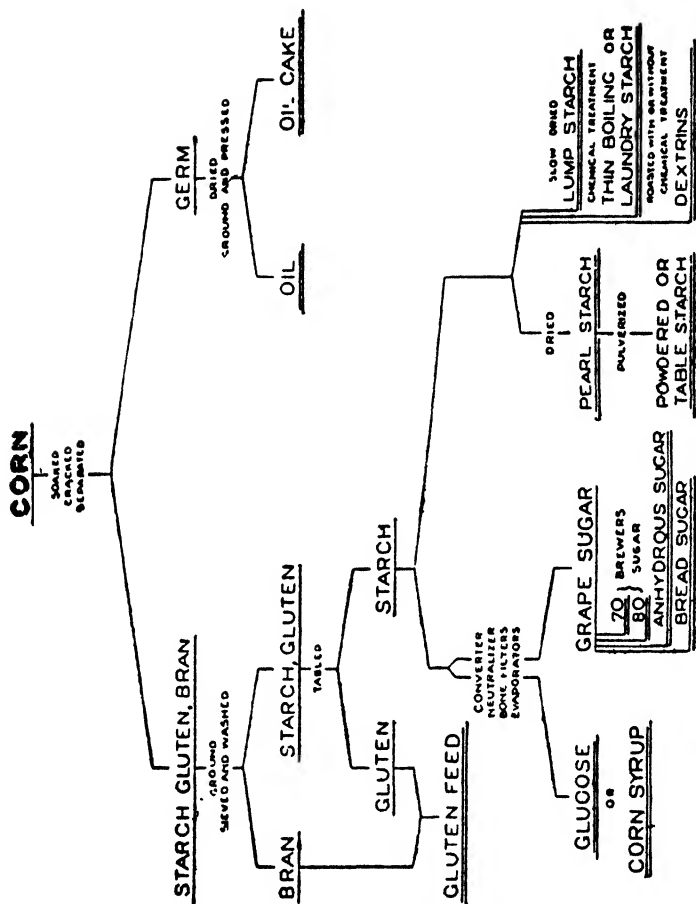


Fig. 3.—Diagram Showing Steps in the Manufacture of Various Products From Corn.

dextrins are also carefully tested during processes of manufacture.

On the farm corn is utilized in numerous ways: harvested in a slightly green state by cutting off the stalk just above the ground followed by careful curing yields a useful fodder known as corn fodder. Permitting the plant to ripen and the corn to cure on the cob, followed by the removal or snapping of the cob either by hand or with machinery yields the fa-

miliar ear corn and the stalks and leaves are known as corn stover and constitute a rather low grade form of roughage for use in cattle feeding. Such corn is usually rather high in its content of moisture at the time of snapping and must be carefully cured to prevent spoilage of the grain. When the green plant is cut and chopped finely and then packed in a tight silo, a form of fermentation takes place which yields products that tend to preserve the silage. Reference to this process is made in the chapter on Fermentations.

RICE AND RICE PRODUCTS

Rough rice or paddy includes the fibrous harsh, outer hull of the rice berry, the bran and the inner edible portion. The hull is removed by a milling stone that cracks and loosens the hull which can then be sifted or blown out of the mixture. This hull is so fibrous and silicious as to be of little value for feeding purposes and it is hazardous to feed it to farm animals, hence it is often burned in the mill furnace. The brown rice which results from this initial hulling process still has attached to it the portions of the berry which lie just within the coarse hull. These layers contain much of the more important mineral nutrients and the vitamins which are present in the original berry. For this reason brown rice may fill a certain place in the dietary which can not be filled by the more highly polished products. When the brown rice is further treated in a huller, the outer or bran layers are rubbed off yielding rice bran as a by-product. This has value as a cattle feed particularly when mixed with other suitable concentrates. The stream of rice is then cooled, and is given a polishing in a machine known as a "brush" which delivers a brighter-appearing product

than the rice from the huller. A still higher finishing can be given with talc and glucose. The finished rice may be graded or sized over a series of screens, and is then ready for cooking. Such polished rice is very attractive in appearance and can be converted into palatable dishes which are a useful source of energy to the individual who uses them in combination with other dishes in a properly balanced ration.

RECAPITULATION

It is evident to those who have read the foregoing sections of this chapter that the important products of the cereal industries designed for human consumption differ in general from the original grain or raw material in several particulars. In the first place, they are not infrequently freed from much of the fibrous and less digestible, outer portions of the berry or grain from which they are produced. Secondly, this process of refining which removes the outer part of the berry likewise tends to yield a refined product which is freer from dirt, bacteria, molds, and other objectionable impurities than the original grain. Third, the keeping qualities of the refined products are ordinarily enhanced in consequence of the processing to which they are subjected. Fourth, the palatability, eating qualities, and general attractiveness of the refined products are not infrequently superior to that of the untreated grain. Fifth, in the instance of certain products these are marketed in such form as to be immediately available for human consumption without further treatment or cooking.

In the development of these industries the chemist has played an important role. While many of the industries, such as flour milling and oat milling made

great advances in the mechanics and technique of essential operations without the aid of the chemist, the laboratory is now expected to aid and guide in the selection of raw material and the control of manufacturing operations. The chemist is also expected to indicate possible uses for the finished products. Biochemists have likewise classified and rated various cereal foods on the basis of their vitamin and mineral content, the adequacy of their proteins, and their proper place in the mixed diet.

These refined food products of the cereal industries fill a very important place in the American dietary. Most of them are marketed in a dry state which means that they may be stored for fairly extended periods at ordinary temperatures without spoiling. Their dry condition also means that pound for pound they yield larger amounts of available energy than do the moist food stuffs. As a source of energy in combination with other normal constituents of the balanced diet our edible cereal products occupy a unique position in the economy of the household and the individual.



Harvesting Sugar Cane

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CHAPTER VII

SUGAR AND SUGAR CROPS

BY C. A. BROWNE

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Have you ever paused to think of the important part which sugar, starch and cellulose play in our daily life? They belong to the chemical group known as carbohydrates and are the most abundant of all plant constituents and contribute most extensively to our various domestic and industrial needs. They are called carbohydrates because they are compounds of the element carbon, with hydrogen and oxygen, the two latter being present in the respective atomic proportions of two to one as in water. They are produced primarily in the leaves of all green plants, under the activating influence of sunlight, by a combination of the carbon, from the carbon dioxide of the air, with the water which is absorbed through the roots from the soil. Sunlight, air and water being thus the only natural requisites which the plant needs for the production of carbohydrates, the latter from the standpoint of fertility may be considered to be among the most economical of agricultural products, for if the crop residues be all restored to the land the removal of carbohydrates does not necessitate the abstraction of any fertilizing ingredients from the soil.

Consider for a moment some of the valuable uses

of this highly important group of plant substances. The three basic necessities of shelter, clothing and food are supplied in a large degree by the carbohydrates. The wood of our houses and furniture; the tissues of our linen and cotton fabrics; the paper that decorates our walls, or that is used in making wrappers, pictures and the materials for writing and printing; all consist mostly of the carbohydrate cellulose. The principal constituent of bread, potatoes, rice, hominy and many other foods is the carbohydrate starch. The sugar which is used so abundantly in the home for sweetening beverages, cereals, fruits, etc., and for making pastry, ice cream, preserves, and candy is another member of the carbohydrate family. In the beautiful white crystalline form in which it comes upon the table sugar may be called the only common food of perfect solubility and chemical purity.

The principal agricultural sources of sugar are the sugar cane and the sugar beet, although a certain amount is also produced from the sugar maple and sugar palm. It is known chemically as sucrose in order that it may be distinguished from certain other soluble carbohydrates, which belong to the general class of sugars and are found in many articles of food—such as lactose (milk sugar), maltose (malt sugar), dextrose (grape sugar) and levulose (fruit sugar). These five crystallizable carbohydrates—sucrose, lactose, maltose, dextrose and levulose—differ greatly from one another in sweetness, solubility and other properties. For certain specific dietary and industrial uses each one of them has individual points of advantage. Although chemically they are all known as sugars, the specific term *sugar*, as commonly understood, has always been limited to sucrose and the word is so used in the present chapter.

THE WORLD'S PRODUCTION OF SUGAR

For the crop season of 1924-1925 the total production of cane and beet sugar for the entire world was 23,115,532 long tons, which is the largest amount ever manufactured in a single year. Of this quantity 14,930,147 long tons, or 64.6 percent, was cane sugar, and 8,185,385 tons, or 35.4 percent, was beet sugar. The production, in order of importance, for the ten leading countries during the crop season of 1924-1925 was as follows:

Country	Long Tons of Sugar	Kind of Sugar
Cuba.....	5,100,000	Cane
United States and Colonies.....	2,757,837	Cane
British India.....	2,537,000	Beet
Java.....	1,977,490	Cane
Germany.....	1,600,000	Beet
Czecho-Slovakia.....	1,460,000	Beet
France.....	830,000	Beet
Brazil.....	500,000	Cane
Poland.....	495,000	Beet
Japan and Formosa.....	460,000	Cane

HISTORY OF THE CANE SUGAR INDUSTRY

Sugar has been known as an article of commerce since about 300 A.D. Previous to this time honey and the concentrated juices of various fruits and plants were used as the only sweetening agents; among the oldest and best known plants to be used for this purpose is the sugar cane.

The sugar cane, which thrives only in tropical and semi-tropical countries, grows in long jointed stalks, varying from six feet in length for inferior plants to twelve feet or more for a well-grown crop, and resembling somewhat in appearance the stalks of Indian corn. The early methods of pressing the stalks and

concentrating the juice were very crude, the sugar that was produced being consequently of a most inferior quality, as is still the case in many primitive countries.

Those of you who are interested in history will find the story of the sugar cane of exceptional interest. The native home of the sugar cane, as of so many other cultivated plants, is southern Asia and we find it mentioned repeatedly in the old sacred books of the Hindus and in ancient Chinese writings many centuries B.C. The Greek soldiers of Alexander the Great saw the sugar cane growing in India at the time of their conquest of Asia in 327 B.C., and brought back to Europe the first accounts of the wonderful reed which yielded a juice sweeter than honey. It is doubtful, however, whether sugar was manufactured from the cane so early as this. The cane was at first simply eaten, just as in primitive countries at the present time, the expressed juice being used also as a beverage or fermented into a kind of wine. At a later period cane juice seems to have been evaporated in the household for making preserves or sweetmeats, and the sweet crystalline deposits which separated from the evaporated juice probably gave the early people of India their first ideas of sugar making. It is not until after the third century of the Christian era that we find, in old Chinese writings, the first mention of sugar as a commodity of commerce, although it is probable that sugar was made on a small scale long before.

From its native home in India the sugar cane was carried Eastward and Westward. It was introduced by the natives through the islands of the East Indies, the Philippines, and the rest of that great archipelago. Thence it was carried to Samoa, Tahiti, and the other islands of the southern Pacific, and from there it was

transported by daring native navigators to the Hawaiian Islands, where it was found growing by Capt. Cook at the time of his voyage of discovery. The Pacific Islanders, however, cultivated the sugar cane simply for the purpose of eating its stalk or drinking its juice; none of them ever advanced far enough to manufacture sugar, and for the development of this art we must turn to the western nations.

The first people to transport the sugar cane westward were naturally the Persians, whose country adjoined India. The Persians not only grew cane for eating, or for its juice, but also made some progress in sugar manufacture. Traces of Persian influence survive to the present day, as, for example, in our word candy, which is derived from the Persian, "Kand," meaning hard or refined sugar. For raw sugar the Persians had a different word, "schakar," similar to our word, sugar, a word very much alike in all languages, and derived from the original Indian or Sanskrit word, "sakkara."

It is to the Arabs, however, that we owe the introduction of the sugar cane to the nations of Europe. The Mohammedans, in their conquests of Persia and India, came early in contact with the sugar cane and transplanted it to the conquered nations of the west. Improvements in cultivation and irrigation were introduced, and the familiarity of Arabian alchemists and physicians with the process of recrystallizing salts led them, no doubt, to apply the same principle in refining sugar. In the books of the great Arabian scientist, Avicenna, who lived about the year 1000, we find sugar described as we now know it, and from this time onward the use of sugar was destined to increase, until from one of the rarest and most expensive articles of

luxury it became one of the cheapest and most abundant commodities.

From the valley of the Tigris and Euphrates the Arabs carried the sugar cane into Egypt and Palestine and, with the extension of their conquests westward, transported its culture to Asia Minor, northern Africa, to the Mediterranean islands of Cyprus, Rhodes, Crete, Malta, and Sicily, and finally to the continent of Europe itself, where it was widely cultivated in southern Spain, its culture surviving there to the present day.

One great factor which favored the introduction of sugar to Europe was the Crusades. Readers of Joinville's chronicle will remember how the crusaders found the sugar cane growing in Palestine and, like the soldiers of Alexander 1500 years before, brought back stories of the wonderful reed whose sweet juice invigorated them after weary conflict or march. One of the chief benefits of the Crusades was the expansion which followed in the commerce between Asia and Europe, the chief city for the importation of Eastern commodities being Venice. The Venetians improved the art of refining sugar, which they learned from the Arabs, and during all of the 14th and 15th centuries held a monopoly for supplying Europe with sugar.

With the increase in consumption of sugar, the areas for the cultivation of the sugar cane widened. In 1420 the Portuguese transplanted the cane from Sicily to Madiera, and shortly after this time it began to be cultivated in the Canaries, Azores, and other western islands.

Immediately after the discovery of America followed the transplanting of sugar cane to the western hemisphere. Columbus on his second voyage, in 1493, car-

ried with him sugar cane from the Canaries to San Domingo. The cane thrived so well in its new surroundings that the sugar industry spread rapidly to Cuba, Mexico, Brazil, and other provinces of the New World. In Louisiana, several unsuccessful attempts were made to introduce cane culture, but it was not until 1794 (three centuries after the first cane was brought over by Columbus) that the industry was established on a paying basis.

PRODUCTION OF NEW SUGAR CANE VARIETIES

In the long years of its history the sugar cane is probably but little richer in sugar than it was when the soldiers of Alexander first tasted its juice. There is an important reason for this; the sugar cane is propagated entirely by planting the stalks, the bud at each joint germinating and producing a new cane of the same character as the parent stalk. It is almost impossible to improve a cultivated plant without the agency of seed production; there must be cross-fertilization and some process of controlled selection. The sugar cane produces seed in a feathery plume at the end of the stalk, but this seed had been regarded as sterile until about forty years ago when it was found under favorable conditions that some of the seeds could be made to germinate.

Thousands of new varieties of sugar cane have resulted from this discovery and some of these so-called seedling canes, from their greater productivity and sugar content, as well as from their greater resistance to disease and unfavorable climatic conditions, have displayed many of the old-established varieties. In the nurseries of tropical countries, where new varieties of sugar cane are bred, the problem of selection de-

volves partly upon the chemist, who, working in close cooperation with the plant breeder, determines the percentage of sugar and the purity of the juices in the different canes.

THE AGRICULTURAL CHEMISTRY OF GROWING, FERTILIZING AND CULTIVATING SUGAR CANE

The agricultural operations of planting, fertilizing, cultivating and harvesting the sugar cane, require a large amount of labor, the expense for these making up about three-fourths of the cost of the raw sugar, the other one-fourth being due to the expense of manufacture.

As with all plants, the chemical substance of greatest importance to the sugar cane is water which makes up about 75 percent of the weight of its stalks and leaves. It has been determined that a single plant of sugar cane transpires through its leaves an average of half a pint of water during each day of its growth, although in times of drouth the quantity may be double this amount. As a general rule it has been estimated that the sugar cane requires a thousand pounds of water for each pound of sugar produced. It is therefore of primary importance that the sugar cane be furnished with water in the proper amount with avoidance of either a deficiency or an excess.

In regions of moderate rain-fall the sugar cane usually thrives best upon calcareous clayey soils. Where rain is over-abundant the soil should be of a more sandy and porous texture in order to facilitate drainage. Water logging of the soil is very detrimental as it causes the cane crop to grow sickly and diminish in yield. This is because the soil is deprived of the atmospheric oxygen which is so necessary for

promoting the biological and chemical activities of the roots and of beneficial soil bacteria. Wet lands require drainage, which is also necessary for soils that are salty or which contain an excess of alkali, otherwise the yield and quality of the sugar cane is very adversely affected. When rainfall is deficient irrigation is required. The water-holding capacity of the field is greatly improved by ploughing under cane leaves, manure and other organic matter, which by their decay contribute to the humus of the soil. Thorough cultivation of the cane fields before and after planting is necessary in order that the effects of weathering and bacterial action may produce the best results. Under the favoring conditions of a humid tropical climate the chemical processes of oxidation, hydration and nitrification advance with great rapidity, the elements of plant food being unlocked from the soil and made available in a much shorter period than in temperate zones. This would be a decided advantage were it not for the fact that denitrification and the other forces which impair fertility are equally rapid.

The four fertilizing elements which must be considered chiefly in growing sugar cane are nitrogen, potassium, phosphorus and calcium. The following table indicates approximately the number of pounds of these elements which are contained in a crop of 1000 tons of stalks and in the factory products when this crop is made into sugar.

If the leaves and tops, filter-press cake, and bagasse ashes be restored to the soil, the removal of the raw sugar and molasses and the burning of the bagasse as fuel will occasion a loss of about 5 percent of the original phosphorus in the crop, about 10 percent of the original nitrogen and about 25 percent of the original potassium. There will be an actual gain in

	Nitrogen Lbs.	Potassium Lbs.	Phosphorus Lbs.	Calcium Lbs.
Leaves, tops and roots....	2,500	6,200	500	1,400
Stalks.....	1,000	2,500	450	350
Contained in the crop.	3,500	8,700	950	1,750
Raw Sugar (96% Sucrose)	50	450	5	35
Molasses.....	250	1,800	45	175
Bagasse (cellular residue after expressing juice)..	100	250	50	35
Filter Press-Cake (impuri- ties from juice).....	600	350	525
Contained in Factory Products.....	1,000	2,500	450	770

calcium owing to the lime in the press-cake that was added in manufacture. The molasses is the chief depleting product, but if this be fed to farm animals and the excreta of the latter be applied to the soil, the loss of fertility from producing a crop of sugar will be much reduced. If the cane stalks be removed from the field without the application of any fertilizer or factory residues, as is often done, there will be a loss, assuming that all leaves and tops are ploughed under, of approximately 30 percent of the nitrogen, 30 percent of the potassium and 20 percent of the calcium removed by the crop. In actual practice the crop and factory residues are only partially restored to the land, the result being a continued gradual loss in fertility, unless the necessary elements of plant food be restored by the addition of fertilizers. When the sugar cane is allowed to spring up continuously each year from the old stumps (a process called ratooning or stubbling), without reploughing of the land, the diminishing yields of cane become more marked since the roots of the growing crop are impeded in their growth and confined to a partially exhausted soil that needs to be reworked for the liberation of new supplies of plant food.

Experience has shown that the fertilizing element which gives the maximum yield of sugar cane is nitrogen in some of its more readily available forms. The highest returns have been secured from quick reacting concentrates such as sodium nitrate and ammonium sulphate. The applications of sodium nitrate should not exceed 250 lbs. per acre, as too great an excess may cause an alkaline condition of the land and exercise an unfavorable deflocculating action upon the soil. Ammonium sulphate has been employed with favorable results in quantities as high as 400 lbs. per acre. Nitrogen has also been supplied advantageously to the sugar cane by the ploughing under of organic materials such as cotton seed meal and cowpeas (planted with corn as a rotation crop). Potassium, phosphorus and calcium are applied less frequently than nitrogen, as fertilizing elements to the sugar cane, as they occur in the soil in relatively larger amounts and are less subject to the causes of natural loss. In many alluvial lands the normal weathering of the soil is found to render more potassium and phosphorus available than is needed for the cane crop. With poorer soils, however, the addition of 50 to 150 pounds of potassium sulphate and of 300 pounds of superphosphate has been found to be of great benefit.

Fertilizers produce the best results at the first stages of the cane's growth by causing an early vigorous development of leaves and roots. The principal effect of nitrogen is to produce a large growth of leaves, and as the latter are the sugar producing organs of the cane their early profuse development is of primary importance for securing the best yields of sugar. The excessive application of fertilizers must, however, be avoided as with too pronounced a growth of the vege-

tative organs there is a marked delay in the ripening of the stalks.

When the cane land has been prepared parallel furrows, about five feet apart, are ploughed across the field, and into these the cane stalks, or tops, which serve as seed, are planted. After being covered with earth the buds quickly germinate and the young cane plant soon emerges above the ground. New underground buds give rise to suckers so that from a single eye on the parent stalk a large stool of canes (sometimes twelve or more in number) may eventually arise. The sugar and other nutrients contained in the seed stalk serve as food to the plantlets until the young canes have sufficient leaves and roots to shift for themselves. The sugar which is elaborated in the leaves of the cane is transported downwards into the stalk, where it gradually accumulates, the amount being always greater in the older lower joints than in the upper younger sections. The approach of cool weather checks the growth of the cane and causes a rapid increase of sugar in the stalks until at the time of harvesting the percentage of sugar in the cane may vary from 10 to 18 per cent, depending upon climatic conditions and upon the variety and maturity of the crop. In Louisiana, where the cane must be harvested in November, before the arrival of frost, the period of the cane's growth is only about eight months, and complete maturity is never reached. In Hawaii, where more favorable climatic conditions exist, twenty-two months are sometimes allowed to elapse between the germination of the cane and harvest.

THE CHEMISTRY OF MANUFACTURING RAW CANE SUGAR

Let us now follow hastily the course of sugar from the time it leaves the field until it is bagged for ship-

ment, basing our observations on modern Cuban practice. When the sugar cane has reached the proper stage of ripeness, which in Cuba occurs in December, the operation of harvesting begins. The cane is cut entirely by hand, this first step of the process having undergone no real change since the industry began. Harvesting by hand is expensive, yet inventors have spent their lives and fortunes in efforts to perfect a cane harvester. The great difficulty lies in the irregular growth of the cane, the stalks in some cases being so crowded and intertwined that the field is an impassable jungle. Consider also the mechanical complications of a machine to cut the cane close to the ground, strip the leaves, and clip off the green top, while wasting none of the valuable part of the stalk. Several inventors have almost solved this problem, and the one who first succeeds will be enrolled among the great benefactors of the sugar-cane industry, and, incidentally, will reap a considerable fortune.

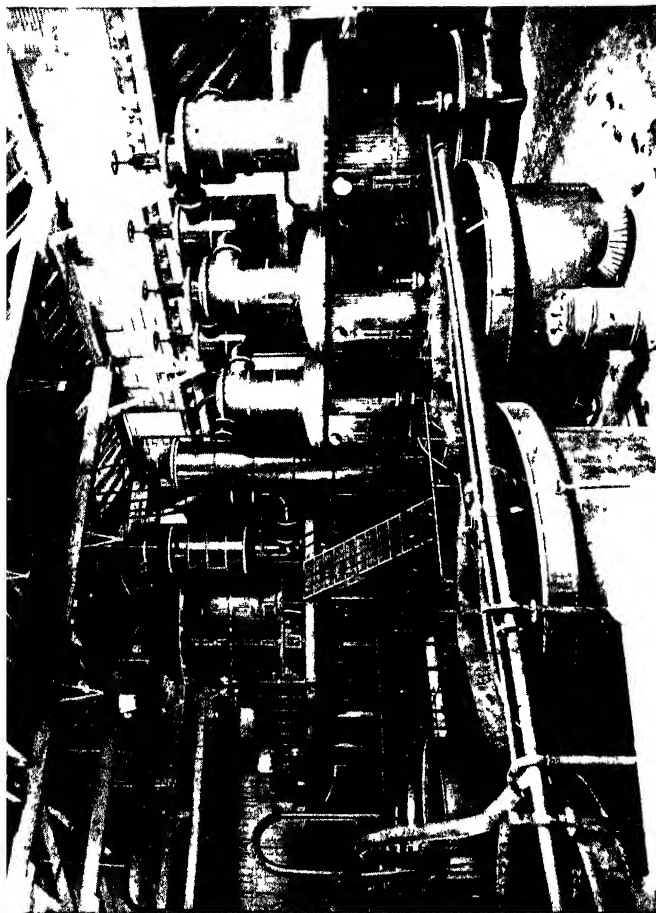
The cane is next piled by hand upon carts and hauled to the factory. In the old days oxen or mules were the sole means of transportation between field and mill, and the area upon which a factory could draw for its supply of cane was limited by the hauling distance. Since the advent of the steam railroad, cane is now sometimes hauled fifty miles or more to the factory. The ox teams deliver the cane to cars at the nearest siding, where it is transferred by hoists. When enough cars are filled, a train is made up and hauled to the factory. This method of transporting has vastly increased the cane areas upon which a factory may draw, and has rendered possible the erection of those large central establishments, some of which manufacture 50,000 or more tons of sugar in a season. One estate owns over 100 miles of railroad, and has

some 1000 cars and 20 large locomotives. A train despatcher and force of signalmen are needed to keep the trains moving with regularity.

The grounds before one of these factories resembles a large freight yard with its numerous tracks and switches. As the trains of cane arrive, the cars are rapidly switched to the proper stations and are emptied by mechanical means onto a large conveyor. The conveyor carries the cane up a long incline, and the mass of tangled stalks finally falls between two huge corrugated rollers forming the crusher. This reduces the stalks to an even blanket of pulp and squeezes out at the same time a large amount of juice, which flows away at the bottom. From the crusher the cane passes to the first mill, which consists of three powerful rollers, two below and one above; it is next conveyed to a second and a third mill, and in some cases to fourth, fifth, and sixth sets of rollers; in the latter case there would be eighteen rollers in the milling plant in addition to the two rollers of the crusher. Between the mills a thin stream of water is sprayed on the cane, which, being eliminated by the succeeding rollers, carries with it more and more of the residual sucrose. This process is called maceration, and requires careful control.

As the cane advances the pressure on the rollers is gradually increased by powerful hydraulic presses. When the fiber leaves the final rollers to be burned as fuel under the boilers of the factory, it still contains between 40 and 50 per cent of moisture (usually nearer 50 per cent), with a small residue of unextracted sugar. The best mills extract over 95 per cent of the total sugar in the cane.

The expressed juice from the crusher and mills is then pumped into tanks, called defecators, where it is



Interior of Cane Sugar Factory

Clarifying tanks at left, triple effect evaporator in background, at right, vacuum fan on raised platform in rear

treated with milk of lime to neutralize its acidity, after which it is heated to boiling by steam coils. The lime combines with the organic acids of the juice to form insoluble compounds, and the heat coagulates the albuminous matter. A flocculent precipitate is formed, which partly rises to the surface to form a blanket of scum and partly settles to the bottom as a sediment. After standing a short time the clear juice is drawn off, while the sediment and scums are passed through filter-presses and washed to remove adhering sugar, the runnings from the presses being then added to the main body of clarified juice.

The clarified juice is next evaporated in the multiple effect evaporator, an important piece of apparatus invented in 1846 by Norbert Rillieux, of New Orleans. He conceived the idea of evaporating sugar cane juice in several large closed pans, which were so connected that the hot steam from the evaporating juice in the first vessel boils the more concentrated sugar liquor in the second, and the steam from the second vessel boils the still more concentrated solution in the third, and so on. Diminishing the atmospheric pressure in the succeeding vessels, by exhausting more of their air as the heating power of the steam diminishes, enables the solutions to be boiled entirely by the heat which was supplied to the first unit of the series.

The concentrated sugar cane syrup from the multiple effect is then further evaporated in a single large closed cylindrical apparatus called the vacuum pan, which was invented by the English chemist and sugar refiner, Edward Howard, in 1813. Previous to that time sugar solutions had always been evaporated in open kettles over the direct fire which caused a large destruction of sugar by over-heating. Howard found that by boiling sugar solutions with steam coils in a

closed apparatus, from which the air had been pumped, the temperature of evaporation was greatly reduced; losses from over-heating were prevented and a greater yield and higher quality of sugar were obtained. The efficiency of the vacuum pan was afterwards increased by the addition of the condensing column, which was patented in 1828 by John Davis for an unknown British inventor. The condensing column consists simply of a large upright pipe, some thirty-five feet or more in length, in which the vapors from the vacuum pan are condensed by means of cold water flowing downwards. This condensation, aided by the barometric weight of the water column, produces a very high vacuum. The vacuum pan, which is one of the most important pieces of apparatus employed in chemical technology, is employed in the manufacture of many agricultural products.

The cane syrup from the multiple effect is concentrated in the vacuum pan until the sugar crystallizes out from the solution, the thick mass of crystals and mother liquor being called the *masse-cuite* (from the French words meaning cooked mass). The latter is then whirled in rapidly revolving perforated drums, called centrifugals, which causes most of the mother liquor (molasses) adhering to the crystals to be eliminated; the raw sugar remaining in the centrifugals is then usually washed with a fine spray of water to remove more of the adherent molasses and then after additional whirling, to render it as dry as possible, emptied into conveyors, from which it is filled into bags and sent to the warehouse for shipment.

The molasses which escapes from the centrifugals still contains a considerable quantity of sucrose, and many processes have been devised to reduce this

amount to the minimum. Owing to the accumulation of soluble impurities, such as invert sugar, gums, etc., in the molasses, and the high viscosity, the sucrose crystallizes out with much greater difficulty than from the original evaporated juice. In order to promote the crystallization, use is made of crystallizers. The molasses is sometimes boiled down to a second crystallization and then emptied into the crystallizer, where it is slowly stirred by revolving arms. Or a certain amount of molasses may be drawn into the vacuum pan and boiled down with the *masse-cuite* from the pure juice, the whole being afterwards run into the crystallizer. Whatever the process, of which there are many modifications, the crystallizer simply facilitates the building up of crystals by keeping the particles of sugar always in contact with fresh portions of molasses. When the crystallization is finished, as is determined by analyzing a sample of the filtered mother liquor, the contents of the crystallizer are run off into centrifugals, the sugar purged, and the waste molasses pumped into tanks from which it is usually sent to distilleries for fermentation into alcohol or to feed-stuff establishments for the manufacture of mixed feeds.

The evaporation of the sugar cane juice to a *masse-cuite* is performed in some places to a very limited extent by the old process of using open pans or kettles. The crystallized *masse-cuite*, thus made, is then poured into hogheads having openings at the bottom for the drainage of the molasses. The residue of moist sugar is called *muscavado*, and the molasses which drains therefrom is usually known as open-kettle molasses. The old-fashioned muscavado sugar and open-kettle molasses had an agreeable flavor of caramel which

made them very popular for cooking. Their manufacture has now largely disappeared.

THE CHEMISTRY OF REFINING RAW CANE SUGAR

The raw sugar which is produced upon tropical plantations contains usually about 96 percent pure sucrose, the remaining 4 percent consisting of moisture, mineral matter, dextrose, levulose and other organic substances. These foreign ingredients must all be removed before the pure white granulated, or lump, sugar for domestic and industrial use can be obtained. The removal of these impurities, a process known as sugar refining, has become a food industry of great importance.

Because of economies in transportation and distribution sugar refineries are located usually in large cities upon the seaboard. The raw sugar, which is brought in steamships from the tropical countries of production, is unloaded at the refinery docks from which it is taken by mechanical conveyors into the refinery. It is first emptied into a large mixing machine, where it is thoroughly mingled with a thick syrup of sugar. This magma of syrup and crystals, which resembles a brown mortar in appearance, is then whirled in rapidly rotating centrifugal machines, the syrup that was added being thrown off and carrying with it much of the soluble impurities adhering to the crystals of raw sugar. The swiftly revolving mass of crystals is then washed with a fine spray of water which, being driven by centrifugal force through the cylindrical wall of sugar, carries with it most of the remaining impurities. Care must be taken not to employ too much water in this process of washing, or *affining*, as it is called, as otherwise a large amount of the sugar itself will be dissolved.

The washed sugar, which still retains a small amount of residual dirt and impurities, is then dissolved in water in steam-heated tanks called "blow-ups" and clarified by the addition of lime and phosphoric acid which causes most of the remaining impurities to be thrown out as a flocculent precipitate. The clear filtered solution from this precipitate has an amber colored appearance, and to render it water-white it is allowed to percolate through large tanks filled with coarsely ground bone charcoal. This substance has a strong absorptive power, for the dissolved coloring matter and the sugar solution runs from the char filters perfectly clear and brilliant. After a few days' use the bone char begins to lose this absorptive power when it has to be washed and burned in revivifying kilns before it can be used again.

The colorless sugar solution from the char filters is next evaporated in multiple effects to a thick syrup, which is further concentrated in vacuum pans to a *masse-cuite*, this part of the process being similar to that employed in the manufacture of the raw sugar. The refined *masse-cuite* is then spun out in centrifugals, the moist, white mass of sugar crystals being then either dried in large revolving drums, called granulators for making granulated sugar, or else after pressing into molds dried in ovens for making into tablet sugar.

The liquors and washings from the centrifugal machines are again boiled down to recover as much as possible of the sugar which they contain; the residual liquor from which no more sugar is obtainable may then be filtered over bone char and sold as "Refiner's Syrup," or else marketed directly as "Refinery Molasses."

THE SUGAR BEET AND THE BEET SUGAR INDUSTRY

The history of the beet sugar industry extends back only about one hundred and fifty years, but though many centuries younger than the cane sugar industry, the story of the development of beet sugar manufacture is in many respects more interesting to the chemist. The sugar beet may be called the foster-child of chemistry. In its wild uncultivated form, even as we find it growing today, the primitive stock of the sugar beet is a very unpromising source of sugar. The beet, however, belongs to a much younger family of plants than the cane; its habits are not so firmly fixed; it lends itself more easily to improvement. The propagation of the beet by seeds, instead of by buds, as with the cane, has rendered it easy to build up the sugar-producing capacity of the plant until its sugar content has reached, and in some cases has even exceeded, that of the sugar cane.

The earliest known reference to the beet is contained in an old Babylonian catalog of the plants that were cultivated in the gardens of King Merodachbaladan, who reigned from 722 to 711 B.C., in which record it appears under the name 'Silqa.' This word, as well as the Syrian "Selka" and other similar terms, indicate Sicily as probably the place where the wild *Beta maritima*, which grows naturally on the shores of the Mediterranean, was first cultivated. It was probably domesticated in Sicily before 1000 B.C., and from this central island its cultivation seems to have spread through all the ancient European, Asiatic and African countries which border upon the Mediterranean Sea. It was grown as a human and animal food, and its use as an agricultural plant was transmitted through the medieval centuries to modern times.



A Field of Sugar Beets

While it had long been known that the cultivated beet had a distinct sweet taste, no one thought of utilizing this observation until a German chemist, Andrew Marggraf, in 1747, made the important discovery that a sugar could be extracted from the beet of identically the same properties as that obtained from the sugar cane. A practical industrial method for obtaining sugar from the beet was lacking, however, until a half century later, when another German chemist, Francis Achard, a pupil of Marggraf, invented a method for producing beet sugar upon a commercial scale. The first beet sugar factory of the world was established in 1799 under Achard's direction at Cunern, near Steinau, in Silesia.

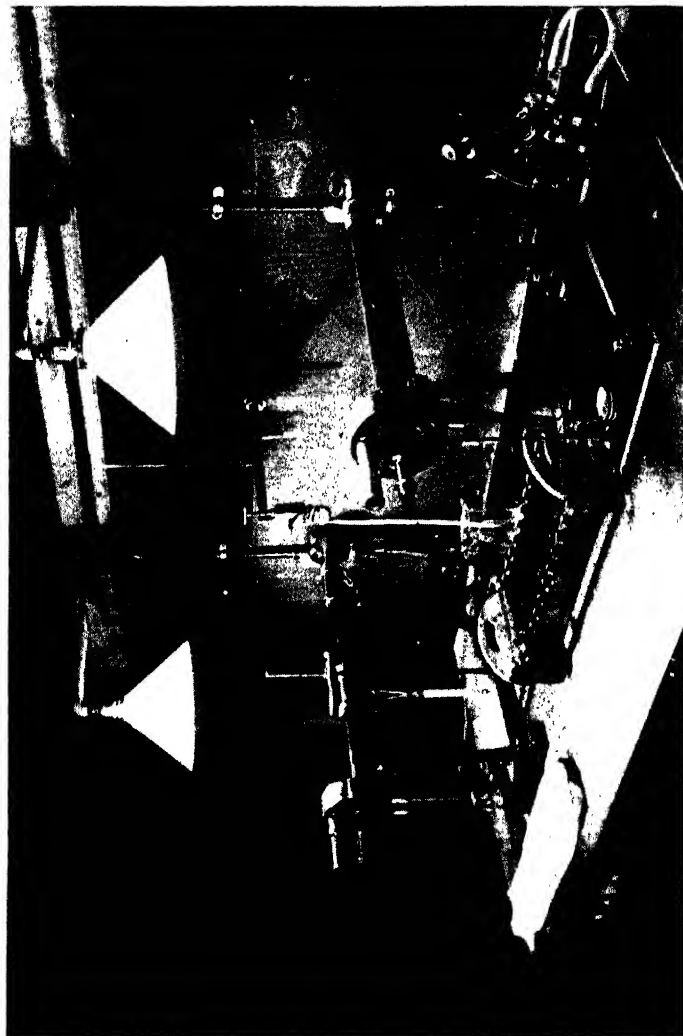
The new beet sugar industry did not prosper well at first, and it was making but little headway, owing to the cheapness of tropical cane sugar, when an important historical event almost immediately established beet sugar manufacture upon a firm basis of existence. This was the announcement by Napoleon, in 1806, of his famous blockade of the continent of Europe against England. While his famous edict failed in its main purpose, it had a great influence in other ways, for it stimulated manufacturing and the arts to an unprecedented degree. In order to relieve the hunger of the people for sugar, heroic efforts were made to devise a substitute. In some parts of Europe, as Bohemia, maple sugar was manufactured, but the yield was not sufficient to supply even local demands. The famous chemist, Proust, then devised a process for obtaining the crystallizable sugar, dextrose, from grape juice. Another chemist, Kirchhof, also invented a process at this time for manufacturing dextrose from starch, and efforts were begun to establish a new starch-sugar industry. Dextrose, however, lacked the sweetening

power of sucrose, and the consumers of sugar refused to content themselves with such a substitute.

The attention of Napoleon was finally called to the possibilities of Achard's discovery, and he at once ordered large tracts of land to be set aside for beet culture. Under his powerful patronage and the guidance of the best scientists of the time, several factories were erected, and the new industry was soon established upon a prosperous basis.

The overthrow of Napoleon and the abolition of the blockade opened again the markets of Europe to the supplies of tropical cane sugar, and it seemed for a long time as if the new beet sugar could not compete with cane sugar, the cheaper product of tropical slave labor. French statesmen, however, were far-sighted enough to protect the new industry with bounties and tariff regulations, so that the manufacture of beet sugar increased. The financial difficulties which the industry encountered stimulated greater improvements and economies in agriculture and manufacture. This policy, after fifty years, placed the beet sugar industry far ahead of its rival. The cane sugar industry, temporarily handicapped by the abolition of slavery, was in its turn forced to make improvements, and this it could do only by adopting the newer inventions and discoveries that had been worked out in beet sugar manufacture.

It is doubtful if the beet sugar industry could have made this progress had an important piece of apparatus, the polariscope, not been invented in 1835 by the great French physicist, Jean B. Biot. The polariscope offered a quick and rapid method for determining the amount of sugar in beets. There was thus established a means of selecting beets for the production of seed-mother beets, as they are called. A small bor-



Inside Polariscopes Room
Polariscopes and Refractometer for analyzing Sugar Solutions.

ing is taken diagonally through the heart of the beet and the percentage of sugar determined in this by the polariscope. The beets of highest sugar content are planted for seed; the same process is carried out with the second generation of beets grown from the seed of the first, and so on generation after generation. In this way the original sugar content of the beet of only a few per cent has been raised to 14, 16 and even 18 per cent. The process of seed selection is still kept up, and in the seed nurseries chemists are kept constantly employed polarizing mother beets for seed production. The work demands constant vigilance; a plant easy to improve will deteriorate even more easily; if the sugar beet were left to itself it would revert, in a few generations, to the old condition of low sugar content.

The sugar-containing organ of the beet is a large tap-root whose tapering point and fibrous lateral rootlets extend downwards into the soil for a distance of two or more feet. Springing from the crown of the tap-root are the leaves which function as the sugar-producing organs of the beet in the same manner as the leaves of the sugar cane. The sugar beet is a biennial, the flower and seed of the beet not being produced until the second year. As the production of seed results in the consumption of a large proportion of the sugar stored in the roots, the latter must be harvested in the first year when the percentage of stored sugar has reached its maximum.

The sugar beet attains its best development in temperate climates and does not thrive well in tropical countries. Loamy soils, which should not be too light, are best for the growth of beets, and they should be deeply cultivated in order to secure the most favorable development of the extensive root system.

THE AGRICULTURAL CHEMISTRY OF GROWING,
FERTILIZING AND CULTIVATING SUGAR BEETS

While the percentages of the fertilizing elements, nitrogen, phosphorus and potassium, are higher in the root of the sugar beet than in the stalk of the sugar cane, the latter crop, on account of its greater yield, removes per acre of land a slightly larger amount of nitrogen and potassium. This is shown in the following table which gives a comparison of the amount of nitrogen, phosphorus and potassium removed from an acre of land by the sugar cane, sugar beet and certain other common crops:

Kind of Crop	Yield per Acre	Nitrogen Lbs.	Phosphorus Lbs.	Potassium Lbs.
Sugar Cane.....	20 tons	40	6	81
Sugar Beet.....	10 "	30	6	58
Tobacco.....	1,600 lbs.	76	7	166
Corn.....	40 bus.	56	9	19
Wheat.....	20 "	41	6	14
Oats.....	40 "	40	6	27
Barley.....	30 "	56	7	42
Clover Hay.....	2 tons	82	8	73

As with the sugar cane, the fertilizing element of greatest importance to the growth of the sugar beet is nitrogen in some one of its more readily available forms. Sodium nitrate is the combination generally preferred, an application of 240 pounds of this salt to the acre being necessary for lands in a state of good cultivation. Because of the rapidity with which sodium nitrate is lost by leaching and denitrification it is not advisable to apply the whole amount at one time, but to add it in smaller quantities at the times of sowing the seed, of thinning the young beets and of cultivating. Very late applications of sodium nitrate are deleterious, just as with the sugar cane, owing to the encouragement of growth at the expense of ripening.

Phosphorus is best supplied to the sugar beet in the form of calcium superphosphate. This element is espe-

cially valuable in the case of both the sugar beet and sugar cane in promoting the ripening of the crop; 160 pounds of superphosphate to the acre, distributed on the field in the spring before planting, is considered to be a proper application. The most suitable form of the element potassium for the fertilization of sugar beets is potassium sulphate, which should be applied to the land in quantities of about 220 pounds per acre before the time of planting. Potassium fertilizers which contain a large amount of chloride should, so far as possible, be avoided, since the latter element chlorine has a tendency to diminish the sugar content and purity of the beets.

The sugar beet is usually grown in rotation with other crops, such as corn, wheat, hay, etc., and it is admirably adapted to this purpose, its deep feeding habits bringing to the surface from the subsoil a large amount of valuable plant food that would otherwise be lost. The introduction of sugar beets into the rotation also improves the texture of the soil, by rendering it more porous and by increasing its supply of organic matter or humus. It has been estimated that the fibrous rootlets of the sugar beet, which are left in the soil after the main roots have been harvested, contribute a ton of organic matter to each acre of land.

The most important point in growing sugar beets successfully is deep ploughing. This is necessary in order that the beet may penetrate deeper into the soil and that the aeration may be secured, which is necessary for the proper root development of the beet. In Germany, when the highest yields of sugar beets are obtained, the fields are often ploughed to a depth of sixteen or eighteen inches, which is twice the penetration usually adopted in the United States. The turning up of new depths of subsoil should be done very grad-

ually, however, and not more than an inch at a time. The land for growing sugar beets should be ploughed in the autumn in order that rain, air, frost and other weathering influences may have as long a period as possible to exercise their favoring action upon the liberation of plant food. At the time of ploughing there should also be an application of barnyard manure in order to furnish the land with the necessary supply of humus. The following April, when the frost has entirely left the ground, the best fields should be well broken up with discs and harrows; the land is also sometimes rolled in order to secure the proper degree of compactness.

The beet seed is then planted by a drill in rows that are about twenty inches apart. The seed of the sugar beet exists in balls which contain from one to seven distinct seeds, and when the latter have sprouted it is necessary that the clump of young plants be thinned in order that only a single beet may grow in a place. This operation of thinning out superfluous beets is the most expensive part of sugar beet culture, as it all must be very carefully done by hand. The most vigorous plant in the bunch is left, and a space of ten to twelve inches is usually kept between the individual plants in a row. The growing beet crop is then constantly cultivated in order to keep out weeds; the fields must also be irrigated in case of insufficient rain.

THE CHEMISTRY OF MANUFACTURING BEET SUGAR

At the time of harvest, which begins in the United States between July and October, the beets are loosened from the soil by digging machines, after which the roots are lifted, the crowns and attached leaves cut off and the beets sent to the factory. Here they are

first washed to remove adhering dirt and then passed through revolving knives, which reduce them to fine slicings or chips. In the beginning of beet sugar manufacture the roots were crushed and the juice was pressed out in somewhat the same manner as was done with the sugar cane. This method, however, after many years' trial, gave way in 1864 to the process of diffusion, which was first introduced on an industrial scale in Austria by Jules Robert.

The extraction of sugar from beet slicings by diffusion is performed in a series of tall boiler-shaped cylinders called cells. These cells are connected together by pipes, the outlet from the top of one cell passing downward into the bottom of the next and so on around. Each cell is filled with beet slicings through a manhole at the top, and when full is tightly closed with a cover which is clamped into place. Twelve cells connected in series usually constitute a battery, and when all are filled, warm water of about 80° C. is passed through the system. The water circulating through each cell removes the sugar from the beet slicings, and, of course, becomes richer and richer in sugar with each succeeding cell. Heaters are placed between the cells so that the circulating water is kept always at the right temperature. When the water has made a complete circuit through the twelve cells of the battery the slicings in the first cell are practically exhausted; this cell is then thrown out of circulation, emptied of exhausted chips, refilled with fresh slicings and reconnected with the system, while the second cell undergoes replenishing. The process is thus a continuous one; ten cells are always in circulation while one is always being emptied and one always being refilled. This goes on continually during the beet campaign, night and day, Sundays and holidays;

interruption at the diffusion battery upsets the work of the whole factory.

The exhausted slicings from the diffusion cells are dried by the heat of the flue gases from the boilers, and are then sold as a cattle food.

The diffusion juice as it leaves the last cell of the battery contains from 12-15 per cent sugar, and is then ready for clarification. The juice is first treated with a considerable excess of lime; and the dissolved lime precipitated by leading in a stream of carbon dioxide, a process which is called "carbonation."

The burning of limestone is an important operation in every beet sugar factory, the lime being used for clarification, and the kiln gases, which contain about 30 per cent carbon dioxide, being pumped off for carbonating.

After the first treatment with lime and carbon dioxide, the precipitate of calcium carbonate and other impurities is removed by filter presses, and the filtered juice subjected to a second carbonation at a higher temperature. The juice from the second carbonation is again filtered, and being now perfectly clear and colorless, it is evaporated, boiled to sugar and centrifugalized, these processes being carried out exactly as described under sugar refining. The resulting product is a clean white sugar, which is ready for direct consumption.

The residual sugar beet molasses still contains about fifty per cent of unextracted sugar, and many processes have been devised for extracting the latter. The best known of these is the trisaccharate process of Steffens, in which the molasses is diluted with water to about 12-14 per cent solids and the solution treated in the cold with very finely powdered lime, using all the way from 80-150 parts of lime to 100 parts of sugar. Con-

stant agitation of the solution is necessary to prevent the formation of clumps of lime, and care must be taken to keep the temperature down. The insoluble trisaccharate of lime which is formed is filtered in presses and washed with cold water to remove impurities. This trisaccharate is then mixed with hot washings from the filter presses and added directly to the diffusion juice. The saccharate is decomposed by the carbon dioxide used in carbonating, and the liberated sucrose is worked up with that contained in the juice.

A considerable amount of sugar beet molasses is utilized, in the same way as the leaves and exhausted chips, for cattle feeding. As in the case of the cane sugar industry the molasses is the only depleting agent of soil fertility if the leaves, pulp, press cake and other residues are utilized upon the farm where the beets were grown.

CHEMICAL CONTROL IN SUGAR PRODUCTION

The great progress in sugar manufacture has been due not simply to the invention of better appliances in manufacture, but also, and in very large part, to the introduction of rigorous chemical control. The best appliances may do wasteful work unless constantly checked by strict chemical supervision. It is the duty of the sugar factory chemist to determine how much sugar enters the factory in the stalks and roots of the raw material, and what percentage of this is obtained in the final product; to control the work of the mills and diffusion battery by determining how much of the sugar is extracted and how much is lost in the refuse; to control the work of clarification by determining the purity of the juice before and after treatment; to control the work of evaporating and boiling by checking losses from inversion or entrainment; to control the

work of the crystallizers by ascertaining that the final molasses has been reduced to the lowest possible sucrose content; and finally to control the quality of the sugar as to polarization, moisture, alkalinity, acidity, or any other factors which may affect the price or keeping quality of the product. Night and day, holidays and Sundays, the sugar factory chemists must be at their posts, for when the sugar campaign begins there is no let-up until the season is finished. The moment a wrong turn occurs at any stage of the process the fact must be quickly noted, lest large financial losses result.

The chemistry of sugar production has one other important side, which, unfortunately, is too much neglected. I refer to the chemical processes which take place where the crop is growing. We must never lose sight of the fact that the sugar which we eat is made in the field and not in the factory. If we determine all the factors that enter into the cost of sugar making, we shall find that about three-fourths of the expense is due to the agricultural operations of ploughing, planting, cultivating, and harvesting, and about one-fourth to the operations inside the factory. Strictly speaking, then, the agricultural side of sugar making should receive three-fourths of the attention bestowed by chemists and trained scientists. This has been largely true of the beet sugar industry, a great part of the success of this branch of sugar making being due to the care given to chemical selection of seed and to other agricultural matters. The day is fast approaching when it will be equally true for the sugar cane industry.

The application of strict scientific principles has been followed more energetically in beet sugar manufacture than in cane sugar manufacture, and this we would expect, for the beet industry was developed in

the highly civilized European countries, where skilled labor was abundant, and the cane industry was maintained in primitive tropical countries where labor was shiftless and unskilled. This condition of affairs existed for many years and gave beet sugar for over two decades a strong ascendancy over the cane. In 1852, taking the whole supply of the world, there was six times as much cane sugar manufactured as beet sugar; beet sugar kept gaining, however, until 1884, the production of the two kinds of sugar was about equal, a little over two and one-half million tons each. Beet sugar then took the lead until, in 1899, the production of beet sugar was about five and one-half million tons and that of cane about three millions. Then came the ending of the Cuban war and with it the introduction of the scientific principles, worked out for the beet industry, to the old dilapidated cane factories of Cuba and Porto Rico. Modern methods of manufacture had also been busy reorganizing the cane industry in Hawaii, Java, Australia and other countries. The production of beet sugar in 1901 reached nearly seven million tons, and since then has remained about stationary; but the increase in cane sugar production has gone forward each year by leaps and bounds. In 1907 the cane had caught up to the beet, the production being a little over seven million tons apiece. In 1908 cane sugar was over 600,000 tons ahead, and in 1909 nearly 2,000,000 tons ahead out of a total world's production of about 15,000,000 tons.

During the World War the beet sugar industry of France, Belgium and other European countries suffered a serious set-back, large fertile sugar beet areas having been within the zone of conflict and many hundreds of factories destroyed. In order to supply the world with the deficiency of sugar, resulting from the

losses in European production, a great stimulus was given to the cane sugar industry of the tropics. In 1919, at the close of the war, the total production of the world's beet sugar had fallen to 3,259,380 tons, while that of cane sugar had advanced to 11,957,232 tons, or over 78 per cent of the entire sugar production. Since 1919 the beet sugar industry of Europe has been rapidly recovering, the total production of the world's beet sugar for the present crop year (1924-1925) being 8,185,385 tons, which is 35.4 per cent of the entire sugar production of the world (23,115,532 tons).

THE FUTURE OF THE SUGAR INDUSTRY

The future development of the world's sugar industry will probably be more extensively confined to sugar cane growing countries. This is due principally to the cheaper cost of producing cane sugar, owing to the cheaper labor of tropical countries and to the much greater yield of sugar per acre which the cane gives over the beet. Under the best systems of cultivation and manufacture, such as are found in Hawaii and Java, over four tons of sugar can be produced per acre. Germany, which leads in the production and yield of beet sugar, can raise barely two tons of sugar per acre. Yet, notwithstanding the natural advantages possessed by the sugar cane, the production of beet sugar is bound to increase for many years to come. The sugar beet, as a root-producing plant of deep-feeding character, plays a most beneficial part in the systems of crop-rotation which are best suited to diversified farming. It is a crop which from the standpoint of both agriculture and national economy should always meet with the most favorable consideration in countries which, like the United States, are climatically suited to its best development.

CHAPTER VIII

FRUITS AND VEGETABLES

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GENERAL

Luscious fruit and fresh vegetables! How vividly we have in mind some loaded orchard of apples, peaches or oranges, and some attractive home garden with its rows of beets, celery or corn. We think, also, of how much would be lacking at our meals, be they breakfasts, dinners or suppers, if these two classes of food were forbidden or inaccessible to us. More than this, not only would we miss these choice foods but, as has been told in another chapter, our diet would be seriously wanting in some of those very important substances known as vitamins.

But, we may ask, what does chemistry have to do with these except as it does with all crops and all farming? Let us see. In our mind's eye we see local orchards and family gardens, but do we realize how much of both the fruit and vegetables which we eat comes from almost the other side of the world, from orchards and gardens which we never saw? We are especially fond of fresh fruit and green vegetables, but we know that most of us probably eat far more

fruit as dried, canned or preserved than we do fresh, and likewise with our vegetables.

Thus we may begin to see that chemistry has had something to do with these two desirable and necessary items of our diet. Indeed, we find that through many channels its influence has been exerted and that there is hardly a branch of the science which has not contributed directly or indirectly to the solution of the problems of fruit and vegetable growers.

Metallurgy and fruit raising seem rather far apart, but who will deny that the production of improved alloys by the metallurgical chemist has made possible the automobile, the truck and the tractor all so invaluable to farming in general, and to fruit and vegetable growing in particular. Then also the same kind of chemical study has solved problems in connection with the use of tin containers for canned foods, which we shall speak of later. The petroleum chemist, by contributing to the production of cheaper and better gasoline, lubricating oils and fuel oils, has made possible not only cheaper transportation of fruit and vegetables but also the heating of entire orchards to prevent frost. Even the ceramic chemist has done his bit in the production of resistant insulators which are necessary for the distribution of the high voltage electric current which is utilized on the fruit ranch for pumping irrigation water. High explosives, also, which are important products of chemistry in industry, have made possible the easier breaking up of "*hard-pan*" soils so that fruit growing may be carried on in regions where otherwise it would have been well-nigh impossible.

In all such indirect ways, through other industries, chemistry has been of great service to the farmer who grows our fruit and our vegetables, but its greatest

service has been in direct ways in the fields of agricultural chemistry and biological and food chemistry. This direct service of chemistry to fruit and vegetable growing we may divide into two lines; first, what it has done to aid in crop production and, second, what it has done to solve the problems of the distribution and utilization of the products and of otherwise waste by-products.

The contribution which chemistry has made to our knowledge of soils, their character, properties and relation to water, especially in regard to the practice of irrigation; of the plants requirements of the soil, the proper and economic use of fertilizers; all of this has been of great value in the growing of fruit and vegetables as well as in the growing of all crops. These relations of chemistry to agriculture have been considered in other chapters, and need not be presented again.

The same is true regarding the service which chemistry has rendered to the fruit and vegetable grower through the study of insecticides and fungicides, a study which has been shared with the entomologist and plant pathologist. It is probably a fact, however, that no other type of farming is so directly and vitally dependent upon the study of insecticides and fungicides as is the growing of fruit and vegetables.

With the improvement in facilities of transportation and the consequent exchange of plant materials throughout the world, danger from the spread of destructive plant pests has frequently arisen. In a new environment such pests usually find freedom from their natural enemies and other agencies which tend to check their destructiveness in their native countries and great losses often result before effective control measures are developed. The lines of attack commonly

followed include the introduction of the natural enemies of the pest and the development of resistant stocks of the plant effected. These are long time measures, however, and for immediate and certain results the greatest reliance is placed on insecticides and fungicides, particularly as applied by spraying and by fumigation. The preparation of materials for these purposes is in itself an important chemical industry.

While neither entomologist, pathologist nor chemist considers the results entirely satisfactory, certainly a number of very dangerous pests are being controlled by these methods at the present time. It is possible, even probable, that the growing of apples and pears in this country is continued today because of the discovery and use of arsenical sprays for the control of the codling moth and other fruit and vegetable pests; while the growing of peach trees and other trees subject to attack by the San Jose scale, is similarly indebted to the lime-sulfur-salt spray. The wide adoption, by orchardists in this country, of oil emulsion sprays, is largely due to the great improvement in the technique of emulsification that has resulted from recent researches in colloidal chemistry.

In citriculture the outstanding achievement has been the introduction of hydrocyanic acid gas for the destruction of various scale pests. That this industry is enjoying its present prosperous condition is largely due to this unique and effective method of control. An orange or lemon tree that is to be fumigated is completely covered with a canvas tent, the approximate cubic contents of which is known. A measured quantity of hydrocyanic acid gas is then liberated within the tent, which is kept over the tree long enough to effect the death of the scale, but with the least possible injury to the foliage. At first the solid

sodium cyanide salt was used, which was placed within the tent and a carefully measured amount of sulfuric acid poured upon it, thereby liberating a definite amount of hydrocyanic acid gas. Improvements in methods of handling the gas, however, make it possible now to take to the orchard tanks or cylinders of compressed gas, so that by turning a valve the required amount of gas may be liberated within a tent.

Insecticides and fungicides play a part not only in protecting the crop while it is growing, but also in preserving it after it is harvested. For some time it has been customary to wash citrus fruit in water containing copper sulfate in order to retard decay during shipment. Recently boric acid, borax and sodium hypochlorite have been used for the same purpose.

There is still another source of loss, through insect infestation, to the fruit and vegetable growers who place their products on the market after they have been dried. Such dried foods are subject to insect attacks and the most common method of control has been to place the dried fruit or vegetables in a large metal drum which is then partially evacuated and fumes of carbon disulfide introduced. This treatment is very effective against the Indian meal moth (*Plodia interpunctella*) which is the most common pest of dried foods. Owing to the combustible nature of carbon disulfide a non-combustible mixture of carbon tetra-chloride and ethyl acetate has recently been introduced. The use of sulfur dioxide, in the preparation of dried fruit, is not, primarily, for the prevention of insect infestation and will be dealt with later.

CANNED FRUIT AND VEGETABLES

The marketing of a fruit or vegetable crop is as great a problem as its satisfactory production, and

here too chemistry has done much in aiding the solution. Most fruits and vegetables are marketed either in the fresh state or after canning or drying. A large quantity of fruit is sold as preserves and jelly, and a like quantity of vegetables as ketchup, pickles, sauerkraut and sauces.

As an industry canning began late in the eighteenth century when the French canner, Nicholas Appert, preserved food by sterilizing it in glass. Since that time it has become the foremost food industry of the day with an output, in this country alone of four and one-half billion cases, comprising more than two hundred varieties of food. Nearly all fruits and vegetables are canned, about the only missing member of the vegetable family being the common potato which is available fresh throughout the year. There is a canning industry in nearly every state of the Union, Alaska, the Hawaiian Islands, Porto Rico and the Philippines. The distribution of fruit and vegetable canning in this country is roughly indicated in the following summary:

Product	States Having Canneries	Product	States Having Canneries
Tomatoes.....	26	Okra.....	3
Beans.....	25	Apples.....	16
Peas.....	15	Berries.....	13
Corn.....	13	Cherries.....	10
Pumpkin.....	11	Peaches.....	10
Sauerkraut.....	5	Pears.....	5
Spinach.....	4	Plums.....	5
Sweet Potatoes.....	4	Figs.....	2
Succotash.....	3	Apricots.....	1
Beets.....	3		

There have been two great advances in the industry since canning foods became important in this country: the development of the cheap container, which came about gradually; and the discovery of the pressure

cooker method for sterilization, which was developed much more rapidly.

The change from glass containers to tin-coated cans was made possible by the metallurgical-chemical process of tinning iron. This process, a great advance in itself, was dependent for final success upon the can-making machine. In the early days of can making a mechanic could turn out at best but sixty a day, whereas at the present time a machine will make twice that number every minute. No one will for a moment detract from the achievement of the inventors and technologists who brought about this advancement, but back of it all has been better chemical knowledge and control of processes in the iron industry. Better quality tin plate has also made possible the sanitary can in the construction of which no solder is used, the closing being done by rolled seams, special cement and paper gaskets. Solder, where it is still used in can making, does not come into contact with food but is applied mechanically to the outside. In all of this improvement of the tin can the metallurgical chemist has had a hand.

It was some time after Pasteur's theories regarding organisms had been generally accepted before their relation to the preservation of canned food was recognized. At first it was thought that the partial vacuum in the container was the agent that preserved the food. This view seemed logical as cans with spoiled contents were usually found to be under a slight gas pressure and the contents of leaky cans were always spoiled.

In 1860, Solomon discovered that raising the temperature of the bath in which the cans of food were being sterilized materially reduced the time required for proper processing, and also the percentage of loss.

At first the required rise in the temperature of the sterilizing bath or cooker was obtained by the addition of a chemical, calcium chloride, and for several years the canning industry was satisfied with this improvement. Then in 1874, Shriver invented the pressure cooker, in which the cans of food are heated in a closed receptacle to temperatures as high as 250°F. (121°C.), effecting both sterilization and cooking. With the knowledge that spoilage in canned food is due to organisms many improvements in the process resulted from research by bacteriologists and chemists. Investigations have been made on heat penetration, on the effect of the acidity of the product on the temperature of sterilization, on the cause of discoloration and on the cause of many types of spoilage.

Studies of the corrosion of the container by the food in it have shown which foods must be packed in lacquered or enameled cans and which are best packed with paper liners. Peculiarly enough some of the foods which most severely attack the containers are not acid in character. Studies of the composition of foods have given canners a mass of valuable information for determining the best methods of pretreatment and proper sterilization.

JELLIES AND PRESERVES

A gradual change has been taking place in the jelly and preserve industry during recent years. For a long time it has been commonly known that certain fruits will not jell. Chemists showed that these fruits contain much less than the usual amount of pectin, a carbohydrate of uncertain composition. Jelly makers hit upon the device of mixing fruit juices, or water extracts, high in pectin, with those of poor jelling

power, in order to obtain a good jelly of the desired flavor. Apples were largely used for this purpose. It was then found that most of the pectin in apples occurs in the cell walls lying next the skin and around the core. Thus, apple skins and cores, with other waste apple products, have found a place in jelly and preserve making, so that now large quantities of pectin solution are manufactured from apple pomace. These solutions are sold not only to commercial producers of jelly, jams and preserves, but also to housewives.

There has been much discussion regarding the use of pectin, for it can be used both legitimately and illegitimately. Unscrupulous manufacturers now use it to give body to products containing much less fruit than is required in good practice. With pectin and only acid and sugar they make what is really a pectin jelly, using just enough fruit to flavor or color the whole. On the other hand the use of pectin aids in the manufacture of very fine products by lessening the time required for cooking, with a resulting retention of the original flavor of the fruit. Housewives are convinced that pectin has a legitimate place in the household for with its aid less than ten minutes' boiling will produce a good jelly from a poor jellying juice, whereas without the pectin such juice would require hours of boiling.

Apple pectin is produced from waste pomace, a by-product of vinegar making, by extracting it with acidulated water, purifying the extract and evaporating, usually under vacuum, to the desired consistency. The pectin may also be precipitated from the extract by means of alcohol or certain metallic salts. Where precipitation methods are used, the product is usually put on the market as a fine grey powder.

Citrus pectin is produced from the peel of lemons and oranges by methods like those already noted.

Owing to the presence in the peel of essential oil, coloring matter and a bitter principle, the pectin must be purified with alcohol before it is ready for consumption. One of the denatured alcohol mixtures is used for the purpose, the solvent being redistilled and used again and again.

DRIED FRUITS

Dried fruits are produced in quantity in several states, but the largest output comes from California. In this state, where the climate is most favorable, grapes, prunes, apricots, peaches, apples, pears and figs are all dried either in the open air and sun or by means of artificial heat.

The use of sulfur dioxide in the preparation of these products can be termed a chemical process and is a benefit to the fruit grower as it permits the utilization of thousands of tons of fruit. Whether the use of the compound is harmful or otherwise is not a subject to be discussed here. In Europe the amount present in food has recently been strictly limited by governmental regulation. As a consequence the quantity used in dried fruits must be greatly curtailed by our producers, and the chemist, who aided in its introduction, must now turn his attention to its material reduction. Prunes and by far the greater part of the grape (raisin) and fig crops are not treated with sulfur dioxide.

Prunes which ripen late in the year are often damaged by rain when followed by cold, foggy weather during the drying season. As a result each year more and more prunes are dehydrated in mechanical driers using artificial heat and forced air currents. The Italian prune grown in Washington, Oregon and Idaho, is always dehydrated, and the practice is

spreading through California. The dehydrated prune is a higher-grade product than the sun-dried prune. It is more sanitary and, everything considered, its cost is not much greater.

Artificial heat is always used for drying apples. As yet, however, most raisins and figs are sun-dried. Apricots, peaches, and pears to be dried are exposed to the fumes of sulfur dioxide (burning sulfur) for several hours. This treatment plasmolyzes the cells, seems to set the color of the fruit and acts as a repellent to insects while the fruit is drying. As soon as the sulfuring is finished, the trays of fruit are placed on the ground in the sun to dry. When partly dried, they are stacked one above another and the drying is finished. This material, known as growers' stock, is bought by jobbers or sent to the dried fruit association, where it is refinished for the trade. As it leaves the dry yard it contains less than 20 per cent moisture. At the packing house it is treated with steam or hot water, sorted, cleaned and resulfured. The result is a product containing at least 25 per cent moisture and somewhat more sulfur dioxide than the growers' stock. It is now pliable, easily packed, and of pleasing appearance.

The output of dried fruit in California, including prunes and raisins, averages between 400,000 and 500,000 tons a year. The northwestern prune output amounts to 25,000 tons, and the dried apple output for the United States to about 10,000 tons.

WINE AND FRUIT JUICES

The preparation of fruit juices was probably one of the first agricultural by-product industries, if it can be called a by-product industry in view of the

fact that most grapes of the world are raised for the purpose of making wine. For centuries wine has been made, but it was not until the last century that man knew anything of the fundamentals of the process, and only recently that light has been thrown upon its chemistry.

Before Pasteur made public the results of his studies wine making was a "rule of thumb" process. As long as the wine maker depended upon wild yeasts for his fermentation, his results were erratic. When it was well understood that the quality of the product depended largely on the fermentation process, more care was exercised in controlling it. Wild yeasts are now retarded by means of sulfurous acid, or its salts, and a pure strain of cultivated yeast introduced in such quantities as to dominate the fermentation. By careful analysis of the product at different stages of the process, a control is established, and faults in the fermentation are corrected before any great damage to the wine has resulted.

The preparation of non-alcoholic fruit juices has been largely a matter of controlling the temperature and time of sterilization. That the problems are largely biological in nature does not alter the fact that some very intricate chemical problems are also present. The changes in flavor which juices undergo on heating and on storage are due to changes in chemical composition, and until the mystery of their action is cleared up the problem of putting some juices on the market will remain unsolved.

The preparation of fine grades of infusorial earth has done much to aid in the clarification of fruit juice, it being possible to use this filtering agent now without imparting off-flavors to the products.

Gelatin is also being used as a precipitant of tannin

which, when present in sufficient quantity, gives an astringent taste to the juice.

VINEGAR

Vinegar making is another by-product industry which the chemist has helped to modernize. Vinegar making naturally followed wine making, probably dating from the first batch of spoiled wine. In the natural course of events, when wine or cider was left unsealed for any length of time under conditions favorable to the growth of acetic bacteria, these organisms started to multiply and before long the wine or cider had become too acid for use as a beverage. Many months had to pass, however, before such a product became a satisfactory vinegar.

With the discovery that the changes were due to organisms, the optimum conditions for their growth were soon worked out and now it is possible to produce vinegar from cider in twenty-four hours. This is accomplished by permitting a mixture of cider and vinegar to trickle slowly over beechwood shavings, rattan, corncobs or coke in a vat. The vat has an automatic distributing head at the top which spreads the mixture evenly over the material, and is also provided with air inlets, just above the bottom, by means of which the air supply can be controlled.

These vats, or generators as they are usually called, are 12 to 16 feet high and 6 to 8 feet in diameter. They are seeded with pure vinegar, after which a mixture of half vinegar and half cider is allowed to trickle slowly through them. When properly regulated, they will convert such a mixture into vinegar in one passage. Part of the vinegar is mixed back with fresh cider to aid in converting it.

Careful analyses of the cider and vinegar are necessary in order properly to regulate the apparatus. Practically all of the alcohol should be converted into acetic acid, but none of the acetic acid formed should be destroyed. It is usual now to pasteurize vinegar before bottling, as it does not materially injure the flavor and the product does not deteriorate as rapidly as that which is unpasteurized. Formerly cider and wine were the sources of practically all of the vinegar made, but now malt vinegar is also produced, and a very large quantity of distilled vinegar, made directly from alcohol, is used for pickling.

CITRUS BY-PRODUCTS

The citrus fruit by-products industry in this country can rightly be called an infant industry. As a means of stabilizing the citrus industry in California, which represents an annual shipment of 50,000 to 60,000 cars, with a gross income of \$60,000,000 to \$70,000,000, it is of prime importance. In every crop a certain percentage of fruit cannot be marketed owing to size, shape or poor shipping quality. There is also the "standard grade" fruit which can be shipped only at a risk to the shipper. Where crops are large and markets oversupplied this fruit rarely pays the expense of handling. This so affects the general tone of the market that the prices for fancy and choice grades are materially reduced. Experience has shown that except when prices are very high it is far better, in the long run, not to ship fruit of this grade. It costs as much to produce it, haul it to the packing house and grade it as it does to go through the same operations with fancy fruit. Therefore, any method by which it can be made to return even a part of these costs to the grower can be counted as profitable.

Chemical studies of citrus waste were made almost as soon as its utilization became a problem, and it was found that the fruit contained several staple products. The essential oils of both oranges and lemons are common ingredients of flavoring extracts and perfumes, and more than a million pounds of them are annually consumed in this country. At least 25 per cent of this quantity is produced in California. The juice of the lemon contains approximately 6 per cent of citric acid, about six million pounds of which are consumed annually in the United States alone. It is used principally for acidifying the so-called "soft drinks," ginger ale, soda, etc., and in the preparation of effervescent medicines, such as citrate of magnesia and effervescent salts. California now produces about one and one-half million pounds of citric acid from lemons.

There is also a growing demand for concentrated citrus juices and citrus peel, candied, dried and packed in brine. The juices are largely used in the industries and for pure fruit beverages, ice cream and water ices. About 200,000 gallons of orange juice go to produce the concentrated juice used as a beverage. Several hundred thousand pounds of orange peel are preserved, and both orange and lemon peel are sold to mincemeat manufacturers and confectioners. Another product lately much in demand by jelly and preserve makers for making fruit products jell is the pectin, previously referred to, which occurs in the peel of citrus fruit to the extent of 3 to 4 per cent. The 1925 output will be around 30,000 pounds, enough to produce nearly five million pounds of jelly. After the important constituents of the fruit are removed the residues have some value, in the case of oranges as stock feed and in the case of lemons as fertilizer.

Lemons to be converted into by-products are sent

by truck or rail to a central factory, where they are carefully washed and separated from all decayed and moldy fruit. The fruit is then passed through fluted rolls and crushed in such a way as to expel some of the oil from the peel. This oil, which is mixed with the juice, is separated from it by means of special centrifugal machines similar in construction to those used in separating cream from milk. The pulp from the rolls is further ground and washed to remove the acid. It is then ready for the extraction of the pectin. The juice is screened and sent to fermenting vats, where the sugar is converted into alcohol. The alcohol is not recovered, but the process causes the sediment to settle rapidly, and subsequent filtration is simplified. This juice is clarified by means of infusorial earth, filtered and precipitated with hydrated lime and chalk. This reaction produces a compound of lime and citric acid, known as citrate of lime. When dried, it is an article of commerce and is exported in large quantities from Italy and the West Indies. It is an intermediate in the manufacture of citric acid, for which purpose it is imported by England, Germany and the United States. In California this citrate of lime is converted at once into acid. To accomplish this, it is mixed with water, and sulfuric acid is added in quantities slightly more than sufficient to react with it. This causes a precipitation of calcium sulfate and the formation of citric acid. The calcium sulfate, known as gypsum, is recovered by filtration. The dilute solution of citric acid is evaporated in vacuum pans and the concentrated solution is permitted to crystallize. The crystals of the first crop being too dark for commercial use, are dissolved, clarified, reconcentrated and re-crystallized. The second crop is water white and, when dried, is ready for the market. The various mother

liquors are worked over as long as satisfactory crystals can be produced, after which they are reprecipitated as calcium citrate.

The method of producing orange oil is similar to that used for lemon oil. The residues from the mill are steam distilled, however, and a further recovery of oil made in this way. This product, sold as distilled oil, brings about half the price of the cold-pressed oil.

Orange juice and sirups of several types are manufactured. The favorite method of producing concentrated orange juice is by evaporation under high vacuum. This makes a product greatly reduced in bulk and available for use in the numerous and popular orange drinks. The flavoring material, consisting of some form of orange extract, is kept separate from the concentrate and added by the bottler when the beverage is bottled. Another form of juice is the fresh product preserved by sugar. Usually both types are preserved with sodium benzoate.

Orange marmalade is made in many forms. The most popular is an orange jelly with very thin bits of peel suspended in it. Others contain the whole fruit cut into pieces and imbedded in the jelly. Bitter marmalades are produced by using the sour oranges or a little grapefruit.

The peels of orange, grapefruit and lemon are readily candied and make excellent confections. This side of the by-product industry is yet under-developed and the greater part of the peel which is placed on the market is in the dried form. The best type is being produced in dehydrators where the temperature, humidity and air currents are controlled.

Excellent vinegar has been produced from orange juice, but several conditions operate against its commercial success. First, orange juice concentrates yield

a better return; second, as oranges are tropical or subtropical fruits, the climate in which they are grown is not ideal for vinegar production, the temperature being too high during a greater part of the year.

The working out of the methods for producing these commodities is largely in the hands of the chemists.

STANDARDIZATION

During the past ten years chemistry has been aiding the fruit industry in a new way. Canning and dehydration were steps toward food conservation by affording means for keeping materials in a palatable state for many months. With the advent of refrigerator cars and increased speed in handling perishable freight, the radius for the consumption of both fresh fruit and vegetables has been greatly extended. Citrus fruits are now shipped from California and Florida to all parts of North America where the demand is sufficient, and American apples and oranges are found in the markets of the British Isles. Many other fruits, together with lettuce, peas, asparagus, tomatoes, cabbage and cauliflower, are also sent from the Gulf States and from California to all parts of the country.

It is of course necessary to harvest these products when they are not too mature, in order to permit their arrival, with a minimum amount of decay, at a place often more than 2,000 miles from that where they were grown. This, together with the fact that the first few arrivals of the season, when fresh fruits or vegetables are again becoming available after a period of rest, usually command a price much above the average for the season, has brought about an unfavorable condition in the harvesting of some crops. Each season the

desire to take advantage of the high prices prevailing at the beginning of the crop and to avoid the shipment of over matured fruit, leads shippers to harvest the crop just a bit earlier than the year before. Especially in the case of oranges, grapefruit and cantaloupes this practice has led to the shipment of such immature material as not only seriously to injure its value as a food, but also to ruin the market for the more mature fruit coming later in the season. This practice finally became so alarming that the citrus fruit growers appealed to the Federal food and drug authorities to regulate, under the food laws, such early shipments. Then the question arose, "What constitutes a mature orange or grapefruit?", and the problem was turned over to the chemists. Now both Florida and California have standardization laws based on their findings. These laws prohibit the shipment of immature fruits and prescribe the chemical and other standards for determining their commercial maturity. Similarly, standards have been set for cantaloupes and grapes.

ENHANCING THE COLOR OF CITRUS FRUIT

Certain varieties of citrus fruits mature and are palatable before the color reaches that intensity which is regarded by the consumer as indicative of maturity. The consumer naturally compares the early varieties with the later ones and expects equally good color in both. The Valencia orange, sometimes known as the summer orange, is a late maturing variety. It blossoms in March, April and May, and the fruit is rarely harvested within a year of the blossoming time, in some districts often remaining on the tree for nearly eighteen months. This orange, when grown in certain

districts in California, becomes fully colored in the spring following its blossoming time, but as soon as the hot summer weather approaches, it begins to take on a greenish tint until finally the stem and blossom ends are decidedly green, giving it the appearance of immature fruit.

Furthermore, lemons must be picked for size, regardless of color. The housewife has long been accustomed to buy lemons of a certain size. Her recipes are all made up for that size and she insists on having it. Large lemons have a very limited demand for display purposes by hotels and soda fountains, and very small lemons compete with limes, but the bulk of the trade insists on fruit that runs from 300 to 360 to the box. The producer is thus confronted with the problem of placing on the market a fruit satisfactory to the consumer in quality, size and color when nature does not produce such a fruit at all seasons of the year.

Early in the history of the citrus fruit industry, some one found that if green colored fruit was kept in a room where an oil stove was burning, the green color disappeared in the course of a few days. This at once became a common method for coloring citrus fruit. At first it was thought that the change was caused by the heat, and in order to avoid the troublesome method of oil stove heating, steam heat was substituted, but failed entirely to accomplish the desired result. Then it was thought that carbonic acid gas, produced by the oil stoves, was responsible for the change, and this gas, produced commercially, was tried, but another failure resulted. After this carbon monoxide was tried, but with only partial success. Chemists then began a thorough search for the constituent in oil stove gas which was the most effective agent for coloring fruit. It was finally dis-

covered that the gas, ethylene, was by far the most effective agent.

Fortunately war-time activity had resulted in the manufacture of this gas on a commercial scale, so that it was available to the citrus fruit packer at once. It is now in common use to restore or hasten the golden color on oranges and the silver-like sheen on lemons and grapefruit. It has also been used for blanching celery and many fruits respond in one way or another to its action. Its action seems to be that it hastens the life processes of the fruit, in this way accelerating the destruction of the green coloring matter of the fruit or vegetable. The amount used is extremely small, usually less than one part in five thousand. The results are accomplished in anywhere from two to ten days.

VITAMINS

The most important factor in nutrition today is that class of substances known as vitamins. Nothing in recent years has done more to increase the consumption of both fruit and vegetables than the knowledge, brought to light by biological chemists, that they are the chief sources of supply of these necessary food constituents.

Vitamin A, the antirachitic or growth-promoting one, was at first supposed to be found chiefly in butter fat, egg yolk and cod liver oil. It is now fully established, however, that the tomato is just as rich in this vitamin as butter fat, when calculated on the dry matter present in each, and that carrots, sweet potatoes and parsnips also contain it.

Vitamin B is a protection against beriberi, a widely prevalent tropical disease. While the source of this compound is largely in the bran layers of cereals and

in seed germs, it is also present in protective quantities in practically all vegetables, fruits and nuts.

Vitamin C, the antiscorbutic vitamin, is found mainly in the juice of citrus fruits, but also in the leaves of the salad vegetables, in tomatoes and onions.

Subsequent work, which has brought forth facts concerning the stability of the vitamins, is almost equally as important to fruit growers as the discovery of their occurrence in fruit. The fact that certain fruits or vegetables contain the required vitamin is of little value to the inhabitants of regions where these foods cannot be grown. If, however, it is also shown how the foods containing them can be preserved for adequate transportation without destruction of the vitamins, the usefulness of these foods is greatly broadened.

The biological chemist has made many careful studies of the factors tending to destroy vitamins in foods, and has shown that with certain precautions the vitamin activity is not impaired in their preservation. Notably orange juice, concentrated out of contact with air at a reduced temperature, loses but little of its vitamin potency. Canned tomatoes and spinach are nearly as active as the fresh material. In fact, it has been shown that the ordinary home method of cooking spinach destroys the vitamin to a greater extent than the commercial canning process. Most of the foods necessary for their vitamin content can be grown in countries at great distances from the place where they are to be used, and yet by proper preservation, reach their destination unimpaired.

These are a few of the more important ways in which chemistry has influenced the fruit and vegetable industry. One or two important subjects, such as the manufacture of beet sugar, nut butters, olive oil,

apricot kernel oil, essential oils, glacé fruits, etc., have not been described, either because they are treated elsewhere or because chemistry plays a minor part in their production. If the indirect benefits of chemistry to these industries were fully covered, an entire volume would scarcely suffice.

CHAPTER IX

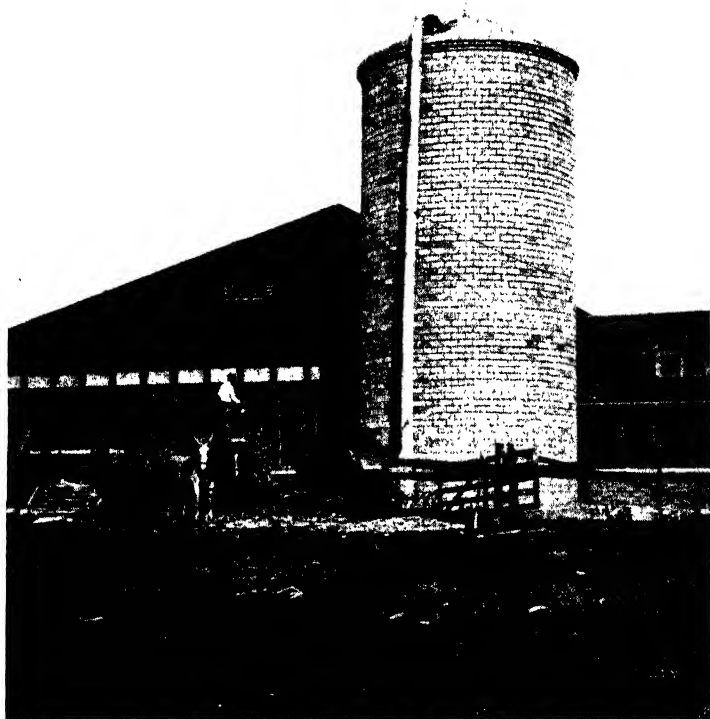
FERMENTATIONS ON THE FARM

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The above title may signify to some readers clandestine operations in opposition to the Volstead amendment, a section in the underground railway of the bootlegger. In fact, the word "fermentation" instantly calls to mind a fruit juice covered with froth, with bubbles of gas actively emerging from the depths of the liquid and contributing their quota to the foam; with a peculiar yeasty odor; and with a covert promise of becoming a delectable beverage for those so inclined.

But there are many kinds of fermentations. There is the lactic acid fermentation when milk sours, acetic acid fermentation during the making of vinegar, putrefactive fermentations in old meat and in our own intestines when all is not well there, fermentation in silage and sauerkraut, manure and bread, soil and sewage. Some fermentations are most useful and beneficent; some are decidedly otherwise. But taking them all in all, the living world could not long survive without them. They maintain a state of flux, of dynamic change, among all the living forms, including our own proud selves. In no field of human activity is the extent of our dependence on fermentation more obvious or more profound than in agriculture; and since fermentations bring about chemical changes, and



Some 500,000 silos in the United States preserve many millions of tons of green feed by a fermentation process. This feed is the mainstay of the dairy cows during the winter months.

are explainable in chemical terms, a brief discussion of them in the present volume is desirable.

Let us define fermentation as the action of microorganisms on organic matter, that is, plant and animal matter of all sorts. The term microorganism includes hosts of bacteria, yeasts, and the common molds and other fungi. Each species carries on a different work, acts upon a different kind of material, and produces therefrom different substances. We shall not attempt, therefore, to follow the chemistry of each species, but will group them to a large extent according to the places and materials in which we find them.

Frequently the term "enzyme" is used in connection with fermentation. In fact "enzyme" and "ferment" are sometimes used synonymously. Enzymes are substances which bring about chemical reactions by their mere presence in the solution. For example, if we boil a little starch in water and let it stand, keeping it free of microorganisms, it will remain unchanged indefinitely. If, however, one adds a little saliva to it, it will, within a relatively short time, become converted into malt sugar. An enzyme in the saliva, manufactured by the salivary glands, does the work. Digestion of food in our stomach and intestines is brought about by a whole series of enzymes, each enzyme having a particular phase of the work to do. Thus certain enzymes dissolve the proteins, others fat, still others act upon the sugars. In the tissues other enzymes bring about combustion. In short, it is generally believed that all physiological processes in all plants and animals, are the result of enzyme action, for all plant and animal cells contain enzymes. Each microorganism usually contains a great variety of them, but the particular list of enzymes differs with each organism. For this reason each form can live on only certain

kinds of food. Thus ordinary bakers' yeast can not ferment milk, because it does not contain the proper enzyme for milk sugar; other yeasts, however, can.

The speed of enzyme action varies with conditions, just as does that of an auto, whether it is going on a concrete road or in sand, or in hot or cold weather, or with high test on low test gasoline. Enzymes are affected profoundly by acidity, concentration of the solution, temperature, and other factors. At or near the freezing point they are practically inactive. With increasing temperature their activity increases, approximately doubling for each rise of 20° F. (-6° C.). It reaches a maximum at about 120° to 150° F. (49° to 65° C.). From there on enzymes are affected adversely, and at about 170° to 180° F. (76° to 82° C.) they not only lose their activity, but are destroyed. Enzymes are also affected by poisons.

The reader may be noting that the above characteristics of enzymes also fit in a general manner the bacteria and other microorganisms. And that is just the point. The activities of these microorganisms are very largely the activities of their contained enzymes. If the reader will bear in mind the above characteristics of enzymes and of microorganisms, the facts in the following discussion will be the more understandable.

SILAGE

There are, probably, 500,000 silos in the United States. The material preserved in them by fermentation is thus counted in the millions of tons. In most dairy regions the silo has come to be recognized as almost as essential to the industry as is the milk pail, and all because it furnishes an easy, inexpensive and efficient way of preserving a cheap and nutritious feed.

For the fermentation process brings about the preservation. Although at first thought fermentation and preservation may seem to be opposed, since the former involves a destruction and degradation of material, we shall see in the following discussion that these two processes can in fact be closely related.

When green corn at the silage stage is harvested, both classes of fermenting agencies are at hand; the outer surfaces of the plants are teeming with a great variety of microorganisms, and the living, succulent tissues of the corn contain active enzymes of many sorts. While the normal corn is standing undisturbed in the field, the organisms on the surface do not have much chance to accomplish mischief, for the epidermis of the corn is an effective barrier. Furthermore, the organisms do not thrive in the relatively dry atmosphere out-of-doors, and with the scarcity of food on the surface of the corn they remain in a dormant condition, often in the form of spores. The enzymes of the plant perform their proper function and maintain normal balances among the constituents of the tissues as long as the plant is rooted in the soil, supplied with moisture, surrounded by air, and bathed in sunshine.

The stalemate, between the microbes on the outside and the enzymes on the inside, is suddenly disturbed when the corn is cut and packed into the silo. The corn is surrounded by only a little air, and there is no sunshine, and the microorganisms find themselves in a humid atmosphere, and with food exuding from the cut surfaces of the corn.

Within a few hours, there is noticeable in the ensiled material the beginning of a series of changes which continue for several weeks and culminate in normal silage as we know it. The oxygen is entirely consumed within 5 hours. Meantime the carbon

dioxide in the silo air has increased from 0.03 per cent, the amount in out-door air, to 18 per cent. It does not stop increasing when the oxygen has disappeared, but continues to rise rapidly for about two days, until it constitutes from 70 to 80 per cent of the silo gases. This indicates that a different form of respiration must have set in. Ordinarily, plant tissue in the dark consumes oxygen and produces carbon dioxide just as animals do. In the absence of oxygen, the materials of the tissues break down, under the influence of the enzymes, producing carbon dioxide and other products.

Heat is generated under both types of respiration, and this is one of the most characteristic phenomena of silage fermentation. Within twenty-four hours of ensiling, the material appears to be warmer than the outside air. The temperature rises for a period of one to three weeks, depending somewhat on the size and insulation of the silo. It ordinarily reaches 90° to 100° F. (32° to 38° C.).

Meanwhile the microorganisms have assumed a new interest in life. Spores germinate and dormant bacteria wake up, and find food ready for the taking. Then a struggle for existence begins. The conditions in the silo are not favorable for all organisms. Molds require oxygen; yeasts need an abundance of sugar and a medium which is not too acid; putrefactive bacteria need protein and a neutral medium; other bacteria thrive in faintly acid surroundings. Therefore, the fight for supremacy in the silo is short lived. Within a few days the yeasts and molds have become insignificant and various acid-forming bacteria monopolize the silage. They multiply at a prodigious rate. Within three to eight days they attain the enormous number of 2000 million in the amount of silage con-

tained in a thimble. In fact, by this time they have worked against their own interests; they have consumed the more readily available food, and have produced acid to such a concentration that it checks their further growth and their numbers become much depleted.

By the end of a month the fermentation is almost at an end; the tissue enzymes have spent their activity, the bacteria have ceased to multiply, heat is not being generated, but instead is slowly radiating away. The mass is quiescent, and unless disturbed will remain so almost indefinitely. Preservation has been effected.

But the preservation of the corn has been attained not without certain losses. Many investigators have analyzed corn at various stages of the silage fermentation; and, although their findings are not strictly concordant, we know fairly well what the main changes are and what losses, in chemical compounds, have taken place. There is a pronounced loss in the total dry matter, varying from 10 to 15 per cent. Most of this loss is in the form of the carbon dioxide produced so abundantly. Part of it is sometimes due to seepage of juice from the bottom of the silo. There is often considerable down-wash through the silo, so that the losses and gains in constituents vary at different levels. The upper third may lose 12 per cent of dry matter and the lower third only 5 per cent. The upper third may lose 3 per cent of its nitrogenous materials and the lower third gain 15 per cent.

The sugars in the original corn are largely consumed, as would be expected. Fortunately the starch is very difficultly attacked under the conditions which prevail in the silo and remains practically unaltered in the finished silage. The more complex nitrogen com-

pounds, such as the proteins, are partly hydrolyzed to simpler substances. The green coloring matter, called chlorophyll, is destroyed and brownish pigments take its place. The crude fiber shows a small decrease. The ether extract shows a large gain; but it is doubtful if this means an increase in true fat as much as an increase in some other ether soluble substances.

The production of acids is the most conspicuous item in silage formation. Lactic and acetic acids are formed in the greatest amount. It will be recalled that the former is characteristic of sour milk and the latter of vinegar. These are formed by a group of bacteria which feed upon the sugars and produce the acids as metabolic by-products. About 2 per cent of acids is usually present. Alcohol is also formed, and in amount about half that of the well-known legal limit of one-half of one per cent.

With the above facts in mind, we are now in a position to discuss the avoidance of unnecessary losses in silage making, admitting frankly that some loss is necessary and is inherent in the process itself. The practice of the careful farmer of packing the cut material firmly into the silo is a good one—it cuts down the oxygen supply, and this reduces the amount of material lost as carbon dioxide. Furthermore, air always induces mold growth, as around air pockets, the top layer of silage, and the newly exposed surface of silage. Although moldy silage is not usually poisonous, it is not desirable, and it indicates a loss in nutritive value.

Considerable loss of nutrients can take place when juice seeps away from the bottom of a silo. In one case over 9,000 pounds of this juice were collected. It contained nitrogen equivalent to 7,500 pounds of silage.

A water tight silo, and the use of corn that is not too green, will help to avoid this loss.

So far, in this discussion, we have established the fact that certain chemical changes accompany the ensiling of green corn, and that the enzymes *within* the corn and the bacteria *upon* the corn are responsible for the changes. And we made these assertions with a certain glib assurance, as if there was not much doubt about either cause or effect. As a matter of fact, however, scientists have been arguing for decades over the relative importance of microorganisms and of plant enzymes in silage fermentation. The crux of the dispute is this: one side has taken dry corn fodder, lifeless and presumably enzymeless, wet it with water, packed it in a silo, and claimed that they got normal silage. The other side has taken fresh corn, packed it in the silo with antiseptics such as chloroform and toluene and claimed that they got normal silage. More recent studies have shown, as is usually the case, that both sides were partly right and partly wrong. For one thing, neither group had perfectly normal silage. For another, each investigator overlooked one or more essential factors. We can summarize the whole question by saying that, under ordinary conditions of making silage, both enzymes and microorganisms play their part, in the manner outlined above.

FERMENTATIONS IN BREAD MAKING

References to leavened bread are as old as written history. Nevertheless, while the Egyptians and Assyrians undoubtedly knew of and used leaven in the manufacture of bread, there is no doubt but that it was regarded as a luxury and that the food of the masses consisted largely of unleavened bread.

The primitive "leavens" undoubtedly consisted of a mixture of different yeasts and bacteria which were able to ferment sugars with the production of alcohol and carbon dioxide. The carbon dioxide gas formed within the mass of dough causes it to become distended or "light," the amount of distention being dependent upon two factors: (a) the rate of carbon dioxide formation in the dough and (b) the rate of carbon dioxide loss by diffusion through the dough mass and escape into the air.

Fermenting fruit juices were probably the earliest form of "leaven." It was early recognized that leavens were acid in reaction, and they were often spoken of as "sour." Pliny in his Natural History states that: "It is very evident that the principle which causes dough to rise is of an acid nature." The original "sour" was obtained in various ways: wine, fruit juices, cider, the fermenting juice of the palm or other plants, or simply a mixture of flour and water which had been allowed to stand at room temperature for several days. For centuries these "sour" were used without any knowledge as to why they were effective.

For generations it was the common practice for each housewife or bake-master to care for his own yeast culture and to propagate it in a separate "sponge" or culture from which portions were taken to be added to the dough batch which was being prepared for bread making. Sometimes a small mass of the dough batch was retained to be added to the next dough. This is evidently the practice referred to in Luke 13:21: "It is like unto leaven, which a woman took and hid in three measures of meal until the whole was leavened." And it is the practice of prospectors in the western part of the United States at the present time.

They merely do not wash the container in which the previous dough was fermented. Such prospectors are our "sour-doughs", a term which indicates very clearly the characteristic fermentation which is produced by their mixed strains of yeasts and bacteria.

With the recent advent of scientific methods into our industrial processes, the bread industry has experienced a series of radical changes. Strains of yeast which are particularly adapted to the manufacture of bread have been isolated in pure culture and are grown commercially in enormous quantities. Probably more than a quarter of a billion pounds of bakers' yeast are used in the United States each year.

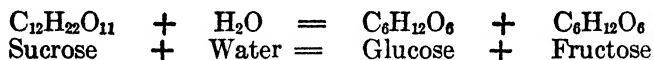
Chemical control is becoming more and more the practice in our larger bake shops so that they may be looked upon as being essentially a part of our chemical industry, characterized by a finished product which, although a food, is satisfactorily manufactured only when careful attention is paid to the chemical processes which take place during the fermentation and baking of the dough.

The yeast used in bread manufacture is known scientifically as *Saccharomyces cerevisiae* and belongs to the group known as "top yeasts", which term includes those yeasts which have the ability to grow and actively ferment sugars at a relatively low temperature. *Saccharomyces cerevisiae* will begin to bud at 1°—3° C. (33°—38° F.) and has a maximum budding rate at about 40° C. (102° F.).

In the manufacture of bread the flour and water are mixed with the other ingredients, including salt, sugar, and yeast, either in the form of a sponge, a more or less liquid mixture, or directly in the form of a dough. The mechanical treatment differs in the two processes, but

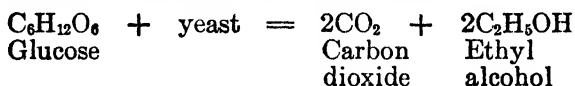
the chemical changes which take place are essentially the same in both.

The yeast plant contains a variety of enzymes, some of which are given off from the surface of the yeast cell and pass out into the watery solution surrounding the cell while others are retained within the yeast cell and act only on substances which are taken into the cell. An example of one of the former is *invertase*, an extra-cellular enzyme which is excreted by the yeast cell and which splits or hydrolyzes sucrose (ordinary cane or beet sugar) into two sugars, glucose and fructose.



This is a necessary process prior to fermentation, for the unhydrolyzed cane sugar is not directly fermentable by yeast.

The simple sugars, glucose and fructose, are then absorbed by the yeast cell and inside of the cell are acted on by another enzyme, *zymase*, with the formation of carbon dioxide and ethyl alcohol.



The carbon dioxide is the active leavening agent. The alcohol does not contribute anything of value to the fermentation process, and is practically completely removed from the dough during the baking process. The carbon dioxide, however, being a gas, occupies a very large volume in proportion to its weight and, as the gas bubbles are formed in the dough, they expand and stretch the dough which surrounds them so that in a short time the dough becomes "light" or, in other words, a spongy mass of carbon dioxide bubbles, surrounded and held together by thin dough membranes.

A good bread flour is characterized by the ability of the dough to stretch into thin membranes which still have sufficient tenacity to retain the gas within the pores; a poor bread flour on the other hand forms a dough which tears readily under the pressure of the carbon dioxide and allows the carbon dioxide to escape, resulting in a soggy or "heavy" loaf of bread.

During the baking process most of the carbon dioxide escapes from the dough; but at the same time the heat affects the gluten proteins so that they become coagulated, in the same way that egg white becomes coagulated when heated. In this way the cellular structure of the dough is preserved in the baked loaf of bread, the air cells of the baked loaf accurately representing the spaces occupied by the carbon dioxide formed during fermentation.

Inasmuch as the carbon dioxide is formed from sugar by the action of yeast, it is important that the dough should be in a proper condition for normal yeast activity and that a supply of sugars should be available.

There are many factors which are necessary for optimum yeast activity. One of these is warmth. Bread fermentation is ordinarily carried out at 28°C. (83°F.) until the dough is formed into loaves. These loaves are then "proofed" for a few minutes by fermenting at 35°C. (95°F.) before they are placed in the oven. The lower temperature of fermentation is desirable because, at this temperature, bread yeasts are satisfactorily active, whereas wild yeasts and bacteria are below their optimum temperature and do not seriously interfere with a normal yeast fermentation.

A second factor necessary for proper fermentation is the correct acidity, and a third factor is a supply of available sugars. These two factors are closely inter-

related. The sugar which is added to the dough when it is mixed is ordinarily all consumed long before the

Maltose production

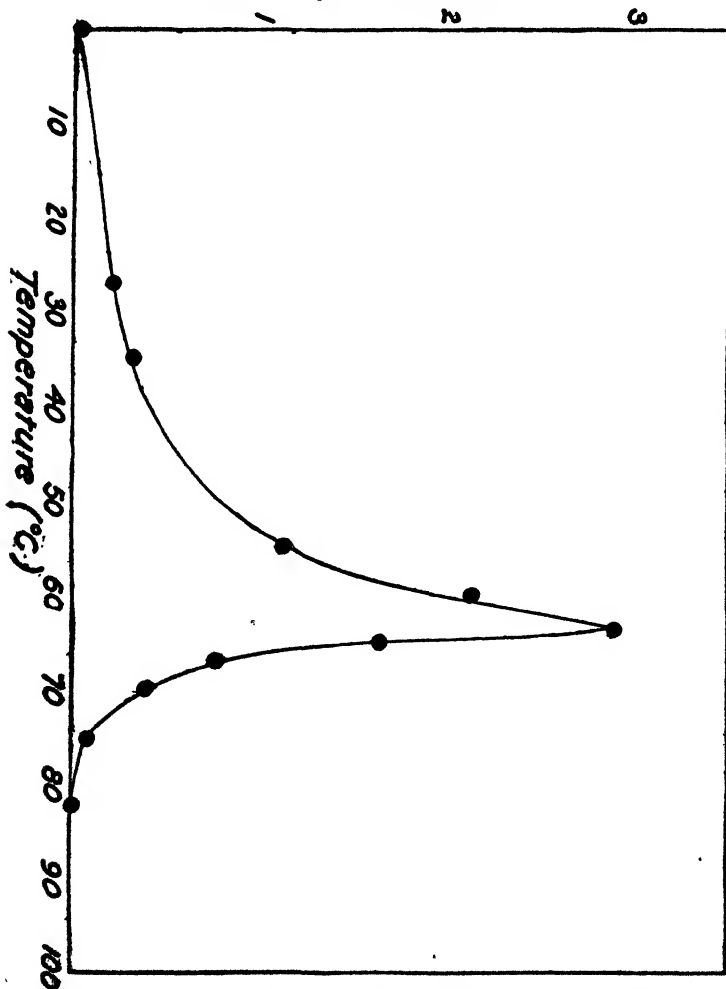


FIG. 1.

dough is ready for the oven. The flour contains an enzyme known as diastase which acts upon starch with the production of a sugar, maltose, which is directly

fermentable by yeast. This diastase thus tends to replenish the sugar supply for the yeast. The diastase activity is very greatly altered by temperature and acidity changes. A curve showing the effect of tem-

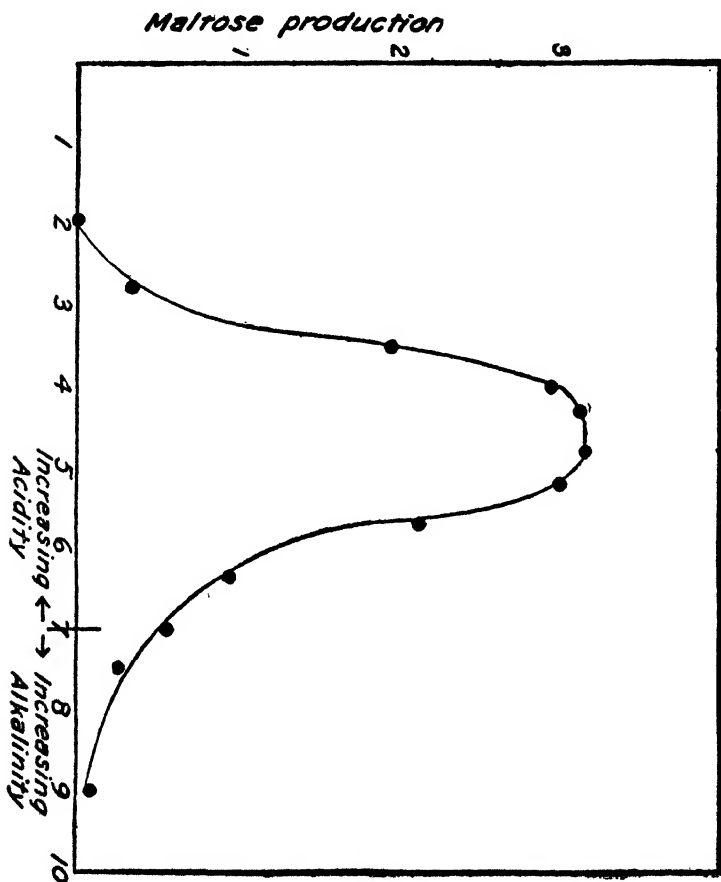


Fig. 2.

perature changes on the diastatic activity of wheat flour is given in Figure 1 and of changes in acidity in Figure 2. The degree of acidity of a fresh dough is usually not favorable for active diastatic activity. Therefore, but little sugar is formed from the starch

at first, and the fermentation proceeds at the expense of the sugar added to the dough batch. The process of fermentation, however, ordinarily results in the production of acids, chiefly lactic acid with some acetic acid; so that as fermentation progresses the dough batch becomes increasingly acid and the production of maltose from the starch becomes more and more rapid.

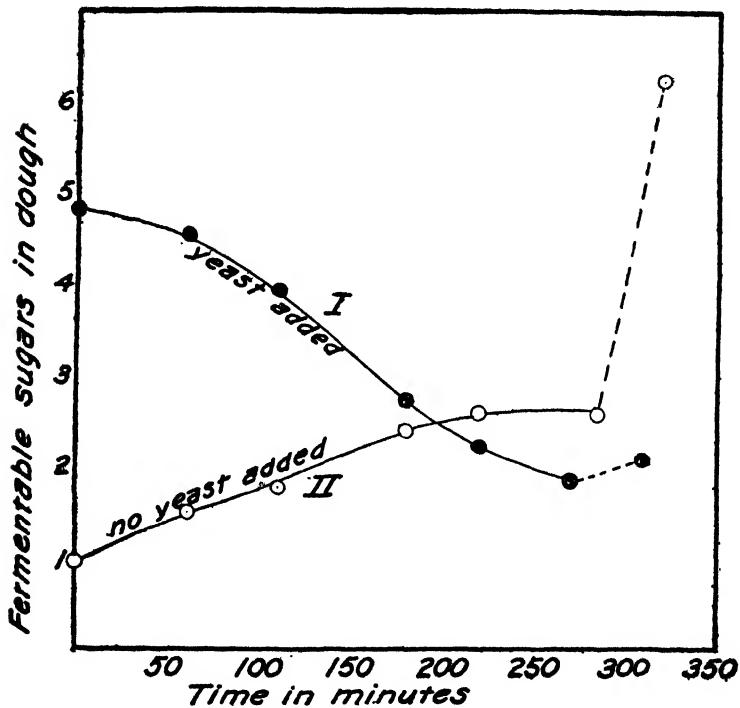


FIG. 3.

Certain flours do not contain an adequate amount of diastase, and such flours have to be especially treated; either a larger amount of sugar has to be added to the initial dough batch or some material containing active diastatic enzymes, such as malt extract, is added to supply the deficiency. Figure 3 shows the changes

in the fermentable sugars present in the dough at different time intervals. In the dough represented by Curve II no yeast was added, and the sugar content continuously increased. In the other dough, yeast was present, together with added sugar, and we see a rapid consumption of the sugar throughout the fermentation, in spite of the fact that the sugar shown in Curve II was being produced at the same time. The upward shoot of Curve II, at the end of the period, indicates the stimulative effect of the oven temperature on the diastase; for, as is shown in Figure 1, the enzyme is greatly speeded up at higher temperatures.

While both the yeast and flour enzymes are rapidly inactivated at the oven temperature, nevertheless, there is a short period, immediately after the dough is placed in the oven, during which the activity of the enzymes is enormously increased. During this period, the carbon dioxide already present in the dough, is rapidly expanding under the influence of the heat. The resulting effects are shown in a great distention of the dough known as the "oven spring."

In the baking of rye bread it is often an advantage deliberately to induce a much more acid fermentation than can be produced by using a pure yeast culture. In such cases it is the common practice to add bacterial cultures—either acetic acid bacteria, by using freshly fermented unpasteurized vinegar or mother of vinegar, or lactic acid bacteria in the form of soured milk. Special flavors may be secured by using particular strains of bacteria such as the Bulgarian bacillus (*Lactobacillus Bulgaricus*). In order that the baker may produce sour rye breads which have a uniform flavor, it is very necessary carefully to control the type of bacteria and yeast which are added to the dough and to exclude as far as possible "wild" forms.

bacteria will feed upon this material, and within a surprisingly short time will consume the greater part of it. That is, they will dissolve it by means of their enzymes and make part of it into bacterial substance. It is a turbid liquid after this phase of the process; and indeed often this is as far as the destruction is carried, this liquid being emptied into a stream or ditch. It still has an offensive odor, however, and pathogenic bacteria are far from being absent.

Hence this simple one-phase system should never be tolerated. It is an easy matter now to give the aerobes a chance at it, and they will finish the job properly. They will render the liquid almost clear, they will destroy the offensive odor, and they will crowd out of existence almost all harmful bacteria which were present in the fecal matter. This final material can then be allowed to drain away into the soil through a covered system of tiling, or through gravel beds, or into a stream.

The construction of the septic tank is simple. It consists essentially of two chambers. The first one houses the anaerobes, and no air is allowed access to it. The second one houses the aerobes, and it is well aerated. Essential items in the process are a sludge of undissolved material at the bottom, and a scum of grease and actively fermenting substance on the top. Baffle plates protect the liquid from disturbance.

The tank acts continuously. The fecal matter supplies the proper bacteria, and, within a week or two after starting the tank, they have increased prodigiously; they have taken complete charge of affairs in the tank; and they have starved out most, but usually not all, of the pathogenic forms, such as typhoid and dysentery. About 50 to 75 per cent of the insoluble matter is rendered soluble; the rest accumulates as a

sludge on the bottom. Hence, every few years the tank has to be cleaned out. That is, the sludge removed. Under no circumstances is the tank to be cleaned *and disinfected*, for its very usefulness demands that it be teeming with bacteria.

As fast as the raw sewage flows in at one end, the clear and relatively harmless effluent leaves the other end to be disposed of in one of several ways. Details of construction would be out of place here. They can be obtained usually from the State Agricultural Experiment Stations.

Sewage disposal by fermentation is one of our finest examples of the harnessing of beneficial bacteria for the aid of man. There are many beneficial bacteria. As was declared above, our very life depends upon them. So let us not have the impression that germs are only loathsome. We have good and bad "bugs", and there are many more good ones than bad ones.

SAUERKRAUT

This good old plebeian food has recently assumed more dignity because of the finding, by laboratory tests, that it has excellent food value. Also, it is another of those products that has passed from the home made to the factory made stage, as it is now packed in canneries on a large scale. Because of this latter change in its status it has recently received some careful scientific study at the hands of chemists and bacteriologists, so that now we know a little more about sauerkraut fermentation than we formerly did.

When cabbage is shredded and packed tightly into containers with salt, it very shortly begins to undergo a very characteristic fermentation process which, if normal, gives us the tender, succulent, semi-transparent, delectable product we know as good sauer-

kraut. Usually the process is normal, but frequently it is not, and there are developed off-colors, and unspeakable odors and flavors. Thus it seems that proper kraut fermentation is largely a matter of chance, that it is due to a number of different bacteria found on the cabbage, and that these bacteria vary from lot to lot of cabbage.

Numerous organisms have been isolated from kraut, and many of these, in pure form, have been inoculated on to cabbage to determine their effect on the kraut fermentation. Several have been found which produce good kraut, but the significant fact is that the organism which consistently gives the best kraut is the common lactic acid bacterium. This is the one that causes the souring of milk. It is the organism found in the pure "starter" of the creamery. It is the same one that is largely responsible for proper silage fermentation. If further studies verify the present indications, it is highly probable that some day pure cultures will always be used in the commercial manufacture of sauerkraut.

The production of acid is the most noticeable chemical change in kraut fermentation. The acids formed are largely lactic, with smaller amounts of acetic, the acid found in vinegar. Ordinary ethyl, or grain alcohol is also formed. The 1.5 per cent of acids formed, and the 2 per cent of salt added, have an inhibiting effect on the growth of other organisms. The result is that after the normal fermentation has ceased, the kraut will be preserved almost indefinitely without further change.

The following is a brief statement of the principal changes in chemical composition which take place in the conversion of cabbage into sauer kraut: The water content is slightly decreased and about 14 per cent of

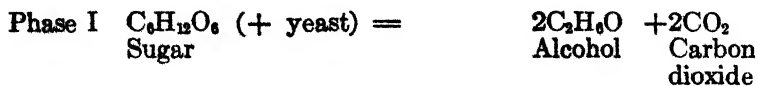
the dry matter is lost. The protein is reduced from 1.5 per cent to 1.2 per cent. The crude fiber is increased from 1 per cent to 1.4 per cent. The sugars are reduced from 4 per cent to about 0.4 per cent.

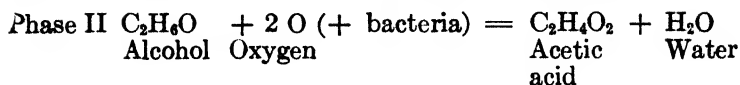
VINEGAR

The making of vinegar is a two-stage fermentation process, brought about by two different groups of organisms at different times and under different conditions. In the first stage, yeast produces alcohol from sugar, just as in the making of any alcoholic beverage. In the second stage the acetic acid bacteria feed upon the alcohol and oxidize it to acetic acid. When the latter has reached a proper concentration we have vinegar.

The first or alcohol phase is no different here from what it is in any other alcoholic fermentation and is almost invariably brought about by yeast. The second phase begins when the first is completed. Pure alcohol itself may be used for the making of vinegar, after it is properly diluted and inoculated with the vinegar bacteria. Any material that contains 12 to 16 per cent of sugar, such as a fruit juice, extract of malt, or diluted honey or molasses, may be used as raw material for alcohol production. This will give an alcohol content of 6 to 12 per cent, which is necessary in order to obtain 4 to 8 per cent of acetic acid in the vinegar.

The second or acetic acid phase is primarily an oxidation. The bacteria require an abundance of oxygen for converting the alcohol into the acid. This is shown in the following equations:





An oxygen supply is secured in various ways in vinegar making. On the farm a cask is usually placed on its side, half filled with the alcoholic liquor, and holes bored in the upper part of the cask to admit oxygen. Complete acid fermentation is here a matter of months. In the commercial "quick vinegar" process the alcoholic liquor is trickled through a tower of beechwood shavings which are heavily impregnated with the vinegar bacteria, or "mother of vinegar." In this case the vinegar is completed in a few days.

Vinegar making on a large scale is another industry in which a knowledge of the chemistry and bacteriology involved is enabling the manufacturer to exercise control over the processes. He analyzes his raw materials and the liquors at various stages of the process. He can always turn out a vinegar of standard composition. He uses pure cultures of yeast and of vinegar bacteria, and keeps out the foreign organisms by sterilization and by exclusion. This may be called "scientific control," if you like.

We have discussed above only five types of fermentation processes. These were chosen because of their great economic importance and because of their diverse nature. Many other processes could have been included such as those in the dairy industry, in the soil, in manure, in the canning and packing industries. Some of these are included in other parts of this volume. If the reader has come to some realization of the great diversity of microorganisms and their action, and of the fact that there are both harmful and beneficial types of fermentations, and if he has been stimulated to observe their everyday and commonplace

occurrence, and to appreciate the importance of both chemical and bacteriological knowledge and control over them, then the writers have succeeded in their purpose in writing this chapter.

CHAPTER X

CHEMICAL WARFARE TO SAVE THE CROPS

ANDREW J. PATTEN

Chemist, Michigan Agricultural College and Experiment Station

In the early history of the human race when the people were largely nomadic in character, food production was a matter of very little concern. As the population increased and people gave up the roving habit, it became necessary that some attention be given to the production of food for both man and animals. With this increase in population and the resulting increase in the amount of land devoted to permanent agriculture there was a proportionate increase in the number of insects and fungus diseases that infest and destroy vegetation.

At first, loss of crops due to the ravages of insects and fungi was considered a form of divine punishment, but as the losses increased to the point where they became an important economic factor in crop production efforts were made to minimize them as far as possible.

It is difficult to determine when measures for the control of insect pests and fungus diseases were first used. One of the earliest attempts in this direction is described by Parkinson, early in the seventeenth century. For the control of caterpillars and fleas on turnips he was advised to drag the field with a rope smeared with "train-oil" and brimstone.



Courtesy J. S. Houser, Ohio Exp. Sta.

(Photo Aerial Division, U S Army)

CAPT A W STEVENS

Dusting by Airplane

Plane flying at an altitude of 20-30 feet 53 yards to the windward of the grove

The selection of materials that were offensive to the senses seemed to be uppermost in the minds of the early investigators for many of the substances used at that time were of such character.

A great variety of substances was tested during the eighteenth and early part of the nineteenth centuries. Many of these had real insecticidal or fungicidal value and are still in use at the present time. A partial list of substances used during this period includes slaked lime, sulfur, powdered tobacco, soap, soot, hellebore, tansy, wormwood and other strong smelling herbs, turpentine, petroleum, and fish-oil. Fresh cow-dung and urine were also believed to possess some insecticidal or fungicidal value for they were frequently recommended.

In the early use of insecticides little thought was given to the characteristics or habits of the insects themselves. As the necessity for the control of injurious insects became more urgent and such control measures became more generally adopted, it was discovered that certain materials were destructive to some insects and of no avail against others. This led to a study of the insects. It was learned that they could be roughly divided into two classes according to their feeding habits. One class, is composed of insects that eat the foliage, called "chewing insects;" the other class is composed of insects that puncture the leaf or fruit in order to suck the juice, called "sucking insects." When this distinction in the feeding habits of insects became known it was plainly evident that different methods of control would have to be used.

This difference has led to a classification of insecticides into poison sprays or *stomach* poisons embracing those materials which act as true poisons when taken

into the system and *contact* poisons embracing those materials that kill upon contact with the body.

Practically all of the effective insecticides and fungicides are true chemical compounds or contain some active principle that is a true chemical compound. The control of insects and fungi is therefore, primarily, a case of chemical warfare.

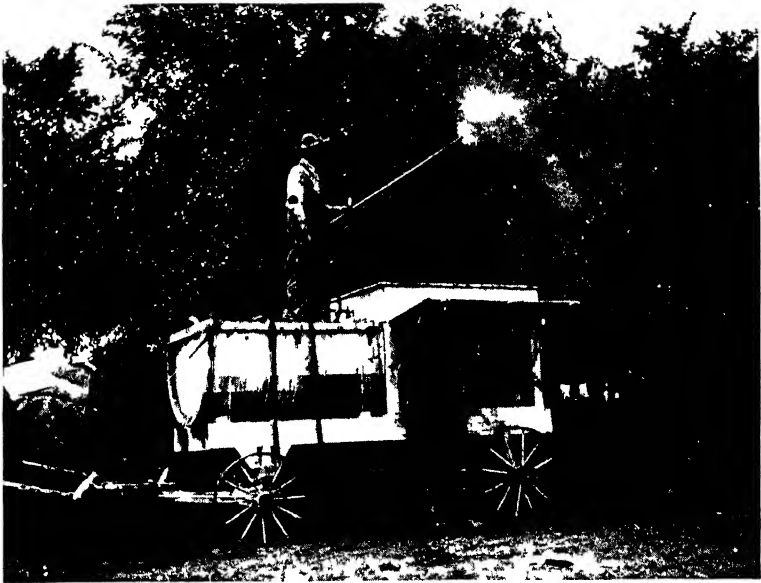
POISON SPRAYS

Arsenic in one form or another has been, and now is, the chief ingredient in nearly all of the poison sprays. Arsenic is principally obtained as a by-product in the production of copper, nickel, and cobalt from ores containing this element. It is obtained in the form of white arsenic (As_2O_3), a very poisonous compound. Formerly, this was a curse to the smelting industry but because of the rapid increase in the use of arsenical spraying materials, it has risen to a place of great importance, for it is the basis of all arsenical sprays.

Like phosphorus, arsenic is capable of forming two distinct acids known as arsenic acid (H_3AsO_4) and arsenious acid (H_3AsO_3). Compounds formed by the union of these acids with basic materials, such as sodium, calcium, magnesium, lead and zinc, are called *arsenates* and *arsenites* respectively.

When arsenical compounds were first proposed as sprays for the control of insects on garden and fruit crops, there was much aversion to their use because of the fear that the products of the sprayed plants might contain arsenic in sufficient quantity to be injurious to persons and animals eating them.

Carefully planned experiments were carried out by a number of chemists and it was definitely shown



An efficient Spraying Outfit

that under ordinary conditions of spraying practice the products from plants sprayed with arsenical poisons were harmless.

Paris Green is a compound of copper and arsenic known to the chemist as aceto-arsenite of copper. It was first used about 1870, with great success, for the control of the so-called Colorado Potato Beetle. It was also used on fruit trees for the control of the codling moth but with less success, because of the danger of injuring the foliage. Although it is still used to a considerable extent it has been largely superseded by other arsenicals that are safer and have greater adhesive properties.

London Purple was soon a rival of Paris Green. It was produced by the London firm of Hemingway & Company. It was first used in this country to kill the potato beetle in 1878 by Professor Charles E. Bessey at Ames, Iowa, who also gave to the material its name. It is a by-product of the dye industry and is of rather variable composition.

Neither of these two substances possesses the qualifications of a universal insecticide either because of the danger of causing injury to the more tender foliage or because of variable composition. A substance capable of wider application was needed and the knowledge of the chemist was appealed to.

Lead Arsenate—Mr. F. C. Moulton, Chemist for the Massachusetts Gypsy Moth Commission, proposed the use of this material in 1894 in the warfare against the ravages of the Gypsy Moth. From that time its use has steadily increased to enormous proportions.

At first very little attention was paid to the chemical composition of lead arsenate other than its total and soluble arsenic content. As its use increased, however, chemists began to study its chemical com-

position and also methods of its manufacture. Two methods of producing lead arsenate were originally used. In one method solutions of lead acetate and sodium hydrogen arsenate were mixed together and in the other method solutions of lead nitrate and sodium hydrogen arsenate. In both cases lead arsenate was produced. Lead arsenate, being insoluble, is separated from the solution by filtration. When the lead arsenates prepared by these two methods were used as sprays, it was found that they possessed somewhat different insecticidal qualities. Chemical analysis showed that the arsenate formed from lead acetate and sodium hydrogen arsenate is largely, what is called, basic lead arsenate. In other words, the total hydrogen equivalent of the sodium arsenate is combined with lead, the product obtained by the other method is largely the acid lead arsenate in which all but one hydrogen equivalent is combined with lead. The acid lead arsenate is practically as insoluble in pure water as the basic arsenate, is a quicker acting poison, contains more arsenic, is lighter and remains in suspension longer. When acid lead arsenate is mixed with water that contains much alkali or carbonate a reaction takes place which renders some of the arsenic soluble and, under such conditions, if sprayed on tender foliage, injury is liable to result. Foliage injury from the use of the basic lead arsenate is less liable to occur.

Fineness and slow sedimentation are two qualities that an insecticide should possess in order that it may be distributed completely and evenly upon the foliage with the spraying outfit. Adhesiveness is another important qualification of an insecticide, for the longer a material will remain on the foliage the longer will it be effective as an insecticide. Chemists have been

studying these problems with the result that the lead arsenate of today is far superior to that of ten years ago. Formerly all the lead arsenate was marketed in the paste form containing as much as fifty per cent. of water, but today nearly all is in a dry powder which mixes readily with water and which remains in suspension well.

Calcium Arsenate—The cost of insecticides has always been a deterrent influence against a more universal adoption of spraying practices. Chemists have directed their efforts toward the production of cheaper and more efficient materials. Lead and lead compounds are relatively expensive. Lime is much cheaper and more abundant than lead; consequently a combination of lime and arsenic in the form of calcium arsenate is a cheaper insecticide than lead arsenate. In the cotton belt, enormous quantities are now used annually in the control of the boll weevil, which, at one time, seriously threatened to destroy the cotton growing industry in this country. It is also used extensively in the warfare against the potato beetle.

An interesting development in the manufacture of calcium arsenate is one by which the product is caused to assume a positive charge of electricity. Since the wet leaf carries a negative charge of electricity the positively charged calcium arsenate is attracted to the leaf and adheres much longer than the ordinary or standard calcium arsenate. Experiments have shown the adhesiveness of a positively charged calcium arsenate to be from 189 to 256 times greater than that of the standard product. Whether or not this discovery can be adapted to the commercial manufacture of the product has yet to be demonstrated.

Scheele's Green (a compound similar to Paris green), zinc arsenite, calcium arsenite, and magne-

sium arsenate, have also been used in this chemical warfare on insect pests but none of them has the wide range of usefulness possessed by either lead or calcium arsenate and for this reason they are little used at the present time.

Hellebore is a powder prepared from the roots of plants bearing the formidable names of *Veratrum album* and *Veratrum viride*. The active principle of the root is a powerful alkaloid known as *jervine*. It is poisonous to insects when eaten and it also possesses some value as a contact insecticide. This material has not, of course, the wide range of usefulness that the arsenicals have but, under some conditions, it is a very useful insecticide.

CONTACT INSECTICIDES

Pyrethrum is one of the first substances to be successfully used as a contact insecticide. It is composed of the powdered flower heads of certain plants of the genus *Chrysanthemum*. In parts of eastern Europe this substance has been known as *Dalmation powder* and as *Persian insect powder* for more than a century. The knowledge of the nature of this material was long kept a secret from the rest of the world. Early in the nineteenth century an Armenian merchant, Sumttoff or Juntikoff by name, while traveling in the Caucasian region, discovered that the insect powder was made from the ground flower heads of *Pyrethrum roseum* and *Pyrethrum carneum*. In 1818 Sumttoff's son began the manufacture of pyrethrum powder on a large scale and it was then, for the first time, introduced into other European countries. The powder was first introduced into America shortly before 1860. Somewhat later G. N. Milco, a native of Dalmatia,

started the industry at Stockton, California. The American product is sold under the name of "*Buhach*" and is apparently equal in every respect to the imported powder.

The insecticidal value of pyrethrum is due to two toxic compounds called *Pyrethrin I* and *Pyrethrin II*. These compounds are present in the insect powder to the extent of 0.2 to 0.3 per cent. They have about the same toxicity as nicotine.

Most of the insecticide powder sold at the present time for household use is pyrethrum although it may parade under other names. The total amount used in this country is probably in excess of 3,000,000 pounds annually.

Pyrethrum lends itself very readily to adulteration and the addition of ground stems and flower heads of other plants is not easy of detection.

Derris is another insecticide of plant origin. It owes its insecticidal value to a white crystalline substance called *tubatoxin* and a series of resins. It is very effective against fleas on dogs and cats, also against mites on poultry and cattle.

Soaps—The value of soap solutions for the control of various soft-bodied sucking insects has long been recognized. A great variety of soaps are used for this purpose, but the more common ones are made from fish-oil and lye, either soda or potash. Sometimes other substances such as resin, carbolic acid, and nicotine are added to the soap. Soap solution added to other sprays often increases the spreading property by lowering the surface tension of the mixture.

Oil Emulsions—Under this heading are included kerosene, crude petroleum, oil distillates, the so-called miscible oils, creosote-oil emulsions, and carbolic-acid emulsions.

Kerosene and other petroleum products have long been recognized as possessing insecticidal value. While highly efficient as such, the unmixed oils alone are harmful to vegetation, often killing the trees, unless used during the dormant season and then with considerable care. How to make them less harmful has been the subject of much careful study. Simple dilution with water is of no avail as oil and water will not mix. Some success was attained by pumping the two liquids out of a common nozzle under high pressure, with the purpose of finely dividing the oil in the water and in this way obtaining an even mixture. Such a mixture, however, soon separates and is far from being satisfactory.

Another method was tried that has proved to be entirely successful. By this method the oil is added to chemicals that act as emulsifiers and when this mixture is added to water a perfect and stable emulsion is produced. The emulsifier used for this purpose is a soap, usually made from fish-oil and caustic soda or potash. An emulsion is simply a fine state of division of oil in the water which is brought about by the soap forming a very thin film around the droplets of oil and preventing their coalescing.

A great many different oil emulsions and miscible oils are now on the market but it is out of place here to attempt a description of them.

One of the most important advances in this type of spray material is the development of the heavy mineral oil or lubricating oil emulsions. This type of emulsion has been used successfully in recent years for the control of San Jose scale and certain citrus scales that have not yielded to lime-sulfur solutions.

A new type of lubricating-oil emulsion has been proposed in which the emulsifying agent is composed of

Bordeaux mixture, iron sulfate-lime mixture, calcium caseinate, and saponin. Such an emulsion not only possesses insecticidal value but, owing to the presence of the Bordeaux mixture, acts also as a fungicide.

Tobacco Products—Tobacco powder has long been used as an insecticide, especially in greenhouses. The active principle in tobacco is the alkaloid, *nicotine*, one of the most powerful and rapidly acting poisons known. Chemical analyses have shown that the nicotine content of tobacco varies from 2 to 7 per cent, while the amount of nicotine in tobacco stems, from which much of the tobacco powder is prepared, is very much less, sometimes as low as 0.12 per cent. For this reason it is not practical to use tobacco dust in large scale spraying operations.

Nicotine as it exists in tobacco is quite readily soluble in water and may be extracted by simply soaking the tobacco in water for twenty-four hours or by heating the water nearly to boiling. Since nicotine is volatile, the extract cannot be concentrated by boiling unless some means are taken to fix the nicotine in a stable form. This can be done by causing the nicotine to combine with sulfuric acid to form nicotine sulfate. With the nicotine in this combination the extract can be concentrated to a small volume without loss of nicotine. Concentrated extracts of the free nicotine may also be prepared by using suitable precautions. Solutions of both free nicotine and nicotine sulfate, that contain 40 per cent. of the alkaloid, are now on the market. Thus a pint of such an extract will have as much insecticidal value as 10 pounds of average tobacco powder.

So-called nicotine dusts have been used extensively during the past few years. In these the nicotine preparations are mixed with some finely powdered carrier

such as kaolin, hydrated lime, gypsum, or quicklime. Some of these carriers, such as kaolin, are objectionable since the nicotine is not given off in sufficient quantities to be effective. Hydrated lime or quicklime, on the other hand, may volatilize the nicotine too fast, especially if an extract containing the free alkaloid is used.

There are several factors involved which determine the proper kind of material that should be used to carry the nicotine when it is to be applied in this manner. Suffice it to say that the most satisfactory material is the one that will volatilize the largest percentage of nicotine in a given time.

Lime-Sulfur—One of the most widely used contact insecticides for the control of scale insects is concentrated lime-sulfur solution. It was first used by a Mr. Dusey of Fresno, California, who, observing that it was successfully being used for killing lice on sheep, borrowed a pailful from his neighbor and sprayed it on his fruit trees. The results of this trial were so successful that its use has spread to all parts of the country.

It is prepared by boiling together a mixture of sulfur, hydrated lime and water. The lime water dissolves the sulfur to form compounds known to the chemist as poly-sulfides of calcium or, in other words, one atom of calcium combines with several (usually four or five) atoms of sulfur. There are other compounds formed in small quantities but the ones just mentioned are the principal ones and those to which the solution probably owes its insecticidal value.

The greater bulk of lime-sulfur is marketed as a liquid although it is also prepared in the dry form. However, the dry lime-sulfur oxidizes much more

rapidly than the solution and for the present, at least, there seems to be no advantage in preparing it in this way.

FUMIGANTS

Hydrocyanic Acid Gas—This was first used for the destruction of scale insects by D. W. Coquillet of Los Angeles, California, in 1886. In using it in an orchard the tree is covered with a canvas tent that is reasonably gas tight and the gas is liberated from sodium or potassium cyanide by the action of sulfuric acid. For a number of years this was the only satisfactory way of controlling scale insects. Other methods have now practically superseded it. Fumigation by hydrocyanic acid gas is still used quite extensively in greenhouses and for killing of scale on nursery stock. A liquefied hydrocyanic acid may now be obtained in cylinders and, in this form, is a much more convenient source of the gas than the solid cyanide and sulfuric acid.

Hydrocyanic acid, otherwise known as prussic acid, is a deadly poison and must be handled with the greatest care.

There is some evidence that calcium cyanide in the form of a fine dust may replace hydrocyanic acid. In the presence of moisture calcium cyanide breaks down, liberating free hydrocyanic acid.

Carbon Disulfide—This foul smelling liquid has long been used for destroying insects that attack stored grains and other dry seeds. It is very effective for this purpose but since it is highly inflammable its use is attended with some risk unless extreme precautions are used.

Chloropicrin—Many of the poison gases used in the late war for the destruction of human beings have been tested to determine if they might be put to the

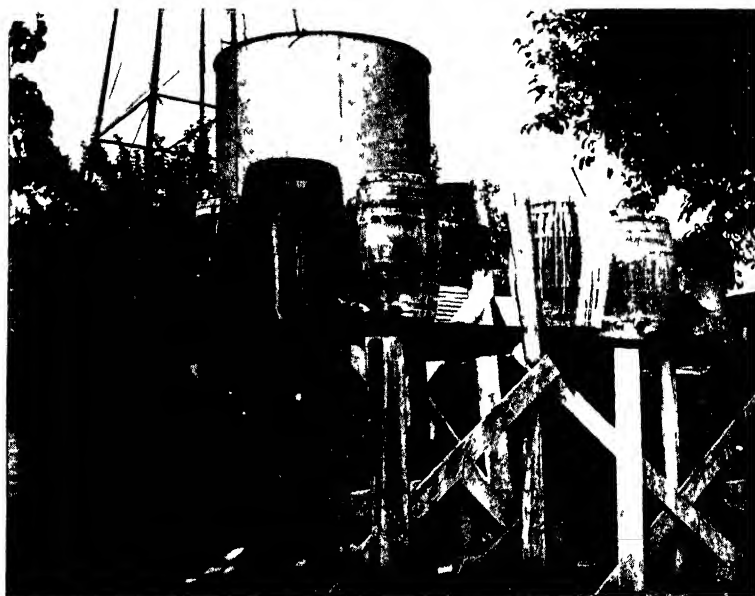
service of man in the control of insect pests. One of these, chloropicrin, which, by the way, is not a gas but a very volatile liquid, gives promise of being a useful insecticide.

Ethyl Acetate-Carbon Tetrachloride—This mixture of organic liquids has been recommended by the U. S. Department of Agriculture for the treatment of stored grain. It is non-inflammable, is non-toxic to man, does not affect germination and leaves no permanent odor or taste in the fumigated product. This mixture is somewhat more expensive than carbon disulfide but the factor of safety should recommend it even though the cost is more.

Paradichlorobenzene—While the name of this substance may be as discouraging to some people as its vapors are to certain insects, such as tree borers, it is in fact as simple as many other compounds used as insecticides. To the chemist, this name immediately suggests that the substance is benzene containing two atoms of chlorine and the first two syllables (*para*) denote the position of the chlorine atoms in the molecule. It is a white, crystalline substance having a strong ether-like odor. It is insoluble in water but vaporizes completely at ordinary summer temperature and is successfully used for killing borers in fruit trees.

FUNGICIDES

The losses caused by fungus diseases are probably as great as those caused by insects. No conception of the magnitude of the losses caused by insects and fungi throughout the country is possible. If one were to hazard a guess as to the amount of such losses the figures would be unbelievable. Suffice it to say that if it were possible to prevent these losses and the



A well-planned Bordeaux Mixing Plant.

amount they represent could be applied to the payment of Federal, State and Municipal taxes the burden upon the taxpayer would be very considerably lightened.

The destruction caused by fungi is more insidious than that caused by insects because the presence of fungi cannot be detected by the unaided eye until the damage has been done. Under proper conditions of temperature and moisture a fungus disease may spread very rapidly and the damage be complete before control measures can be undertaken. The control of fungi, unlike that of insects, is, therefore, a matter of prevention rather than a cure after the disease is apparent.

The use of vinegar to prevent canker on trees, as recorded by the same Parkinson referred to early in this chapter, is probably one of the first attempts at controlling fungus diseases. Since then many different materials have been tested for the control of fungus diseases, but in studying the development of the practice of spraying we find that sulfur and compounds of sulfur and copper have been more consistently used than any other substances.

Sulfur was used to control mildew as early as 1821. Dr. William Kendrick, in 1833, advised the use of a mixture of quicklime, sulfur and boiling water. Various modifications of this formula have been used from that time until the present day for the control of many fungus diseases.

Bordeaux Mixture—The discovery of the fungicidal property of copper is accredited to Benedict Prevost, of Montaubon, France, who published a memoir in 1807 giving the results of a series of experiments on the control of smut in wheat. He found that one part of copper sulfate in 400,000 parts of water was suffi-

cient to prevent the smut spores from germinating and that one part in 1,200,000 parts of water retarded the germination. W. F. Radclyffe, in 1861, used a solution of copper sulfate in water for the control of mildew on rose bushes.

The full appreciation of Prevost's discovery was not realized, however, until 1882, when Professor Millardet, of the Faculty of Sciences, Bordeaux, France, made the following accidental discovery. In passing through a vineyard one day, Professor Millardet noticed that some of the vines retained their leaves while elsewhere they had entirely fallen. In searching for an explanation of this condition he was informed by the manager of the vineyard that it was their custom to cover the grape leaves along the border of the vineyard with a mixture of copper sulfate and lime to keep away marauders who were not bold enough to eat the fruit for fear it was also contaminated with the same substance.

Following this chance discovery, Millardet and Gayon, a chemist, began a series of experiments with copper sulfate and lime for the control of fungus diseases which resulted in firmly establishing the fungicidal value of this mixture. Many changes have been made in the formula originally used by Millardet as the chemical properties of the mixture became better understood, and today a much smaller proportion of copper sulfate is used with equally good results.

Bordeaux mixture is prepared by mixing a solution of copper sulfate and milk of lime. A precipitate is formed which is generally believed to be a basic copper sulfate. If the mixture is properly made the precipitate will be of such character that it will remain in suspension for a long time.

Pickering and Bedford of England believe that the

fungicidal value of Bordeaux mixture is due to the regeneration of copper sulfate by the action of carbonic acid of the air and, on the basis of this theory, have proposed the use of a spray that has come to be known as the Pickering spray. This is prepared by mixing a solution of copper sulfate and lime *water*.

Since, as has been said, "an ounce of prevention is worth a pound of cure," the treatment of certain seeds before planting, for the purpose of killing fungus spores harbored by them, has become an established custom. For this purpose solutions of formaldehyde, corrosive sublimate, and copper carbonate dust have been very successful.

During the past few years a number of organic compounds of mercury bearing such names as "*Seedosan*," "*Chlorophal*" and "*Germisan*" have been used for treating wheat, for the prevention of a fungus disease known as *bunt*, with excellent results. These compounds are relatively expensive, however, and not readily available.

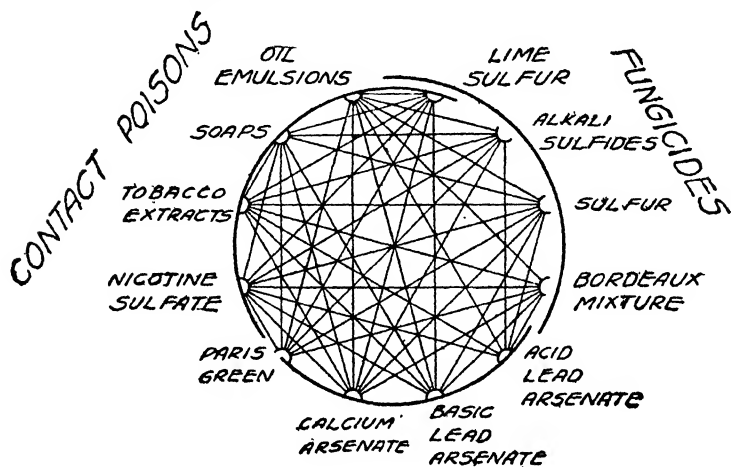
COMBINATION SPRAYS

It is a common practice to use a combination of insecticides or of insecticides and fungicides in order to control different kinds of insects or fungi at one and the same time. This materially reduces the labor cost of spraying. When this is done, it is necessary to know something about the compatibility of the different materials. Paris green and lime-sulfur or Paris green and oil emulsions should not be mixed together because a chemical reaction, setting free soluble arsenic compounds, would result and the use of such a combination would cause serious damage to foliage.

The compatibility chart adapted from one published

in California Agricultural Experiment Station Circular No. 195 indicates some of the sprays that may

COMPATIBILITY CHART



STOMACH POISONS

KEY TO CHART

- SAFE COMBINATIONS
 - - - DANGEROUS COMBINATIONS

be safely used in combination and some that should not be used.

SPREADERS AND STICKERS

The spreading and sticking properties of spray materials are very important since those materials that will cover the sprayed surface with an even, thin film, and adhere for a long time are the most economical to use.

Such substances as calcium caseinate, soap, glue, flour paste, and skim milk have been shown to increase the spreading and adhesiveness of many sprays.

DUSTS

The application of liquid sprays is, under some conditions, attended with considerable difficulty, inconvenience and much labor.

Orchardists have long desired some way of reducing the labor of spraying without reducing the efficiency of their efforts. The use of insecticides and fungicides in the form of very fine dusts offers a solution of the problem that is receiving much attention at the present time.

The use of dusting materials is by no means new for sulfur as a dust was used as far back as 1846. The use of dusts as a substitute for spraying started in Missouri in 1900.

Numerous experiments have been made in the principal fruit growing states but the work is still in an experimental stage, except in the Southern States, where dusting cotton with calcium arsenate for the control of the boll-weevil has superseded all other methods.

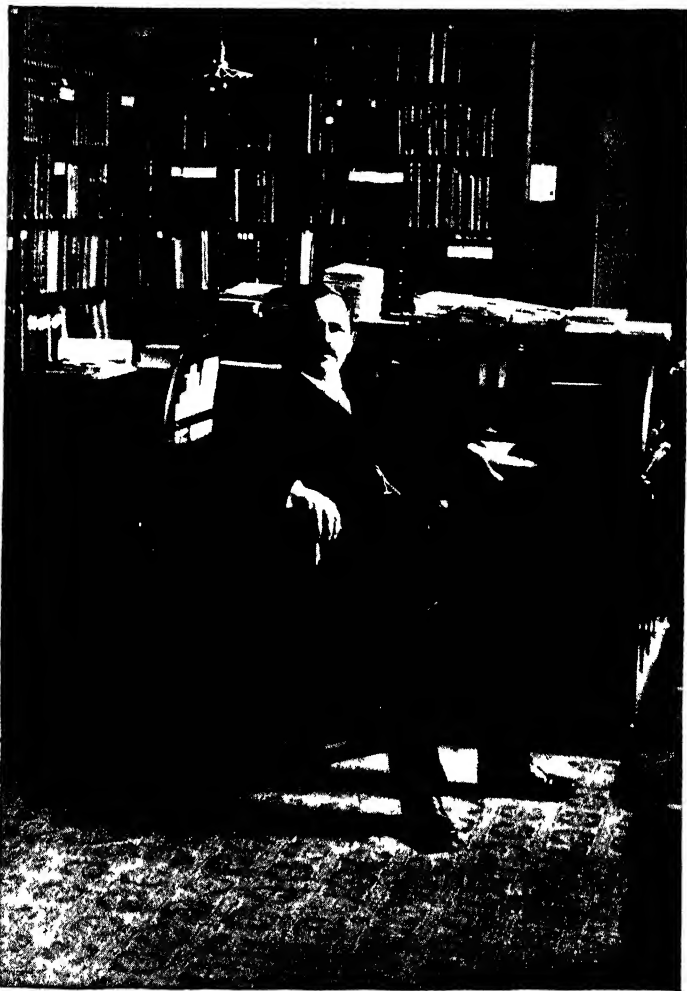
The materials used as dusts are chiefly lead arsenate, calcium arsenate, sulfur, dehydrated copper sulfate, and nicotine products, diluted with such substances as hydrated lime, kaolin, and gypsum or land plaster. All the materials must be very finely pulverized.

The advantage of dusting as against spraying is chiefly the saving of time, as it is still a mooted question whether this method is as cheap or as efficient as the older methods.

The distribution of dusts by means of the airplane is one of the most recent developments. The first trial of the airplane for this purpose was made by the Ohio Agricultural Experiment Station, in cooperation

with the U. S. Air Service, for the control of catalpa sphinx on catalpa trees by lead arsenate. Extensive experiments have been carried on in the South with the use of airplanes for dusting cotton to control the boll-weevil. That this use of the airplane may become a reality on large scale operations is not improbable.

Through the combined efforts of the chemist, entomologist, and plant pathologist new destructive agents and more efficient means of applying them are continually being developed. Much remains to be accomplished, however, before the warfare against destructive insects and fungi is won.



Professor W. O. ATWATER in his library in the Chemistry Laboratory of Wesleyan University.

CHAPTER XI

AGRICULTURE AND THE EVOLUTION OF OUR DIET

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The ultimate aim of agriculture is to provide food for man, to furnish raw materials for clothing and household textiles, and since forestry is a specialized branch of agriculture, to provide timber for house construction and furnishing and, in lesser degree than formerly, wood for fuel. In older times the farm furnished means for land travel and transportation and this still is important. The ox team has almost gone but the horse is still indispensable. The chemist, the physicist and the engineer have wrought so successfully that a marvelous transformation has taken place in traffic and transportation and the end is not yet.

More clearly than ever before can be seen the relation of such things to the home and the life lived in it. The self-sufficient farm home is within our tradition, almost within the memory of persons alive today or of some whom we have known. The milling, baking, dyeing, spinning and weaving, and a host of other arts and industries have passed from the home to the mill and manufacturing plant where science has provided a perfection of technique and a uniformity of product and very often a quality not hitherto obtain-

able. Science and agriculture have here united to the benefit of mankind, but the credit due to those who did the pioneer work through uncounted ages cannot be overestimated. Observation, empirical knowledge and later the development of chemistry and other branches of science have made possible the growth of agriculture. From this has come the possibility of a regulated and adequate food supply.

FROM PRIMITIVE TIMES TO AGRICULTURE AND THE HOME

No one can say how long it has taken man to develop from the primitive state to civilization, but the time was long.

Early man ate anything and everything available, insects, grubs, animals, shellfish, fruits, vegetables, bulbs and whatever else he could find. Those which experience showed were poisonous he ultimately rejected, but many which were very disagreeable, if not indeed distinctly harmful, were eaten in times of stress and famine. The Australian natives, one of the most primitive peoples known in modern times, lived in this precarious manner.

In time, plants and animals were domesticated for food and for other uses, and cooking, weaving, garment making, and other household arts developed. In the Western hemisphere we have a cross-section of this development particularly interesting to us, which begins at the time when man had so far progressed that he could make a fire, build a sort of primitive boat and make a net in which he could catch fish. Apparently the domestication of animals, with the possible exception of the dog, was not known to these earliest pioneers. Such men, there is good reason to believe, drifted over from Asia to the northwestern

extremity of the North American continent. That the drift was early in man's progress towards civilization is evidenced by the fact that the wheel, one of the very great factors in civilization, was not known to this primitive people, nor was it later discovered by them, but remained unknown until after 1492.

Out of this beginning in the Western hemisphere, which is far back in the progress of mankind, has grown not only the American Indian civilization of which one commonly thinks, but also the advanced civilization which in different degrees extended over what are now the southwestern pueblo states into Mexico and Central and South America, where it flowered to so great an extent that we are only beginning to realize how marvelous it was.

The ever-present need for food and the struggle to obtain it must have made the early inhabitants of this or any other country always on the lookout for something which could be eaten and always hoping for more. As a result of observation came, no doubt, the knowledge that seed sprouted and a plant grew from it and bore fruit. It is a long step from this to the raising of a regular crop, but it was finally taken.

Indian corn, one of the most important food plants, was domesticated and cultivated as a result of the American Indian's work. Originally a tropical or semi-tropical cereal it was so modified under cultivation as to yield a crop as far north as lower Canada. Such progress was not limited to Indian corn but similar results were obtained with many plants used for food and other purposes. More than thirty plants are known to have been cultivated before 1492. Besides corn, these included potato, sweet potato, tomato, cacao, kidney and lima beans, peanut, pineapple, and other food plants, cotton, cinchona, coca, tobacco,

barnyard grass, and others. Animals domesticated included the dog, for food as well as a draft animal, llama, guinea pig, turkey, alpaca, and honey bee. This is an achievement comparable with domestication in the old world, for instance, of emmer, barley and flax and the development of wheat, which are credited to ancient Egypt.

It is an event of great importance to domesticate a wild plant, improve and develop it, increase its range of cultivation and so provide for the regular production of a food supply. It is also a great advance to learn the use of fertilizer to improve a crop. When the American Indian found that the corn would give a better yield if a fish was buried with it when planted, he made a great discovery. Manure, too, was used as a fertilizer in pre-Columbian times.

Food preservation for future use was also discovered and became of great value. Surplus food was smoked and dried, storage in pits was practised and, perhaps most surprising of all, these early people learned to boil down sweet plant juice and make sugar. Their maple sugar was greatly appreciated by the early colonists. The Indian had also learned to separate animal fats and vegetable oils for immediate need and to hold them for future use. •

At the time the early colonists came to North America the Indian had a varied but uncertain food supply, and one whose abundance depended very largely upon climatic and other conditions which he could not control. Large dependence was placed on wild foods; fish and game, roots and tubers, wild rice, berries of different sorts, wild fruits, including plums, cherries, currants, grapes, papaws, and persimmons, most of which are still eaten in quantity. Nuts were much prized when newly harvested as well as for

winter use and for oil making. Corn and pumpkin were grown, and the Indian in some localities was a farmer in a way, with the boundaries of his "farm" or hunting ground widely extended, though in some particular cases fairly well defined by common consent. Had the population not been relatively scattered the problem of an adequate food supply would have been even greater than was the case.

The growing of food crops by Indians was extensive and it was kept up. For instance, it is recorded that in Mount Hope, Rhode Island, in 1681, the Indians had a thousand acres of corn under cultivation. That the Indian was in the habit of raising a large supply of corn was fortunate, for the New England colonists, during their first winter in New England, were saved from starvation by the corn they were able to procure from their Indian neighbors, and it afterwards became a custom with the colonists to purchase corn from the Indians to supplement what they themselves raised.

Agriculture was highly developed in South America, but the accomplishments there are less familiar to most of us.

In house building, in selecting of fibers, in spinning and in weaving of textiles the marvel is equally great, ranging from the tepee and the bark house of the North American Indian to the pueblo farther south and the great buildings of Central and South America; from bark cloth to the marvelous textiles of Peru; and from the cultivation of food crops fertilized by a fish buried in a corn hill to the wonderful irrigation works for use in agriculture on the Andean slopes. In the discovery and use of pigments and dyes the achievements were remarkable in North and particularly in South America, and so it was also with spinning and

weaving, which were carried on often to great perfection.

The reasons back of the results achieved were not known to the pre-Columbian people, but their accomplishments presuppose a splendid working knowledge of the properties of raw materials and of possible modification and ways of using them to attain the desired uniformity in results. It would seem that they must have pondered these matters as did the early peoples of Asia and Africa, and it would seem fair to believe that a people who could devise a chronology like that of the prehistoric inhabitants of Mexico must have given thought to the reasons why some vegetable and animal substances were to be preferred for use as food, or why some plants or roots prepared in certain ways would not only impart color but also would ensure its permanence. Trial and error, recognition of success, observation and profiting by it, must have long been followed and the progress which was made is astonishing.

Even from so brief a summary it is obvious that to the home, to agriculture and to the arts, the Western hemisphere made a great contribution.

With European domination following the discovery of the Western by the Eastern hemisphere, the native American civilization was not only interrupted in its progress but was almost destroyed and much that might have been learned to the advantage of the future was lost.

THE EMPIRICAL AGE IN FOOD AND IN AGRICULTURE

Exploration and study of rock shelters and caves and other places where primitive man lived have furnished much evidence as to the mode of life. Bones

broken for their marrow, seeds from foods eaten and grains from later though very ancient Lake Dwellings are evidence not only that all things were eaten but also that from earliest times, man's diet was made up of animal and vegetable foods and not from a single food group.

As man emerged from the early stages of his progress the surroundings of his daily life began to take on something of the aspect of things as we know them. Wild food grains were cultivated and developed, fruits were grown, animals were domesticated and the daily tasks were performed, though under conditions which were most primitive.

As ages passed the life slowly took on the aspects of living as it was known in later times. Grinding grain, making bread, slaughtering and dressing food animals, spinning and weaving and other tasks went on. Thanks to the archeologist much is known about the early civilizations and their development. The knowledge is based chiefly on what the peoples have left behind, covered by earth mounds and drifting sand and by the ruins of later civilizations, recovered at last and examined and read as an open book by those who know how.

With success in food production and with a regulated food supply came more effective use of it. This brought with it the art of preparing food for the table and later an attempt to understand the functions of food and its proper use. Because of its importance food must always have occupied much of man's thought as well as much of his time. The literature of old races is full of observations about food, most of them interesting, and some of them surprising not only for the ingenuity shown in getting data but also for the wisdom shown in drawing conclusions. Food

played a great part in the religious and ceremonial observances of early people, as well as in the homelier aspects of everyday life. It is to this that we owe a great deal of the available information, since matters of so great importance would be the first to be recorded.

The Old Testament is a storehouse of information concerning the daily life of an ancient people with a long history behind it. The Jews formulated a remarkable sanitary code and recorded much about the growing, the selection, the preparation and ways of cooking food. Indeed, we know more about the foods of that time, and their ceremonial and everyday use and about the management of the home and the duties of the housewife, than we possess of home life in much later times.

Occasionally the remains left by earlier civilizations are in many details surprisingly like those with which we are familiar. Such, for instance, are the water supply systems and the sewage works of ancient times. The Cretan clay water pipes were fitted together on the same principles as those made and used today and were laid with due regard to the pressure which would be exerted upon them. The cooking utensils of ancient Crete, found with other remains of Cretan civilization, do not seem strange when compared with some modern utensils. A cooking pot with a lid so devised that it condensed steam and prevented the pot from going dry is an idea not unlike one of the objects sought in the modern pressure cooker. In the use of textiles for clothing purposes Crete at this time also seems much nearer in some of its forms to the customs of today than do the draped garments of the much later Greeks and Romans or the garments of ancient Egypt.

As civilization developed knowledge increased. The intellectual achievements of the philosophers of the classical age have remained a marvel. The homely things of everyday life found a place in their thought, as well as more profound questions. That man speculated and reasoned about his food is certain, and the question whether he should choose animal or vegetable food or both is one which is very old. Plato in one of the "Dialogues" expresses the opinion that man once lived on the fruits of the earth in a blameless state from which he later turned to a mixed diet, an idea which may have antedated his day. Something of this persists in the medical literature of the Greek and Latin classics, and Plato's idea has been quoted often in later as well as in ancient times.

John Evelyn, in a publication which appeared in 1699 dealing primarily with vegetable foods, states as his belief that man originally used a vegetable diet and that it was preferable. He based his belief on his interpretations of statements made in Genesis. It is clear that this idea has been taken up from time to time and that, although it has never been generally accepted in practice, it has appealed to one writer or another and passed down the centuries.

So far as actual evidence goes, and there is much of it, such conclusions are not justified. Man is and always has been anatomically adjusted to the digestion and assimilation of a mixed diet. As occasion has demanded he has accommodated himself to whatever food supply was available, his digestive tract being fitted to the handling of both animal and vegetable foods. This might be expected, for the conclusion reached is that the food formed the digestive tract and not the other way around. In actual experience man's diet has varied from an entirely ani-

mal food diet among the Eskimos to the almost exclusively vegetable diet of tropical countries and to a diet composed almost completely of milk products and some cereal foods characteristic of inhabitants of Central Asia.

From remote antiquity it has been believed that the growth of crops could be influenced by rites and ceremonies. Such beliefs have survived to relatively recent times and some to this day, and not alone in remote and isolated regions. As an instance, there are those who still believe that the success of the crop depends upon the time of the moon in which the seed is planted. Unfortunately, opinions are not uniform, some holding that success comes with planting at the new moon and others when the moon is waning. Another instance is the belief current not long ago and which, perhaps, has not entirely passed away, that if a hog is slaughtered at the time of the waning moon, the pork will shrink unduly on curing.

Greek and Roman writers of ancient times had much to say of foods which they characterized as "cold" or "hot" or "dry" or "low." On the basis of such characterizations they discussed the selection of food and its uses in health and disease. Keen observations were made on food preparation, on the processes of digestion and on the length of time required for such processes. In the discussions, urine and feces were taken into account. Great importance was ascribed to the times and seasons of eating and drinking, to sleep as related to food, and to much else. Today popular opinion unknowingly quotes some of the contentions of this period; for instance, with respect to the proper time of water drinking, whether before, during or after meals, and each opinion has its defenders now as it had then. In considering the fre-

quency of eating one writer so far departs from the usual that he recommends three meals in two days instead of the more usual procedure of three meals in one day.

There was much difference of opinion about foods and their desirability. Thus some favored fruit but differed as to its place in the meal, whether at the beginning or at the end. There were others who believed that fruit should not be eaten at all, both opinions being well defended. One writer believed nuts to be the best of fruits and always "healthy for the liver."

In later times, to foods as to precious stones and other animate and inanimate objects, were attributed marvelous properties for good or ill. A survival is, perhaps, to be found in the belief which some entertain that to wear one's birthstone is to bring good luck, and many more might, perhaps, admit a kind of belief in the virtues of a four-leaf clover. The "white magic" of curing a wart by rubbing it in secret with a bean or a piece of meat, preferably stolen, has survived to a time which some of us can remember. Such matters are intimately connected with food and with many other things of everyday life and deserve the consideration they have received at the hands of scholars concerned with man's development and the progress of civilization. Perhaps it is not unreasonable to think that the attribution of such qualities to foods and to other things can be regarded as the beginning of analytical methods of research. In Frazer's "Golden Bough" are available, for those interested, the results of careful investigations on such subjects which have extended over many years.

From time to time opinions have been expressed about the special relation of food to health. John Evelyn in his "Sallets" already referred to treats of

garden making, the cultivation of vegetables, their uses and preparation for the tables as salad and in other ways. He mentions that black Spanish radish is "the most effective for the scurvy."

How many others have made similar statements one cannot tell, but it seems fair to say that others of his time or earlier may have had similar beliefs. A much later instance is to be found in John Monroe's "American Botanist and Family Physician" published in Wheelock, Vermont, in 1824. In this volume is gathered much lore then current regarding "the medical virtues of the Mineral, Animal and Vegetable productions of North America . . . likewise a large number of Indian discoveries in the medical art." Like others he believed that food had a relationship to scurvy. It is worth noting how nearly he expressed the modern view in specifying the relative value of foods, for of the lemon he says: "The juice is anti-alkaline, anti-scorbutic and mildly refrigerant. It is supposed to be the most potent remedy in the scurvy belonging to the vegetable kingdom." Of the orange he says that the "juice is refrigerant, anti-septic and anti-scorbutic" and notes similar properties in some other vegetable foods. To cite another example, he notes that the wintergreen is excellent in rheumatism and a good stomachic and that the virtues of this plant were recognized by the Indians. If he were alive today, he would be interested to learn about vitamins and scurvy and to find that the salicylates still hold their own in medicine.

Other examples of a similar nature could be cited from early writers. One from more recent times but antedating by many years modern work on the problem can be found in Dana's "Two Years Before the Mast," the potato and also the onion being the vege-

tables which were so successfully used in the instances of scurvy cited.

Another instance of keenness of observation and logical deduction is the apparent realization by different writers that in some way the lack of health and the poor physical development noted in many children were ascribable to faulty diet and to a lack of light and fresh air in the open. From descriptions it would seem clear that the condition noted was rickets. In his "Human Health" (Philadelphia, 1844) Robley Dunglison writes:

"The experiments of Edwards (in his 'On the Influence of Physical Agents on Life,' 1838) exhibit that light is necessary for the full development of many animals, and it is probable that its privation may give occasion, with other causes, to the deviations in form observed in children in confined and dark situations. This applies especially to those in large manufacturing establishments, who are often misshapen and unhealthy. When the subject was brought before the British Parliament some years ago by Sir Robert Peel, Mr. Owen of New Lanark (later of Indiana and the New Harmony Movement) stated that although the children employed in his manufactory were extremely well fed, clothed and lodged; looked fresh, and to a superficial observer were healthy, yet their limbs were generally deformed; their growth stunted; and they were incapable of making much progress in the first rudiments of education. The extensive experience of Mr. Owen corresponds with that of numerous other observant individuals, and was corroborated by Sir Astley Cooper on the same inquiry, who stated that the result of confinement is not only to stunt the growth, but to produce deformity. How striking, indeed, is the contrast between the pale, deformed being, brought up in this manner, and the ruddy native of country situations, who is accustomed to spend the greater part of his time in the open air, and to take adequate exercise; and how rare it is for us to meet with deformities under the latter circumstances."

Other instances could be cited from early writers in accord with those here given. This conviction based on experience and observation is of greater interest owing to the recent experimental proof of the influence of sunlight in the prevention and treatment of rickets. It is also interesting to note that the early observers concluded that food, too, played a part.

The physicians of antiquity—Galen and Hippocrates—had not overlooked or ignored the idea of “insensible perspiration,” but it remained for Sanctorius, a physician born in Capo d’Istria in the year 1561, but who spent most of his life in Venice and Padua, to make exhaustive experiments on this subject by means of a balance with a “weighing” chair attached. He took account of his own weight and of the weight of his food and drink and of the urine and feces excreted. He also observed the excretion of moisture in the breath by breathing on a looking-glass, but estimated that the total quantity per day was small. In his experimental work he observed that as time passed there was a continual loss of weight and that the total which he could determine with the balance, did not equal the losses during the day and night. His conclusion was that the discrepancy was due to insensible or invisible perspiration. On the basis of his observations and deductions from them, he wrote his famous “Aphorisms” on insensible perspiration in relation to health and disease. So great was the interest in his work and his conclusions that he influenced medicine for generations and inspired others to similar studies, including John Lining of Charleston, South Carolina, who made, with himself as subject, a statistical experiment of this nature which covered the entire year 1740.

Work on respiration, of which Sanctorius can, perhaps, be called the ancestor, was carried on by Lavoisier at the end of the 18th century with apparatus which he devised for the study of the respiration of man. From the work of Sanctorius and the later work of Lavoisier it is a long step to the respiration apparatus and the respiration calorimeters of today, remarkable instruments of precision for the study of many



From a drawing by Mme. Lavoisier

Lavoisier Engaged in Making a Respiration Experiment

physiological problems, representing a great advance along a road of which the end has not yet been reached.

NATURAL SCIENCE AND FOOD AND ITS USES

Two men interested in science and everyday matters stand out in the early years of American science—one, Benjamin Franklin, born in 1706; and the other, Benjamin Thompson, afterward Count Rumford, born forty-seven years later and not far from the Massachusetts town which was Franklin's birthplace. Both were greatly concerned with the study of home problems, a common interest being the use of heat for domestic purposes. Count Rumford's attention to domestic problems is particularly noteworthy, for not only did it include extended studies in food preparation but also a chance to test his theories in feeding troops of the Elector of Bavaria with what he considered and showed to be a reasonable, as well as rational, and well-prepared diet. The writings of this pioneer in American work on food and nutrition have greatly influenced the study of the subject and are still of interest.

So far as has been learned the first definite attempt to study the chemistry of food and nutrition experimentally in the United States was made by John Richardson Young of Maryland, who devised and carried on experimental studies of gastric digestion with himself and a friend as subjects and also with small animals—frogs and snakes.

Young was born in Hagerstown, Maryland, then called Elizabethtown, about 1782 and died in his twenty-third year, in June, 1804. After graduation at the age of seventeen years from Princeton University, then called the College of New Jersey, he continued his

medical education (begun with his father who was a physician of Irish birth) at the University of Pennsylvania, entering in 1802 and graduating in June 1803, when he presented his thesis, "An Experimental Inquiry Into the Principles of Nutrition and the Digestive Processes."

In carrying on his experiments Young inserted a small frog with a thread tied to its leg into the stomach of a large bullfrog. The smaller frog was withdrawn at intervals and the rapidity of digestion noted, also the absence of putrefaction. Experiments were also made in which beans, peas, wheat and bread were introduced into a frog's stomach and after thirty hours the little bag containing the bread was empty but the beans and peas had not been acted upon. When crushed cereals were used they were digested. Young also made experiments on himself and a friend, Mr. Mitchell. Food ejected after it had remained in the stomach for some time was examined and carefully studied.

Of the process of digestion he writes:

"We would therefore explain this process in a few words. Aliment is dissolved by the gastric menstruum; it then passes into the duodenum and meets with bile and pancreatic liquor; after being united with these, a heterogeneous mass is formed called chyme, and from this the lacteals secrete chlye."

In his discussion of Young's work, Dr. Howard Kelly to whom we owe most of the available information about this remarkable pioneer American experimenter, sums up Young's contribution to the understanding of digestion as follows:

"(1) He did away with the theories of innate heat and vital spirits as the essential factors in the act.

(2) He did away with the notion that digestion was essentially a process of trituration, fermentation, or putrefaction.

(3) He showed that it was effected by an acid which he attempted to analyze, and concluded that it was phosphoric acid.



JOHN R. YOUNG

AN
INAUGURAL DISSERTATION,
FOR
THE DEGREE
OF
DOCTOR OF MEDICINE,
SUBMITTED TO THE EXAMINATION
OF THE
REVEREND JOHN ANDREWS, D. D.
(PROVOST PRO TEMPORE),
THE
TRUSTEES AND MEDICAL PROFESSORS
OF THE
UNIVERSITY OF PENNSYLVANIA,
ON THE
EIGHTH DAY OF JUNE

AN
EXPERIMENTAL INQUIRY,
INTO
THE PRINCIPLES
OF
NUTRITION,
AND THE
DIGESTIVE PROCESS:

BY JOHN R. YOUNG, M.D.
OF MARYLAND.

MEMBER OF THE AMERICAN LIGNEAM AND PHILADELPHIA MEDICAL SOCIETIES

"We ought in every instance to submit our reasoning to the test of Experiment, and never to search for truth, but by the natural road of Experiment and Observation."
Lavoisier

PHILADELPHIA:

PRINTED, FOR THE AUTHOR BY

BAKER & BROS.

—1868—

Title and Dedication Pages of Thesis of JOHN R. YOUNG.

- (4) He experimented on animals and men (himself and a friend).
- (5) He secured pure gastric juice and experimented with it in vitro.
- (6) He showed that the acid gastric juice checked putrefaction.
- (7) He drew the inference that dyspeptics ought not to dilute the gastric juice with water."

On receiving his medical degree Young returned to Hagerstown and joined his father in the practice of medicine. His death from tuberculosis occurred there very soon after. Doubtless, owing to the fact that his thesis like others of the time, was not widely distributed and probably also to the fact that he died so soon after graduation, his work was apparently completely lost and forgotten until it was found again in 1908, in connection with some bibliographical studies made in connection with the nutrition work of the U. S. Department of Agriculture.

The importance of Young's pioneer work in physiological chemistry was so great that his grave in old St. John's churchyard in Hagerstown, Maryland, might well become a shrine for American chemists.

A few years later came another, William Beaumont. Like Young, he was a man of great promise and achievement, but fortunate enough to have a long career. He was born in Lebanon, Connecticut, on November 21, 1785. As a young man he left home and went to northern New York, teaching school in Champlain to earn money and then reading medicine in St. Albans, Vermont. His license to practise medicine was given him by the Third Medical Society of Vermont at Burlington, June 2, 1812, and a little later in the same year he was appointed surgeon's mate (practically equivalent to assistant surgeon) in the U. S. Army.

In 1820 he was ordered to Fort Mackinack and there his great opportunity came to him when he was called

to attend a young French-Canadian, Alexis St. Martin, who had sustained an accidental gun-shot wound. Some of the shot entered the back and tore an opening through the chest, the injury seeming so severe that there was apparently no chance of recovery. However, under Dr. Beaumont's care, St. Martin became better and after many vicissitudes recovered. The opening in his chest healed in such a way that it left a fistula under the left breast of sufficient size to permit examination of the stomach and also the insertion or withdrawal of material. Eventually Beaumont's interest in his patient was so great that he took him to his own home and cared for him in every way until he was so far recovered that experimental work could be begun. This was first undertaken in Fort Mackinack in 1823 and carried on at intervals at Fort Niagara, Fort Crawford, near Prairie du Chien, Plattsburg and Washington. In 1833, St. Martin, then at the age of twenty-eight years, was enrolled as a sergeant in the U. S. Army at Washington where Beaumont was stationed. It is not without interest to wonder whether this is not the first instance of experiments which had to do with nutrition undertaken under government auspices. If so, it was a fine example for those who were to follow in such work in the army and various departments of the government service.

The records of the experiments on the digestibility of food in the stomach and of those in which food was submitted in bottles to the action of digestive juice withdrawn through the fistula from St. Martin's stomach, are detailed and the observations and deductions are clear and consistent. It would seem from the records that the experiments did not cause St. Martin distress or any great inconvenience. However, it is a matter of record that at the end of the period neither

Beaumont nor any other investigator was able to persuade St. Martin to serve as a subject for further experiments, though there was abundant opportunity as he lived to the advanced age of eighty-one years.

The details of Beaumont's experiments are recorded in full in his book, "Experiments and Observations on the Gastric Juice and the Physiology of Digestion," published in Plattsburg in 1833 and reprinted a number of times.

In a paper entitled "William Beaumont—A Pioneer American Physiologist," Dr. William Osler not only gives an appreciative account of Beaumont's achievements but points out their importance, and has supplied much bibliographical data not hitherto readily available. The following quotations from Dr. Osler's paper sum up the most important results of Beaumont's observations:

"Firstly, the accuracy and completeness of description of the gastric juice itself.

"Secondly, the confirmation of the observation of Prout that the important acid of the gastric juice was the muriatic or hydrochloric.

"Thirdly, the recognition of the fact that the essential elements of the gastric juice and the mucus were separate secretions.

"Fourthly, the establishment, by direct observation, of the profound influence of mental disturbances on the secretion of the gastric juice and on digestion.

"Fifthly, a more accurate and fuller comparative study of the digestion in the stomach with digestion outside the body, confirming in a most elaborate series of experiments the older observations of Spallanzani and Stevens.

"Sixthly, the refutation of many erroneous opinions relating to gastric digestion and the establishment of a number of minor points of great importance, such as, for instance, the rapid disappearance of water from the stomach through the pylorus, a point brought out by recent experiments, but insisted on and amply proven by Beaumont.

"Seventhly, the first comprehensive and thorough study of the motions of the stomach, observations on which, indeed, are based the most of our present knowledge.

"And lastly, a study of the digestibility of different articles of diet in the stomach, which remains today one of the most important contributions ever made to practical dietetics."

Beaumont's account is, throughout, characterized by a style which is simple, direct and adequate. Those who have quoted him, often refer to his experiments as if they recorded the time for complete digestion, but it is noticeable that in his writings Beaumont is more exact and is careful to refer to his work as a study of gastric digestion.

Following the period which included the experiments on St. Martin, Beaumont settled in St. Louis where he continued in the practice of his profession until 1853 when he died on April 25, respected and honored by all who knew him, and generally recognized as a great investigator. A full biography by Dr. John S. Myers was published in 1912.

A pioneer in his interest in dietary studies was John Stanton Gould, who, at the request of the Commissioners of Education and the Board of Governors of the New York Almshouse Department, published in 1852 a report "On foods and diet in Almshouses, Prisons and Hospitals." He takes up among other topics general considerations respecting diet, the consumption of food in families, various articles of food and the influence of cooking upon their food value, kitchens and cooking utensils, heating and ventilation, etc. He brings together a large amount of information about institutional dietaries of the period and makes many recommendations.

For long it was the custom to consider that foods as well as all other matter were made up of four elements: Fire, water, earth and air; but as the different chemical elements were discovered, it was recognized that food was made up of such elements, those then included being carbon, hydrogen, oxygen and nitrogen. The presence of water and also of a number of the commoner mineral elements was recognized in food.

Much information regarding the ideas held, at this period, and the methods followed in the analytical work dealing with composition of food has been summarized in the section on "Foods" in Thomas Webster's Family Encyclopedia, an English work which first appeared in England in 1809 and later appeared in a revised edition in England and the United States. The book was carefully compiled and the editor had the assistance, in the matters pertaining more particularly to domestic life, of Mrs. Parks, an English woman of considerable reputation as a writer on such subjects. It is not without interest to find that Webster claimed that his own knowledge of food preparation and other domestic matters was obtained from his intimate friend, Count Rumford.

"All animal and vegetable substances including those of our corporeal frame are composed or made up generally of four elements. . . . Carbon, oxygen, hydrogen and nitrogen and a few others in very minute quantities—phosphorus, sulphur, chlorine, potassium and lime.

Water composed of hydrogen and oxygen is essential to all the living functions and constitutes a large portion of the structure of living bodies as well as of either food or drink."

The more exact determination of the chemical composition of foods has had a gradual and steady growth and it is perhaps fair to say that in the United States a considerable part of it was carried on in connection with agricultural studies. As noted in one of the earlier publications of the Department of Agriculture, the first effective impulse to the systematic investigations of the chemistry of food was given by Liebig some seventy-five years ago. Nearly all the definite knowledge regarding the chemical composition of food materials and their nutritive value has, however, accumulated within comparatively recent times.

The earliest quantitative analyses of food materials

which were noted are those of potatoes, reported by George Pearson in England in 1795. He estimated the proportions of water, starch, fibrous matter, extractive matters and ash and also recognized the presence of fat, acids and sugar.

Einhoff in 1805 made a somewhat similar analysis of potatoes and also of rye and attempted further the separation of albumin. In his analyses of potatoes he determined several of the ash constituents.

As respects American work of this sort, the earliest noted is the ash analysis of rice, rice flour, husk, etc., reported by C. U. Shepard in 1844 and 1845, who also reported ash analyses of Indian corn and sweet potatoes.

Perhaps the earliest European analyses comparable with those made today are the analyses of milk reported by Peligot in 1836, by Boussingault in 1836 and 1838 and by Boussingault and Le Bel in 1839. For a number of years after this, chief stress was laid upon the proportions of carbon and nitrogen, though efforts were made to determine the amounts of fats, carbohydrates and nitrogenous compounds. About 1840 Liebig and his followers, Playfair, Boeckmann and others, analyzed a considerable number of foods and feeding stuffs by methods more or less resembling those in use today. In the period between 1840 and 1865 many more or less accurate analyses of food and food products were made, the earliest American work noted being that of Salisbury on Indian corn published in 1848. Other contributions noted of about the same time were those of Beck, Emmons and Jackson.

Much of this earlier work is interesting today, chiefly from an historical standpoint. The analyses in most instances were very carefully made but accurate methods of organic and analytical chemistry had not

yet been developed. A great advance was possible when Henneberg and his associates elaborated the Weende method for proximate analysis, so named because of the agricultural experiment station of that name near Göttingen. This method is based on earlier work, the procedures being simplified and systematized. Instead of determining individual elements or substances the idea was to determine general groups which would represent the whole and permit comparison. Those determined upon were water, protein, ($N \times 6.25$), nitrogen-free extract (sugar, starch, etc.), crude fiber and ash. It was not until this method came into general use in 1864 that any considerable number of chemists in the United States and elsewhere undertook a systematic study of food materials from the standpoint of nutritive values. Individual investigators and associations of chemists have studied its details and devised ways by which it could be improved. Minor alterations have been adopted and in several countries details have been agreed on officially by organizations representing agricultural experiment stations and government officials charged with the responsibility of making analyses in the interests of the public. The methods followed in different countries agree so closely that for many years it has been possible to accept analyses by chemists in different parts of the world and compare them one with another without hesitation.

The first work in the United States by the Weende method so far as is known was the study of the composition of corn made by Professor W. O. Atwater in 1869 in Dr. Samuel W. Johnson's laboratory in New Haven, Connecticut. Others were undoubtedly interested but with the exception of investigations by Professor Storer at the Bussey Institute little work along

this line was done until the establishment of the State Agricultural Experiment Stations. Since that time the contribution made by investigators has been very large and of great importance. With the passage of years emphasis has been laid on the determination of individual constituents for particular purposes though proximate analysis still has an important place.

Knowledge of the composition of food materials has been greatly enlarged as the result of the determination of fuel value per unit weight, the discovery of vitamins and an approach to their quantitative estimation and detailed analytical studies of individual constituents. The largest contributions to food analysis have been made by different branches of the United States government, including the Bureau of Fisheries, the Smithsonian Institution and the Department of Agriculture. A very long list of analyses has been contributed by the Agricultural Experiment Stations.

ECONOMICS OF FOOD PRODUCTION AND USE

Interest in work on the whole question of food and its rational use has grown and become very general. Investigation and research have developed and work, extended in scope, is now carried on under national and state auspices, at colleges and universities, in public and in privately endowed institutions and elsewhere. It has included studies of composition, digestibility and nutritive value of food, preparation, preservation and the conservation of it; of food as a source of energy to the body and more recently the problems connected with vitamins. Attention has been given also to food in relation to health and disease, to invalid dietetics and other dietary problems. Experimental methods have been greatly augmented and the

field of activity has been extended. Much has been done to make the results of technical study available for general use to the homemaker, teacher, extension worker, public health worker and others who need such subject matter.

Without doubt the most pressing problem is the daily food and its right adjustment to individual and family needs. Though the character of the foods eaten in different parts of the world varies greatly, it has been found that when expressed in terms of composition and energy value, the food requirements of individuals doing the same work under similar conditions, in any country, are essentially the same irrespective of geographical locality. This is not surprising, for naturally under comparable conditions the human machine would need as much to sustain it and to enable it to produce a given amount of labor in one place as it would in another.

When one examines foodstuffs on the basis of their characteristics, it has been found that they can be logically divided into five groups; namely, (1) vegetables and fruits (fresh, dried and canned); (2) foods characterized by protein (meats, fish, eggs, cheese, nuts, beans, etc.); (3) cereal grains and their products (flour, breakfast foods, breads and similar things); (4) sugar and foods rich in it (honey, sirups, jams, jellies, etc.); (5) fats, (butter, table and cooking fats, salad oils, fat meats, pork, bacon, and similar foods).

An examination of meals shows that the common custom is and should be to draw largely upon the cereal group and the fruit and vegetable group, which fortunately, in this country is easily possible because of the abundance of such products. Less heavy though adequate demands should be made on the other three groups. With a diet thus chosen it is practically cer-

tain that the protein requirement, the vitamins, mineral matter, fuel value and other needs will be met. A person can be reasonably certain that his diet is adequate and yet not excessive, if over a considerable period of time, he seems in good health and there is no marked change in weight.¹ Those who for any reason are not in good health need special attention and advice should always be sought from competent sources.

In order that the needs of individuals, of families and of large groups can be adequately and satisfactorily met a varied, reasonable and steady food supply is essential. This is much more easily provided now than in earlier times when production was less varied, transportation facilities less satisfactory and food storage had not been developed in any large way. When one considers such large units as countries taken individually and collectively, it becomes evident that production and intelligent and reasonable distribution to meet world needs provide a problem of enormous magnitude and corresponding importance. This is very generally recognized and it is interesting to note that it has aroused international interest and that already work is going on which has for its object the carrying out of the great ideal of world production suited to world needs.

¹From the United States Department of Agriculture publications can be obtained which discuss such matters in greater detail.

CHAPTER XII

VITAMINS IN HUMAN AND ANIMAL NUTRITION

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One day, in the early spring, a high school instructor was conducting his science class on a tour of inspection through the laboratories of a neighboring Agricultural Experiment Station. They stopped, at one point in their trip, to watch the Agricultural Chemist, who was feeding a large number of pigeons, guinea pigs, and white rats. "Professor," said the high school instructor, "would you be willing to tell these young people what you are doing and what you hope to accomplish with these animals?" "Certainly," the agricultural chemist replied, as he finished weighing a tiny albino rat, "this is our nutrition laboratory, where we are making a study of the vitamins in some of our common foods and feeding materials." "Some of our text-books mention these 'vitamins.'" the high school instructor replied, "but I have been unable to give my students a very clear idea of their nature, occurrence and importance. I shall appreciate a simple definition of the term 'vitamin.'" The chemist brought forth some chairs, in order that the students might take written notes if they desired to do so, and said, "You have asked me to do a rather difficult thing.

It is difficult to give you a simple, and yet comprehensive, definition of vitamins because we are just beginning to realize how little we know about their chemical and physiological characteristics. It is doubly hard," the investigator continued, "because your students do not possess much knowledge of chemistry, physiology and anatomy. I shall do my best, however, to give you some idea of what vitamins appear to be."

At this point the research worker stepped to his laboratory cupboard and brought forth a small metal syringe, in which he placed a hollow needle. "You have all seen this instrument before—it is a hypodermic syringe used by the physician to inject solutions and suspensions of chemical substances into the living organism. Imagine with me, if you will, that a coal miner has been entombed alive through an accident in the mine. In his attempt to escape this living death, he has dug incessantly without food or water for hours and hours and finally falls exhausted. Some time later the rescue party finds him, and the mine physician, feeling the man's pulse, discovers that his heart is barely beating. With the view of stimulating the heart to activity, the physician takes one of these hypodermic syringes out of his case and gives the miner an injection of a powerful drug. In a few moments the color begins to return to the miner's face and his breathing becomes more vigorous, because of the stimulating effect of the drug.

What has this to do with vitamins?" the chemist inquired of the high school students. "Simply this" he added, answering his own question, "the drug produced a stimulating effect on certain organs of the miner's body, causing him to recover from his state of physical and nervous exhaustion.

“Vitamins seem, in a way, to be nature’s drugs, stimulating the body cells in order that they may function in a normal manner. Some foods do not contain these vitamins, with the result that long continued feeding of poor foods of this type brings about an unhealthy condition which can be corrected by other foods which contain these natural stimulants in sufficient quantity. In other words, vitamins are thought to be chemical substances, occurring in some foods but not in others, which are required to stimulate our bodies to use the other food constituents in repairing and manufacturing new bones and tissues, as nature originally intended.

Although we might consider vitamins as nature’s stimulants,” the chemist concluded, “I do not wish to leave the impression that they are like drugs. There is no evidence that an excess of vitamins does us harm nor is it possible to develop a ‘vitamin habit,’ although it would be to our advantage if we could do so.”

This story has been told with a view of showing, in simple words, the present conception of vitamin action. In order that we may have a clearer understanding of other interesting phases of the vitamin question, let us go back, for a moment, and see what has happened in the past.

Before the development of science, man found by experience that certain foods were necessary for his own health and welfare. In other words, man chose his foods largely by instinct and experience. Scientific nutrition really came into existence with the birth of modern chemistry. In the early part of the nineteenth century, chemists began to use chemistry as a tool to study the common foods, with the result that they discovered that foods contained at least four important classes of chemical substances, viz. proteins,

which were utilized by the body for repair and construction of muscles and similar tissues; carbohydrates (sugars and starches), which furnished heat and energy for the body; fats, which also served as body fuels; and the inorganic salts which were used for the construction of such tissues as bones and teeth. After studying the diets, week by week, of families in different walks of life, scientists were able to set up dietary standards and say that a healthy normal person should eat a certain amount of food which contained proteins, fats and carbohydrates in proportions which varied with the size of the person and the physical work he or she was to perform. In other words, the early nutrition workers devised feeding standards for people and for animals using chemistry as the "measuring stick." We might call this the *chemical period* in nutrition studies.

Not many years later scientists began to conduct experiments in which they placed their experimental animals in a complicated box-like apparatus called a "calorimeter." This apparatus was so constructed that all of the heat radiated from the animal's body could be caught and measured. These scientists made the discovery that the body is not unlike an internal combustion engine and that the food is quite comparable with the fuel that is burned in the engine. It was observed that the amount of food needed by animals depended upon the amount of heat to be given off and work to be done. As a result of these interesting studies a new type of feeding standard was finally devised which measured food and feed values in a manner quite similar to that used by the factory superintendent when he buys coal, i.e. in terms of heat units called "calories."

As a result we can step into many restaurants in the

larger cities and find, printed on the menu card, the number of calories of heat stored in each dish of food that we desire to order. This new measuring stick, which measures foods in terms of calories, has also been useful in the feeding of farm animals. It is now possible for the modern farmer to feed his dairy cows, what are known as "balanced rations," which help him to produce the greatest amount of milk at a minimum cost and still keep his dairy herd in excellent physical condition. This period of nutritional research might be called the "*calorie period*" or the "*energy period*," in which the value of foods was expressed in terms of available heat or energy units called calories.

During the time these studies were being made other scientists were making some interesting and valuable discoveries. Some of these discoveries were directly traceable to certain diseases which seemed to be related in some way to the diet of the people so afflicted. For example, one disease, known as beri-beri, had been known in certain sections of the world for hundreds of years. This disease was quite common in certain sections of India, Japan, the Dutch Colonies, and elsewhere. Eijkman, a Dutch physician, like several other keen observers, had noted that beri-beri was most prevalent in those districts where the people were in the habit of subsisting, very largely, on white rice or polished rice, from which the brown outer coat had been removed. This outer coat or bran, which is removed during the manufacture of white rice, is sometimes called "rice polishings." On the other hand, these early physicians found other localities in which beri-beri was about as prevalent as the proverbial needle in the haystack. Inquiry showed that the people in these localities also depended on rice as the most important article of diet, but, either through laziness

or preference, they preferred to eat the brown rice in its natural form, without removing the branny portion. This set Dr. Eijkman to thinking and, finally, to experimenting. He found that white rice produced a disease in fowls which seemed to be very similar to human beri-beri. Much to his joy and surprise, he discovered that he could cause the disease to disappear if he fed the rice-bran to his birds which had become paralyzed from the effects of the white rice feeding. He then extracted rice bran, with alcohol and water, and obtained a solution. He allowed this solution to evaporate until the alcohol had disappeared and, after adding a little water, administered the clear solution to his sick birds and they recovered just as quickly as if he had fed the rice bran itself. Evidently the doctor had dissolved something out of the rice bran which possessed a curative or stimulative effect on the diseased fowls. This was in 1897.

In 1906 an English biological chemist by the name of Hopkins created considerable discussion by announcing that he had fed rats on protein, carbohydrate, lard, and mineral salts without obtaining growth. When he added about a quarter of a thimbleful of cow's milk, however, the rats almost exceeded the speed limit in their apparent desire to grow and "catch up" with their brothers and sisters, which had been on normal diets. Dr. Hopkins drew the conclusion that, since milk is 87 per cent water, it is impossible to attribute this growth-promoting power to the proteins, fats and carbohydrates in such a tiny quantity of milk. He suggested that there must be something in milk that is not protein, or fat, or carbohydrate, or mineral salt, which is necessary for normal development. Later he gave these unknown growth-promoting substances the name "accessory

food factors." We may, therefore, give Eijkman and Hopkins the credit for calling attention to the presence of these unknown stimulatory food factors.

In Germany, a young Polish chemist by the name of Casimir Funk decided that, although he could lay no claim to previous residence in Missouri, he must "be shown" regarding these mysterious substances. He repeated Eijkman's work and obtained the same results but, being a chemist, he decided to try to find out what Doctor Eijkman had extracted from the rice bran with the alcohol. Dr. Funk finally obtained a few tiny crystals of a substance which contained nitrogen, carbon, hydrogen and oxygen. He found, also, that these crystals behaved, chemically, very much like substances known, in organic chemistry, as amines, which are a sort of first cousins to ammonia. When a solution of these crystals was fed to, or injected into, fowls which had developed beri-beri, the birds recovered. He thought that he had isolated an "accessory food factor." He wanted to give it a name; so he probably said to himself—"This substance is very *vital* to the welfare of these birds, and it behaves like an *amine*. I will combine these two ideas and call the substance a 'vitamine.'" The credit for the term "vitamine," therefore, goes to Dr. Funk. Later, it was considered wise to drop the final *e* in the word "vitamine," because the poisonous drugs, morphine, strychnine and cocaine all end in *ine* and no self-respecting vitamin wished to be associated in any way, shape or manner with these occasionally disreputable members of the chemical family. The first and accented syllable of the term *vitamin* is pronounced as in the word *vital*, and the last three letters of the word are pronounced exactly as you would pronounce the name of the wife

of our well known friend, Mr. Andy Gump, and we assume that every one knows about "Min."

About 1910 three prominent American investigators, Osborne and Mendel of the Connecticut Agricultural Experiment Station and Yale University, and McCollum of the Wisconsin Agricultural Experiment Station, published scientific papers describing experiments in which rats were fed diets composed of chemically purified substances. By this method it was possible to show the effect of the presence or absence of any chemical substances they desired to study. They were able to show which of the mineral salts were absolutely essential and which ones could be dispensed with, at least for a time.

Osborne and Mendel made the interesting and valuable discovery that some proteins were more valuable than others. In some of their experiments animals died of protein starvation in spite of the fact that the amount of protein in the ration was high. This, they explained, was because some proteins were not capable of building body tissues efficiently, while others were highly satisfactory. This work will be described in another chapter of this volume, so we will not go into detail here. We are forced to mention the work, however, for it marks a third period in nutrition investigations which served to give us better feeding standards. As we have already stated, *period one was the chemical period, period two was the calorie or energy period, and the third, which we have just described, we will call the biological period*, because living animals are used as the "measuring stick" in helping us set up better feeding standards. The biological method, where animals are used, really involves all other methods, for we pay even greater attention to the chemical composition of the diet we balance the

rations with reference to calories, but we consider the quality, as well as the quantity, of the various food constituents.

Dr. McCollum and Dr. Cornelia Kennedy had not worked long before they discovered that rats would grow much better if they added some of Dr. Funk's anti beri-beri vitamin to the diets. Evidently this vitamin possessed growth-promoting properties in addition to its anti beri-beri properties. Just prior to this time the Connecticut and Wisconsin workers exploded a new scientific bomb. They announced that some fats and oils were more valuable than others for growing animals. They discovered that this was due to the fact that the more nutritious fats or oils contained a new vitamin. Butter fat, they said, contained this vitamin, while olive oil did not. Lard was practically devoid of it, while egg yolk fat was comparatively rich.

In order that it might be possible to distinguish between the vitamins, Dr. McCollum suggested that the latter be called "fat-soluble A," because it is soluble in fats, and that Dr. Funk's vitamin receive the name "water-soluble B." Hence we have alphabetical system of names that is now in use, with the exception that we now usually refer to these accessory food factors simply as "Vitamin A," "Vitamin B," etc. At the present time we have used but five letters of the alphabet to designate these mysterious food factors, and, while it is entirely possible that new vitamins will be discovered, as scientific work progresses, there is little danger that we will ever exhaust the English alphabet. If it becomes necessary, a wag has suggested that we can always resort to the alphabetical system of naming which is now in vogue in designating our numerous radio broadcasting stations.

We will now consider some of the more important and practical facts regarding vitamins and their relation to growth and health.

VITAMIN A

It was pointed out, in a previous paragraph, that McCollum gave this vitamin the name "fat-soluble A" on account of its solubility in fats. To prove his point more emphatically, that he was really dealing with a new vitamin, he fed olive oil to one group of rats and butter fat to another group. The rats receiving butter fat grew well, while the olive oil group declined in weight and died. He then succeeded in transferring the vitamin from the butter fat to the olive oil and, from that point, his rats grew as well on olive oil as they had on butter fat, proving that the vitamin can be transferred from one fat to another.

Succeeding work, by these and other investigators, has shown that the rat is not the only animal that responds to Vitamin A feeding. The rabbit, the chicken, the dog, the cat and higher animals also decline and die if this vitamin is not present in the food. When animals have been fed, for a time, on a ration deficient in Vitamin A, an eye disease known as xerophthalmia often develops. This disease can be cured by the addition of butter fat, cod liver oil or similar foods to the animal dietary.

During the world war, this observation (which was first made in an American Experiment Station laboratory) was applied in a very practical way. The Austrians had driven out, or had killed, practically all of the dairy cows in Roumania, with the result that there was no milk for the babies. Roumanian children were forced to live on soups and bread, a diet com-

posed almost entirely of cereals. An eye disease developed, which became so serious that medical authorities became alarmed. There seemed to be no solution of the problem until an American scientist, with the American Red Cross, was able to use his influence to obtain a large shipment of cod liver oil. This was apportioned to the families in those districts where the eye disease was prevalent, with the result that the disease disappeared.

Just as soon as the existence of Vitamin A was established, scientists turned their attention to a study of some of our common foods. It was found that cod liver oil and other liver oils, butter fat, cow's milk and egg yolk were rich in vitamin A, while the vegetable oils, such as olive oil, cottonseed oil and peanut oil, were devoid of this food factor. Turning to the foods of plant origin, it was found that the green leafy plants were valuable sources of Vitamin A, while the seeds or cereals, with the exception of yellow corn, millet and one or two others, contained little or none. It was not long before the conclusion was drawn that animals cannot manufacture vitamins but must depend upon the plant kingdom for their vitamin supply. While plants seem to be the only living organisms that synthesize vitamins, it has been found that animals can store relatively large amounts in the various body tissues, obtaining them, of course, from the plant materials in their feed.

The same principle seems to apply to the vitamin content of milk and eggs. If the cow or hen receives a vitamin-rich ration, the milk or the eggs are rich also. If the diet has been poor, the milk or eggs will often be almost vitamin-free.

While dry seeds are usually deficient in Vitamin A, they appear to have the power to synthesize this

vitamin during germination or sprouting. While a small amount of vitamin may be manufactured by the seed when sprouted in the dark, the process proceeds much more rapidly when the germination takes place in the light.

After the seed has sprouted to the point where leaves are formed, the manufacturing process seems to go on much more rapidly. It is quite evident that vitamin synthesis is related to the green or chlorophyll-bearing portions of the plant. For this reason the leafy plants such as spinach, chard, lettuce, alfalfa and clover are valuable foods from this standpoint, while the grasses which contain less leaf surface are proportionally less nutritious. The carrot and the tomato are also valuable foods from the standpoint of Vitamin A content.

When we begin to treat our foods by heating or drying we often destroy the vitamins. It is not possible to predict, with certainty, whether vitamin destruction will take place, unless we know all of the conditions. Vitamin A seems to be somewhat easily destroyed by heat, if air or oxygen is present. If air is removed, Vitamin A seems to be able to withstand fairly high temperatures.

From a practical standpoint, it is entirely probable that the average person, who is in the habit of eating a varied diet of milk, eggs, vegetables, salads and fruits, will receive sufficient Vitamin A for normal growth and development. It is only the food faddist or "crank," who insists on "one-sided" diets, that may not obtain a sufficient amount of Vitamin A. There are, however, a large number of people who depend entirely too much on poor combinations of such foods as meat, potatoes, white bread and coffee. It would be distinctly to their advantage if they ate

a larger variety of foods. The reader must not obtain the impression, however, that meat, potatoes and bread are foods to be shunned, merely because they do not happen to be rich in vitamins. On the contrary, these foods will continue to occupy their important place in the American dietary. The trouble lies in the fact that many people do not realize that food combinations of this type should be accompanied by such foods as fruits and vegetables. It might be pointed out at this point that the average individual, in the average enlightened community, will probably seldom arrive at the point where vitamin deficiency is so marked as to bring about the so-called "deficiency diseases." The great danger, for the average individual, lies in the fact that when vitamin intake becomes too low the body is not as resistant as it should be, with regard to colds and contagious diseases. When resistance is low, bacterial diseases have a much better opportunity to become serious than when resistance is high.

When we consider the feeding of domestic animals, however, we have a different problem, because the domestic animal cannot choose from a large variety of foods but must eat what man is willing to furnish. In this manufacturing age there is a great temptation to purchase many types of by-products of mills and factories, many of which are very poor in their vitamin content. In the case of farm animals, and poultry in particular, the fat-soluble vitamin problem is probably the most important. Most farmers feed a large proportion of grain, which is relatively rich in Vitamin B. Unless yellow corn, greens, sprouted grains, alfalfa, or clover are fed, there is likely to be a low consumption of Vitamin A. Some investigators are inclined to the belief that there is but one fat-soluble vitamin. Others, however, are of the opinion

that there are two vitamins soluble in fats; one, which has to do with growth and the prevention of the eye disease, is known as Vitamin A, while the other, which has to do with better bone and teeth formation, is sometimes called the anti-rachitic (rickets curing) vitamin or Vitamin D. Recent chemical data indicate that Vitamin E is also soluble in fats.

VITAMIN D

We will depart for a moment from our alphabetical order and discuss Vitamin D, because it is soluble in fats and, often, it is associated with Vitamin A. It may be said that the term "Vitamin D" is considered a provisional term. It may be that there are not two fat-soluble vitamins but that Vitamin A possesses all of these interesting properties. Until we know more about this situation we will assume, however, that there are two different and closely associated vitamins possessing fat-soluble properties.

Physicians have been familiar for many years with a bone disease known as rickets. It is most common in babies and growing children. The bones, which should be hard and strong, become soft and weak. Teeth do not develop properly and other complications arise. It was found that the softness of the bones resulted from the fact that the body had become unable to put the lime and phosphorus into the bones as nature intended. Physicians discovered that some foods never produced this disease, and when these foods were fed to babies suffering from rickets the disease symptoms disappeared. Cod liver oil was found to be the most valuable cure for rickets. In order that they might learn more about the curative properties of cod liver oil, chemists fed rats on rations which did not contain

this factor and found that the bones of the rats became soft just as they do in human rickets. X-ray pictures showed that the bones were not dense like healthy normal bones. When the rats died, the chemist analyzed the bones and found that the mineral matter had fallen, in some cases, from 63 per cent in normal bones to 25 per cent in the soft rachitic bones. When a few drops of cod liver oil were fed, the bones became strong and the percentage of mineral matter or ash returned to normal. When cod liver oil was analyzed, it was found that there was practically no mineral matter present. How can a few drops of oil, free from mineral matter, cause a large increase in mineral matter in bones? The nutrition chemist answers this question by saying that cod liver oil contains a vitamin, which we have called Vitamin D, which stimulates the bones to utilize the mineral matter in the blood, which, in turn, obtains it from our food. If this vitamin is not present, the bones cannot utilize the mineral matter, in spite of the fact that the food may be relatively rich in salts. If a baby's diet is deficient in calcium and phosphorus and contains no Vitamin D, rickets will develop much more rapidly.

While we are discussing cod liver oil we should mention the work of Dr. Drummond, an English worker, who showed how the cod fish and other fish store large quantities of the fat-soluble vitamins in their livers. Dr. Drummond states that the vitamins are synthesized originally by the diatoms and other minute marine vegetable organisms. These marine plants are eaten by tiny marine animals and these, in turn, by larger fish until, finally, the cod fish receives and stores large amounts of the fat-soluble vitamins in its liver tissues. There should be no reason why other

fish liver oils should not come into commercial use, eventually, in competition with cod liver oil.

Dr. Hess of New York City has contributed a great deal to our knowledge of this disease. He called attention to the fact that rickets in children seems to vary with the season. This could not be explained satisfactorily on a food and nutrition basis. In order to determine what other factors might be playing a part in the development of this disease, Dr. Hess placed two groups of rats on the same diet. One group was allowed to remain in the light while the other group was placed in absolute darkness. Examination showed that the rats in the dark had developed rickets much quicker than the ones in the light. Cod liver oil protected both groups, but the rats in the dark room required more cod liver oil than the group which had been fed in the light. Black rats were compared with white rats, in the sunlight, and it was found that the black ones developed rickets while the white ones did not. This experiment confirmed the observation made by Dr. Hess on human rickets. He had noted that rickets was usually much more prevalent in colored children than in white children.

Dr. Hess finally concluded that the ultra-violet light of the sun possesses a curative effect in rickets and acts much like Vitamin D in cod liver oil. He is of the belief that colored children and black rats develop rickets more readily, because the black pigment prevents the penetration of the ultra-violet light. As a result of these and other experiments, hospitals are now using ultra-violet light, produced by the quartz mercury vapor lamp, in the successful treatment of rickets, and cod liver oil has become a regular household article, following closely, in every case, the arrival of Dr. Stork.

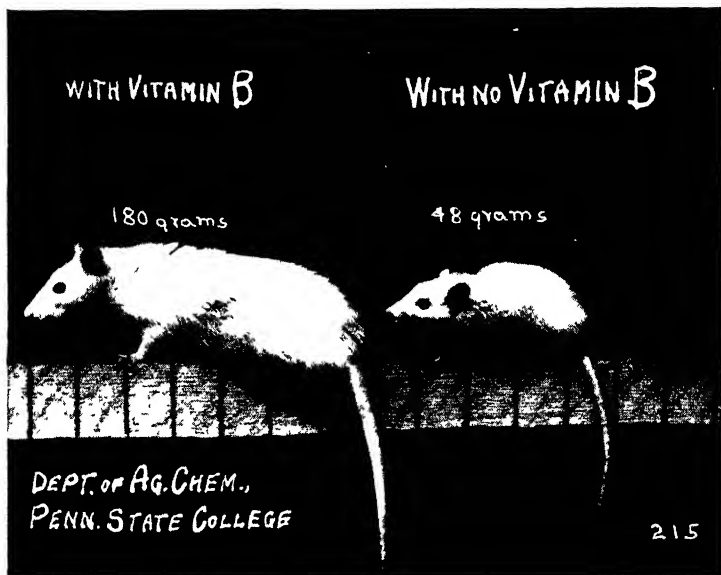
Of the many valuable and interesting contributions made in this field by Dr. Steenbock of Wisconsin, one discovery merits special mention. Dr. Steenbock found that it was possible to feed certain foods which produced rickets in rats in a relatively short time. When these foods, however, were subjected to the action of the ultra-violet rays of the sun or of the quartz mercury vapor lamp, it was found that rickets was not produced. Olive oil, for example, which in its natural state did not possess curative properties, became almost as good as cod liver oil after it had been subjected to the action of ultra-violet light. In order that this discovery may be used for the benefit of humanity, the discovery has been patented by the University of Wisconsin. The reader can readily see the commercial possibilities of a method of this kind for the treatment of all sorts of food materials.

To show that rickets is no respecter of persons or animals, research workers have found that the well known leg-weakness of baby chicks and growing poultry is nothing more or less than rickets. Cod liver oil, fresh alfalfa and egg yolk have been used with success in dealing with leg-weakness in poultry. In addition it has been found advisable to give the young birds as much sunlight as possible. The writer had the pleasure, a few weeks prior to the preparation of this chapter, of assisting a prominent Pennsylvania poultryman who was losing a large number of baby chicks with leg-weakness. He reported that in one hatching (3000 chicks) there were 750 baby chicks afflicted with this disease. The writer prescribed cod liver oil treatment, and a recent letter from the poultryman states that he saved practically all of the chicks which had not died prior to the cod liver oil

treatment, and that he had experienced no trouble in subsequent hatchings.

It would appear, therefore, that the fat-soluble Vitamins A and D are of great practical nutritional importance in the rearing of growing children and young domestic animals. Veterinarians report that rickets is quite common in dogs and swine. Authorities on hogs and hog feeding are paying considerable attention to the supply of Vitamin D and sunlight, on account of the swine diseases known as "stiffness" and "posterior paralysis." They find that these diseases can be prevented by liberal feeding of ground bone and foods containing Vitamins A and D, in addition to plenty of sunshine.

When cod liver oil is treated with a strong alkali, such as sodium hydroxide, a large proportion of the oil forms a soap. The small amount of oil which remains, after the soap is removed, is composed very largely of non-fats, of which an alcohol called cholesterol is a good example. When this alcohol residue is fed to rats, it is found to contain practically the entire vitamin activity possessed by the original oil. One writer has stated that cod liver oil is 250 times richer than butter fat in its content of fat-soluble vitamin. It should be borne in mind, however, that foods like butter fat and cod liver oil will vary in their vitamin activity, depending on their source and the treatment they have received. The writer has produced butter fat (from cows which had received a vitamin-poor diet) which was lower in its vitamin content than some oleomargarines made from animal oils. Although it will seldom occur in farm practice, it is possible to make an oleomargarine from the body fat of cattle, fed on a vitamin-rich pasture, which might be richer in the fat-soluble vitamins than a butter produced



These rats were of the same age and came from the same litter. They both received the same ration with the exception that Vitamin B was present in one case and omitted in the other.

from cattle fed on dry vitamin-deficient rations. Cod liver oil will vary in its vitamin content, depending upon the richness of the diet of the codfish and the subsequent treatment of the cod-livers during the manufacture of the oil.

VITAMIN B

We have already referred to the disease known as beri-beri, which results from a diet which contains no Vitamin B. Birds were used for experimentation in the early stages of the work, but the rat has become the more useful animal for the purpose of ascertaining the relative amounts of Vitamin B in foods. Both types of animals still play a very useful rôle in vitamin studies. The bird (pigeon and chicken) is very susceptible to the lack of this vitamin and in 15 to 30 days will develop a form of beri-beri called *avian beri-beri* or *polyneuritis*. The rat, as a rule, does not develop the paralysis or beri-beri symptoms which are so characteristic in birds. When the diet contains no Vitamin B the rat will lose its appetite and, in turn, a considerable proportion of its body weight. If a vitamin-rich food is introduced, the rat's appetite will improve and growth will start again. Examination of the body, after death as a result of Vitamin B deficiency, reveals the fact that most of the organs have ceased to develop. The stomach, liver, pancreas, thyroid, etc., waste away and cease to function normally. This is particularly true with the organs of reproduction. If the experiment is not carried too far, it is possible to cause these organs to return to normal by feeding yeast or wheat germ, both of which are excellent sources of Vitamin B.

Yeast is probably the richest single source of Vita-

min B, although preparations may be made from wheat embryo or germ which are also highly active. Vitamin B is found in the embryo or germ of seeds, in leafy plants, fruit juices and vegetables. The animal cannot synthesize this vitamin nor can it be stored in the animal body to the degree that the fat-soluble vitamins can be stored. The average dietary contains sufficient quantity of this vitamin and only in rare cases should it be necessary to resort to yeast or commercial vitamin preparations. This is particularly true with domestic animals on account of the fact that the whole grains and forage crops constitute a large portion of the diet. Yeast feeding has proved beneficial in many instances, but it is somewhat doubtful if it will ever replace the natural foods for economic reasons. In spite of the fact that we do not have to worry about our supply of Vitamin B to the extent that we do concerning some of the other vitamins, nevertheless, from a physiological standpoint, it is just as important as any of the others. It stimulates appetite and helps the body to become strong and resistant to disease and exposure. Foods which may be considered good sources of Vitamin B are the cereal grains, vegetables, fruits, and to a less degree milk and eggs. Patent flour, which is used to make white bread, is practically devoid of vitamins, inasmuch as the vitamins are removed with the bran and embryo. We should not condemn white bread for this reason, however, for it is a very valuable food. It is the better part of wisdom to recognize these deficiencies and make up for them by eating vitamin-rich foods with white bread, although the writer feels that the whole grain breads (graham or bran breads) should be served occasionally.

Vitamin B is not easily destroyed by methods of

food preparation and it will withstand higher temperatures than either Vitamins A or C. In the presence of alkalies, however, such as baking soda, considerable destruction may occur.

Valuable work has been done in recent years by Eddy, Seidell and others with regard to the chemical nature of Vitamin B. A discussion of its chemical properties would be too technical for a book of this type, but it can be said that chemists have obtained much suggestive information concerning its chemical constitution and properties. The writer is willing to venture the assertion that the time may not be far off when Vitamin B, and possibly other vitamins, will be manufactured artificially, just as we now synthesize drugs and other chemical materials.

VITAMIN C

This vitamin prevents the development of a disease known as scurvy. This disease has been known and described since the 12th century. Ordinarily, scurvy is not common among adults in ordinary walks of life, but it is found to be quite common in infants, especially in the poorer sections of our large cities. Scurvy is not confined to babies, however, for epidemics have been quite common in troops in times of war and few Arctic explorations have been made that were not handicapped through the loss of some of their members, afflicted with this disease. In addition, it is a disease that has been quite well known in almshouses, prisons, asylums, and similar institutions where large groups of people have been fed, for long periods, on deficient diets.

In the days when sailing vessels plied the seas and refrigeration was unknown, it was quite common for a

ship to be blown out of its course in stormy weather. Under these conditions, ships were unable to touch land for months at a time, with the result that all fresh and perishable food was either consumed or destroyed. For weeks, or perhaps months, the sailors were forced to subsist on hardtack, beans, salt pork and similar foods. As a result "ship scurvy" was a disease with which most seafaring men were familiar in the days of sailing vessels. Since the advent of steam-driven ships and the use of refrigeration, coupled with our modern knowledge of vitamins and nutrition, the disease has practically disappeared or, at least, has become somewhat of a rarity in the experience of seafaring medical men.

While it has been known, for many years, that fresh vegetables and fruits were necessary for the prevention of this disease, the real explanation was not forthcoming until small animal experimentation brought out the facts. It was found that guinea pigs and monkeys are very susceptible to this disease and consequently most of the experimental work has been conducted with these animals, the lowly guinea pig, however, receiving most of the credit.

Ellis Parker Butler, in his admirable story "Pigs is Pigs," would have us believe that guinea pigs multiply in unbelievable numbers over night. While this is not literally true, it is true that it is possible to obtain supplies of these little animals in a relatively short time and at a comparatively low cost. Monkeys are not easily available for experimental work and their cost is almost prohibitive for the average laboratory.

When it was discovered, by Holst and Frölich of Norway, that guinea pigs could be used for the study of scurvy, investigators began a systematic study of our common foods. It was found that scurvy could

be produced by feeding diets of certain foods even though they contain Vitamins A and B. When small amounts of raw cabbage, orange juice or other fresh foods were fed, it was found that scurvy could be prevented and cured.

When human beings or guinea pigs become afflicted with scurvy, the bones become brittle, the gums become affected and the teeth loosen and fall out. Other pathological conditions develop, including paralysis, and death follows, unless proper foods are fed.

These biological investigations had not progressed far before it was clear that the prevention and cure of scurvy was due to the presence of another vitamin. It was shown that orange juice was a very valuable food for the treatment of this disease. Continued investigations showed that Vitamin B could be removed from orange juice by the use of Fuller's earth and the remaining orange juice still retained its scurvy curing properties. It was found that the curative substance was soluble in water and dilute acid solutions. Scientists finally concluded that they were dealing with another vitamin and it was given the name Vitamin C, or the *anti-scorbutic vitamin*. The latter name is derived from the medical word "*scorbutus*," meaning scurvy.

Chemical studies revealed the fact that this vitamin was somewhat readily destroyed, especially when it was heated, in solution, in the presence of oxygen. When air or pure oxygen was bubbled through orange juice, the curative properties disappeared. This was particularly true when the orange juice was heated. Acids seemed to protect the vitamin, while alkalis tended to destroy it. All of the citrus fruits, especially lemons and oranges, were found to be excellent sources of Vitamin C, and tomatoes and raw cab-

bage were found to be about the best garden vegetables. In fact, welfare workers in New York City, applying the results of the guinea pig experiments, found that it was possible to substitute the juice of fresh or canned tomatoes for orange juice in the treatment of infantile scurvy among the children of the poor. As a result of this type of scientific research, the modern baby specialist is able to prevent a large proportion of the nutritional diseases common to babies and growing children.

Vitamin C is present in cow's milk, but its quantity depends upon the vitamin content of the cow's ration. The writer and his co-workers found that milk from cows on a vitamin-rich summer ration was at least four times as valuable, as a scurvy-curing food, as milk from the same cows when the ration consisted of vitamin-poor feeds. This undoubtedly accounts for the different results obtained, from cow's milk, by many investigators.

While pasteurization undoubtedly possesses some destructive action, it is the writer's opinion that milk may be pasteurized in the presence of a small amount of air without appreciable destruction of Vitamin C. From the standpoint of Vitamin C, milk can probably never be considered a vitamin-rich food. Physicians have recognized this fact and, as a result, usually prescribe orange juice for bottle-fed babies. It is also possible to dry milk to the powdered state without appreciable destruction of its scurvy-curing properties.

Cereal grains, in the dry state, are practically devoid of Vitamin C. When germination or sprouting takes place, vitamin synthesis begins. The British Army took advantage of this fact and required that

sprouted lentils be fed to all troops in districts where fruits and vegetables were not obtainable.

Vitamin C is found in the leafy plants but it does not seem to be directly associated with chlorophyll, the pigment which imparts the green color to plants. The white leaves of lettuce and cabbage are unusually valuable as anti-scorbutic foods.

The British Government has prepared a small lozenge made of milk sugar and dried lemon juice, which they require to be carried on all ships and Arctic explorations. As a result of these precautions ship-scurvy and arctic-scurvy are probably things of the past.

VITAMIN E

This vitamin, formerly known as Vitamin X, was first introduced to the world by Dr. Herbert Evans and his co-workers at the University of California. Dr. Evans found that rats could be reared on various "synthetic" food mixtures consisting of fat, protein, carbohydrate, a salt mixture and Vitamins A and B. While these animals possessed "every appearance of health" and grew well, eventually they became sterile and were unable to reproduce.

Further investigation led to the discovery that certain foods corrected this abnormal condition while others did not. The addition of a little lettuce or wheat embryo, for example, enables sterile animals to recover the ability to reproduce and, with these foods present in the diet, rats which had previously been sterile were able to produce and rear normal families.

While this work is still in its infancy, it is quite clear that there is an "anti-sterility" vitamin which prevents sterility brought about by abnormal diets.

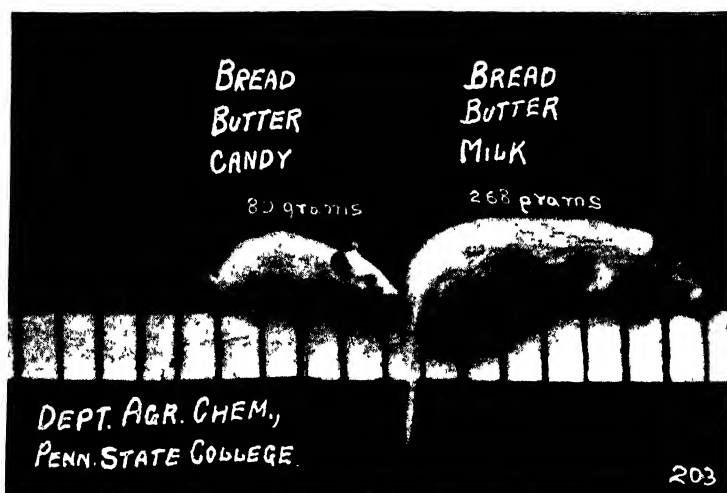
It is present, but never highly concentrated, in animal tissues and, contrary to our expectations, muscle tissues (lean meat) are more valuable in this regard than liver tissue. While milk fat contains this vitamin, the amount is extremely low. Cod liver oil, though a valuable source of Vitamins A and D, is practically devoid of the anti-sterility factor. Dried lettuce, alfalfa, peas or tea seem to have lost no Vitamin E during the drying process.

Vitamin E is found in oats, corn and wheat, while wheat embryo is considered a very rich source for chemical studies. Dr. Burr, a biochemist working with Dr. Evans, has found that Vitamin E is soluble in fats and many of the so-called fat solvents such as ether and benzene. It is not easily destroyed by heat—in fact, Dr. Burr has been able to distill it at 233° Centigrade, under which conditions the vitamin distills over in a very highly concentrated form leaving much of the extraneous material behind.

Dr. Burr is now working on these new chemical fractions with the hope of finding methods of isolating Vitamin E in pure form. It is entirely possible that this may be accomplished. If the vitamin can be isolated in pure form, the next step will be to find its chemical composition and structure. Once this is accomplished, attempts will be made to synthesize the vitamin artificially, just as chemists have done with many of the naturally occurring dyes and perfumes.

SUMMARY

Vitamins are chemical substances necessary for growth in the young and for health and well-being in adult human beings or mature animals. There is no danger of vitamin deficiency if we plan our meals or



A Practical Lesson in Dietetics

This photograph has been used to a great extent in the Pennsylvania grade schools. The teacher has no difficulty in impressing the under-nourished children that it is best to eat less candy and drink more milk.

the rations of farm animals in such a manner that a variety of foods are fed. The old saying that "variety is the spice of life" applies to our dietary habits as well as it does to our social, physical and mental activities. If we desire to do the best mental and physical work we must have healthy bodies. Intelligent feeding will play an important rôle in helping us to develop healthy bodies. This can be accomplished by eating the foods which contain the necessary proteins, fats, carbohydrates, mineral salts and vitamins. We should obtain our vitamins from the garden, the orchard, the poultry yard and the dairy.

The following table, taken from Bulletin 184 of the Arkansas Agricultural Experiment Station, gives the approximate vitamin values for a few of our most common foods:

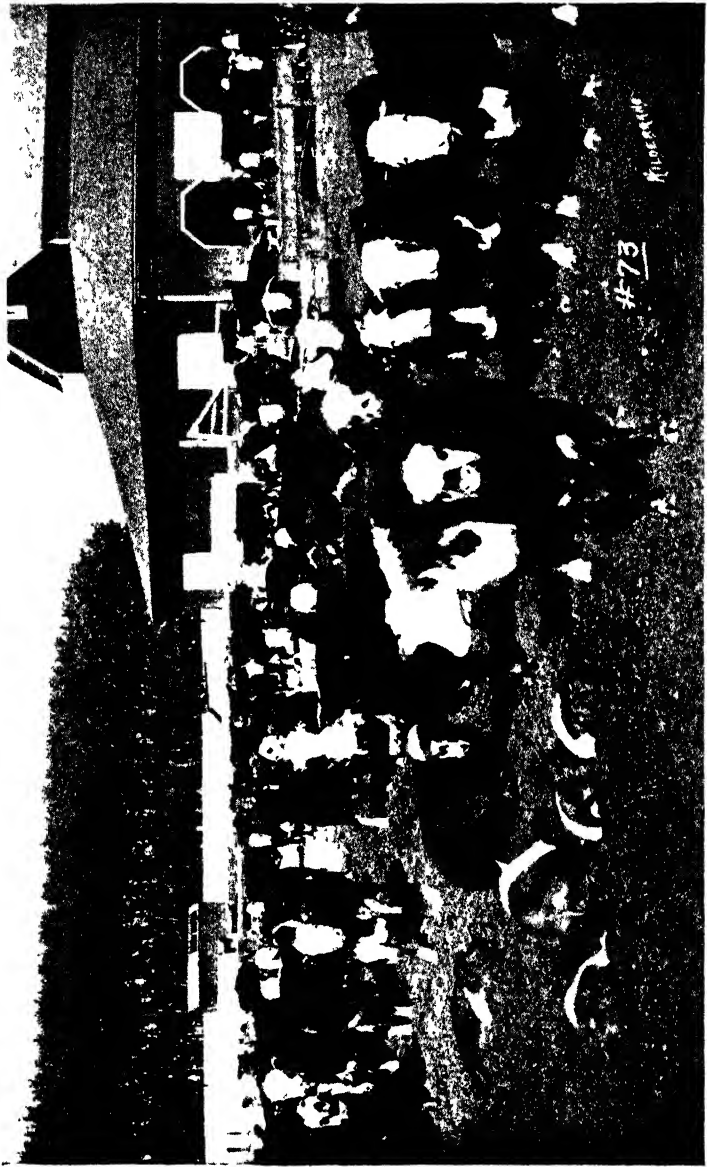
Article of Food	A	B	C
Apples.....	Poor	Poor	Fair
Bananas.....	Little	Little	Fair
Barley, whole.....	Poor	Good	Trace
Beans, navy.....	Unknown	Rich	Trace
Beets.....	Fair	Fair	Fair
Bread, white (water).....	Doubtful	Little	Doubtful
Bread, whole wheat (milk).....	Good	Good	Doubtful
Cabbage, raw.....	Good	Good	Rich
Carrots, fresh raw.....	Good	Good	Fair
Codliver oil.....	Very rich	Trace?	Trace
Corn, white.....	Trace	Good	Trace
Corn, yellow.....	Fair	Good	Trace
Cottonseed oil.....	Little	Trace	Trace
Eggs.....	Good	Fair	Poor
Grapefruit.....	Unknown	Good	Good
Kidney.....	Good	Good	Little
Lard.....	Little	Trace	Trace
Lemon juice.....	Unknown	Good	Rich
Lettuce.....	Good	Good	Rich
Liver.....	Good	Good	Fair
Meat (muscle).....	Trace	Little	Little
Milk.....	Rich	Good	Fair
Oats.....	Poor	Good	Trace
Orange juice.....	Poor	Good	Rich
Peas, green.....	Good	Good	Poor?
Potatoes, white, boiled (15 minutes).....	Little	Fair	Fair
Spinach, fresh.....	Rich	Rich	Good

Article of Food	A	B	C
Tomatoes, raw.....	Good	Rich	Rich
Tomatoes, canned.....	Good	Rich	Rich
Yeast.....	Absent	Rich	Absent

NOTE.—Comparatively few data are available concerning the distribution of Vitamins D and E in our ordinary foods. For this reason no attempt has been made to include this information in the table.

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Cattle in a Feeding Lot in the Corn Belt

CHAPTER XIII

MEAT—ITS RELATION TO HUMAN NUTRITION AND AGRICULTURE

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THE EARLY USE OF MEAT

Unquestionably the use of meat as human food antedates the earliest records left by prehistoric man. These records are clear in showing that roast meats, especially from the sheep and goat, were highly prized and acceptable as offerings to the deities worshiped. Ancient civilizations of Assyria considered the preparation of meat of sufficient importance to engage the attention of the priestly order to whom this work was reserved by law. Among the ancient Egyptians the priests, under the law, were judges of the meats intended for food. Among the Hebrew patriarchs "burnt offering"—or roast—was a frequent sacrifice on their altars. An idea so widespread and an esteem so deeply planted could only have been the outcome of long established practice and of high appreciation of meat.

The more sturdy races of mankind from time immemorial have had their flocks and herds which yielded wool and leather, milk and meat, as the need arose, for clothing and feeding man. The keeping of flocks

and herds is an occupation involving much exercise and permitting, if not requiring, at least under primitive systems of agriculture, frequent change of location. The outdoor life led by these people probably had as much to do with their physical strength and endurance as the excellent food they ate. Nevertheless, the kind of food must be given its proper share of credit.

At the very beginning of things, when the world seems to have been a vast common pasture, man's wealth was measured by his possessions of clothing—and food-yielding live stock. Jacob served seven years as a shepherd for Rachel and found time in his leisurely wooing to develop a unique system of breeding sheep and goats. The Hottentots and Kaffirs of South Africa even now count themselves rich or poor only as they have large or small herds of cattle. What may be called the market value of their cattle is not important to them—only plenty of cattle. That is their "wealth," or well-being. This primitive conception of live stock ownership as wealth survives in the Ten Commandments, where we read: "Thou shalt not covet thy neighbor's wife nor his ox nor his ass."

THE DEVELOPMENT OF AGRICULTURE AND INDUSTRY

As civilization advanced and agriculture became more fixed with the growing of more crops on the land, the breeding and feeding of live stock became more of an art and a science both in its production and in its products. By the twelfth century butchers had formed powerful guilds, or trade associations, in most of the large cities of Europe. Larger animals, such as beef animals, became highly developed and efficient pro-

ducers of food. It was found that the droppings of the cattle and other live stock increased the fertility of the soil and it became increasingly apparent that a well managed live stock industry made far greater returns from the crops raised, as well as from the animal products produced.

THE ADVANCE OF CHEMISTRY

The nineteenth century brought with it a marked change in industry, involving a great expansion in the use of machinery, the devising of improved means of transportation on land and sea, and rapid methods of written communication by other means than by letter. It was a century when great strides were made in the sciences. Physics and engineering advanced and chemistry emerged from its Dark Ages mantle of alchemy to step forth as a great servant of mankind. Rocks and minerals, metals and foods, manures and soils were analyzed by the chemist. Man was really getting acquainted with his surroundings and testing the properties of the material things of the earth not by putting them into his mouth and handling them as an infant does but by placing them in the chemical crucible and determining their chemical make-up.

Prominent among the food products studied and analyzed during the nineteenth century was meat. Some earlier work had shown the elementary composition of meat, that it was rich in azote or nitrogen and that it contained rather highly flavored compounds called extractives. Its content of carbon, hydrogen, oxygen and other elements had also been determined.

About this same time the chemist was classifying things chemical into inorganic forms, such as rock,

minerals, salts and similar things, and organic forms such as fat, sugar, starch, and protein. Meat contains fat and protein. These organic things were supposed to be the products of living organisms and to be peculiar to them. However, a chemist named Wöhler, in 1828, succeeded in making, from inorganic sources, a compound known as urea, which was found in meat extractives and was believed to be formed only by animals, such as man, from protein food. This is the chief form in which man eliminates any excess of digested protein nitrogen that he may eat. Some other animals void this excess nitrogen in the form of uric acid and hippuric acid.

With the discovery of Wöhler the old distinction between inorganic and organic forms of matter began to disappear. The classification today is one of convenience rather than of origin and there is an ever increasing "no man's land" between. Some of the compounds derived from proteins have been artificially made, or synthesized, from laboratory products by chemists such as Curtius and Emil Fischer. The conquests in the field of organic chemistry would make an entrancing story but it can not be followed here.

THE EARLY CONTRIBUTIONS OF CHEMISTRY TO OUR KNOWLEDGE OF FOOD VALUES

Justus von Liebig, a German, interested in meat as a food, made an extract of beef which was recommended as an excellent article of diet. The beef extract, or Liebig's Extract as it was known to our fathers, is still in vogue today although in many modified forms and under other names. While its food value is not high, it is an appetizing and useful substance which serves as a source of bouillon and

soups, of gravies, and of other food adjuncts in which flavor is of importance. These and other extracts from meat, including meat jelly, were also found to be good foods in which to grow bacteria and microorganisms—minute animals and plants which work in mysterious ways to cause disease, to make wine and vinegar from fruit juices, to raise bread, and to do other tasks both harmful and harmless. Pasteur, a French chemist who was foremost in this field, was of the generation following Liebig and Wöhler.

Most readers know, doubtless, that when things are burned the oxygen of the air combines with parts of the thing burned to form compounds, mostly gases but also some solids, the latter remaining as a small amount of residue known as ash. Priestley, an American chemist, discovered this oxygen. A French chemist, Lavoisier by name, studied the products of combustion, or burning. Later he turned his attention to the changes which foods, such as meat, undergo in the body. He was able to show that when food is used for purposes other than construction of body substance it is really oxidized and yields much the same material as it does when burned in the air. Protein foods, for example meat, are not completely burned in the body but leave some "charred" parts such as urea or uric acid, which have already been mentioned. Rubner, a German chemist, did further work along this line and showed that when these unburned residues are taken into account, this combustion in the animal body really obeys the same laws as combustion in the air.

Henneberg and his associates deserve the credit for the method of proximate analysis as a means of expressing food value. Their work had to do primarily with animal feeding but the idea was soon applied to

foodstuffs as well. Such men as Voit in Germany and Atwater in the United States gave much attention to this subject, and it was finally accepted as a general procedure. König in Germany and Atwater and his associates in the United States made large collections of analyses of foods for man. Jenkins and Winton, and Henry made compilations of analyses of feeding stuffs.

THE CHEMICAL COMPOSITION OF FOOD ANIMALS.

All these and other facts and discoveries began to open new and ever-increasing fields of work. The last quarter of the nineteenth century found a number of men at work analyzing the animals used as human food and determining the composition of the increase in weight achieved by growing and fattening animals. Rubner did some work along this line and the list of German chemists includes also, among others, Wolff, Pettenkofer, Carl and E. Voit, Bunge, Henneberg, Stohmann, and Zuntz. Most of these men worked with smaller animals in the chemical laboratory or in the respiration chamber and animal calorimeter.

The first to work on the larger meat animals were Lawes and Gilbert, of the Rothamsted Experiment Station in England. They analyzed various parts of and the whole animal, using three beef animals, five sheep and two pigs. Soxhlet and Tschirwinsky, in Germany, had analyzed some swine, and Wilson and Jordan, in the United States, had worked on pigs and cattle, respectively. The work of Lawes and Gilbert, however, remained the classical work of the type for over fifty years.

The work of Lawes and Gilbert inspired chemists in this country. In the United States Atwater was a

pioneer worker in the study of the composition of flesh foods and the World's Fair in Chicago in 1893 gave him an unusual opportunity to obtain a very representative collection of samples. Haecker, at Minnesota, and Moulton, Trowbridge and Haigh, at Missouri, made numerous analyses of cattle. The work at the latter place is the most extensive on record. Washburn and Jones, at the Vermont Experiment Station, analyzed a large number of young pigs, and Swanson, of the Kansas Experiment Station, reported the composition of hogs weighing from sixty pounds to four hundred pounds.

CHEMICAL CLASSES OF FOODS.

The early applications of chemistry to foods and feeding stuffs and to human and animal nutrition had shown that foods supply certain kinds of organic material which can be burned or used as building materials by man or animals. These are, first, the proteins or nitrogen containing materials found in all cells but in rich proportions in certain foods such as meat, fish, eggs, cheese, peas, beans and nuts. A second class includes the fats such as butter, olive oil, lard and similar fats found in fat meat, nuts or milk. A third class consists of what are known as carbohydrates and includes sugar, starch, and cellulose found in relatively great abundance in vegetables, cereals, and fruits. It had been shown, also, that various mineral salts are needed by animals, especially for bones and teeth, as these contain much ash or mineral matter, but also for the flesh, fluids and organs of the body which contain smaller but appreciable amounts. Water had also been recognized as necessary. These foods were known to be used to build the animal's body,

to supply material for milk or egg production, or to supply energy to keep the animal going at its daily tasks such as eating, digesting, breathing, walking, and working.

THE VALUE OF ANIMAL PROTEINS

Before the beginning of the present century this classification was supposed to be sufficient; all proteins were supposed to be much alike in quality and the energy or calorie content of foods was supposed to represent adequately relative food values. Such men as Voit, in Germany, and Atwater, in America, had classified human foods according to this knowledge and had made large compilations of analyses. But after 1900 the work of Fischer, Kossel, Osborne, and Mendel showed a marked difference in the make-up of the proteins. These good foods are built up of smaller nitrogen-containing compounds called amino acids of which some eighteen or twenty were soon known. Some proteins were found to contain a more complete mixture of these building stones, or amino acids, than others did. For example, animal proteins, such as those present in meat, eggs and milk, contain a very adequate mixture of amino acids while many vegetable proteins are lacking in one or more of the essential ones.

All this work confirmed the early esteem in which meat was held by man and showed why it should be considered a desirable food. In addition, it was known that, while lean meat contained only a modest supply of energy or calories, the fatter meats were rich in energy and that bacon and lard were among the richest sources of it.

The importance of the mineral constituents of foods

had received some attention and it was recognized that certain mineral elements, calcium, phosphorus, iron, and iodine, were of relatively great importance. However, for a number of years following 1900 it was believed that foods in general supplied enough of these elements so that one had not to concern oneself much about them.

THE DISCOVERY OF VITAMINS

Before the first decade of the twentieth century had passed Funk, McCollum, Osborne, Mendel, and Sherman, and soon after many other chemists, had shown that foods might supply all the ingredients listed and yet fail to support life, growth and health. More investigation followed and certain mysterious, almost magic things in foods termed vitamins were thus discovered. It was soon shown that there were several classes of vitamins and that their functions were more or less specific. Chemists for convenience labelled them vitamins A, B, C, D, and E or X. These vitamins have been specially considered in another chapter.

Early work showed that milk and green leafy vegetables were rich sources of certain vitamins and that meat and bread and some other common foods such as sugar were very low in them. More work, however, has established the fact that the body fats of meat animals may contain appreciable amounts of vitamin A; that fresh meat contains an ample amount of the antiscorbutic vitamin C which, however, is destroyed by cooking; that meat is an excellent source of the vitamin needed for reproduction; and that fresh or cured pork, even when cooked, supplies important amounts of vitamin B. Meats may, then, supply modest amounts of certain vitamins. The most important discovery the chemist made, however, was that the

edible glands such as liver and kidney, were very rich sources of vitamins. In addition, the protein and mineral content of these glands is excellent.

THE VALUE OF MINERAL ELEMENTS

Vitamins were soon obliged to share the stage with the mineral constituents of foods, for it was shown, by such chemists as Sherman, that the American diet was very likely to be low in calcium, and perhaps, iron and iodine (at least in certain parts of the country). Phosphorus and other mineral elements were more abundant. Milk and certain green, leafy vegetables, roots and nuts were shown to be rather rich in calcium, while meat, cereals, and starchy vegetables contained but very small amounts. On the other hand, meat was known to be a rich source of iron, the lean meat exceeding spinach, whole egg, and raisins, but containing much less than egg yolk, bran, dried peas and beans, and whole wheat. Meat was also shown to be rich in phosphorus.

The iron content of foods is important because iron is needed to form hemoglobin, the protein in the blood which enables us to carry oxygen from the air in our lungs to each cell of the body for its uses. It also is part of a hemoglobin in the muscle tissue itself. Iron-containing foods may contribute to this need but their value depends upon other factors than the iron content alone. The problem is now being studied by Whipple, of Rochester, New York, and his published work shows that, as a blood builder, lean meat exceeds fish, spinach, other vegetables, and perhaps, whole egg, and that liver and kidney are the most potent in this respect of all foods studied.

THE BALANCE OF MINERAL ELEMENTS

The chemist has long classified inorganic chemical elements into two groups, viz.: acid-forming and base-forming. To illustrate, chlorine unites with hydrogen to form hydrochloric, or muriatic acid; and sulphur combines with oxygen and hydrogen to form sulphuric acid. Sodium, however, unites with oxygen and hydrogen in another way to form an alkali or base. Calcium, potassium, magnesium, and iron do likewise. When an acid and a base or alkali react together they form a salt, or, as the chemist says, they neutralize one another and the result is a salt—like sodium chloride, or common table salt. One eats these acid or base-forming elements in the diet generally in the form of a salt, but sometimes they are not united to another inorganic element but are in some organic compound. If one should eat a great excess of acid-forming or base-forming elements there would be serious trouble, due to acidosis or alkalosis as the case may be. Therefore, it is necessary to eat of both groups. Fortunately, few foods are preponderantly of one kind, and a mixed diet is seldom unbalanced in this respect. Vegetables, fruits, and milk have an excess of base-forming elements, while cereals and grains, meats and fish have an excess of acid-forming elements. However, one generally eats meat and potatoes, corned beef and cabbage, and bread and milk, and so avoids the danger of an unbalanced mineral diet.

Acidosis, or alkalosis, may be of alimentary origin, that is, these conditions may sometimes be caused by the food eaten. For example, some authorities believe that an acidosis resulting from the eating of excessive quantities of starch and sugar may be the factor caus-

ing the breakdown of the kidney and pancreas known as diabetes. In most cases of acidosis or alkalosis, however, the primary cause lies in some factor other than the food which may be but a contributory factor.

PROPORTIONS OF PROTEIN IN THE DIET

Previous to the current quarter century it was believed that protein should form a large part of a diet. This belief was based on the fact that all living tissue consisted primarily of protein and water, with larger or smaller amounts of salts and fat-like bodies. In certain cases large amounts of mineral matter, fat, starch or other material would be laid down in or around the cells and would thus obscure their composition. Protein food was known to be the only food that would supply the body's need for protein building material. An increase in body size or in the amount of work the body was made to do was held to increase greatly its need for protein. Rubner was chiefly responsible for this belief. Voit, in Munich, and Atwater, in America, had made statistical studies of the consumption of human foods and had shown that an adult man consumed from 118 to 120 grams of protein a day. According to Voit's studies, 56 grams of fat and 500 grams of carbohydrates were consumed, and the total calories in the food were 3,000 large calories.

Chittenden, at Yale University, was the first seriously to question the value of this evidence. He made cautious experiments which showed that an adult man could get along on as little as 40 grams of protein a day for months at a time. Since then a controversy has been waged between the apostles of Chittenden and the believers in a high protein diet. Rubner's early contentions have been disproved, but, on the

other hand, experiments on humans covering only a few months, or two or three years, are too short to prove anything concerning the adequacy of a diet for a complete life or for successive generations. Experiments with laboratory animals have shown quite definitely that a more liberal allowance of high-class protein leads to greater vigor and activity, better health, better ability to beget and rear offspring, and, perhaps, to a larger stature. The tendency is now very marked to consider, not the minimum or the maximum amount of any food constituent, but to follow the principle of the optimal amount. In this sense the amount of protein desired is probably neither Voit's and Atwater's 120 grams nor Chittenden's and Hindhede's 40 grams. Most nutrition chemists place the proportion of protein desirable at between 10 and 15 per cent of the diet measured in calories. Sometimes 20 per cent is preferred. These figures mean 75, 100 and 150 grams of protein respectively. The 150 grams scale, or 20 per cent, is recommended under certain specific conditions, for example, when a good flow of milk is desired in animals, or even in lactating women.

SOME OLD BELIEFS ON HEALTH AND DISEASE

There is another consideration regarding the place of meat in the diet and the amount of protein that should be consumed, viz.: the specific effect upon health. In the past there have been many strange beliefs concerning the cause of disease and its cure. All sorts of superstitions held sway, and charms, incantations, the witch and medicine man have been called upon in times of need. One carried an amulet around the neck to ward off fever, another a potato in his pocket for the rheumatism, and a third wore a jade

stone for the pain in his side. Before the age of chemistry and bacteriology this ignorance and superstition, perhaps, was excusable.

The lord of the manor, the prince, or the king was frequently a high liver prone to eat large quantities of food, to drink much wine, and to leave exercise to his underlings. All sorts of dishes graced his board. A menu of an early Victorian feast reads today like a complete list of domestic animals and game. Gout was a frequent visitor, and in gout, rheumatism, and arthritis, uric acid was thought to play a part. It was known that protein foods left some unburned part to be eliminated by the kidneys, and, in addition, supplied various amounts of uric acid or materials which would give rise to uric acid. Meat was most frequently referred to in this connection. An Englishman named Haig evolved a theory that all uric acid consumed by man was prone to accumulate in the body and to cause the diseases referred to. Hence one was advised to eat sparingly of these protein foods in health and to omit them entirely from the menu in a case of one of these diseases.

These old beliefs, however, gradually faded away before newer light. Bacteria and disease germs were isolated. The specific causes of many diseases were discovered. Most cases of arthritis and rheumatism were shown to be due to specific local infections with germs such as occur in an ulcerated tooth, a diseased tonsil, a pussy appendix, or an ulcerated colon. The final overthrow of the old uric acid theories is just under way, due largely to the work of an American chemist named Folin, who has shown that man can destroy uric acid at a comparatively rapid rate and that healthy muscle and other tissues are nearly impermeable to uric acid.

INTESTINAL DECOMPOSITION

Another source of possible trouble lies in changes which occur in the digestive tract. In the lower part of this tract, known as the colon, food residues may accumulate and micro-organisms may abound. Some of these are capable of bringing about changes in the composition of food residues with the formation of products that would prove harmful if allowed to get into the blood stream. Some micro-organisms feed on carbohydrate material and yield more or less harmless products. Others prefer to feed on protein and may yield putrefactive products, which are harmful. A high protein diet, especially a meat protein diet, may lead to the latter type of changes, notably if the intestines are sluggish in action. The use of a mixed diet and the employment of measures insuring prompt elimination will prevent as well as remedy such trouble. The first point is gained by using proteins, fats, and carbohydrates together, and the second by eating green leafy vegetables, fruits, roots and the rougher parts of grains along with the concentrated foods.

THE PLACE OF MEAT IN THE DIET

Perhaps it would be well before leaving this phase of the subject to sum up our knowledge of food values and to indicate meat's place in the diet. We know that an adequate diet must supply:

1. An adequate quantity and quality of protein.
2. A sufficient amount of energy-producing foods with a distribution among the three classes of proteins, carbohydrates, and fats.
3. A proper amount, distribution and balance of mineral elements.
4. A good supply of vitamins.
5. An amount of neutral, indigestible material such as cellulose in fruits and vegetables, to insure intestinal cleanliness.
6. Digestibility and palatability. A mixture of completely digestible foods with rougher vegetables is desirable, for a non-residue diet is not the best for health. One should mix bland, neutral flavored foods with appetizing and flavorful dishes.

Judged by these standards, meat is an excellent food. It supplies large amounts of protein of the best quality. It may supply both fat and protein and thus furnish good sources of energy. Meat can supply some of the vital minerals in large quantity. It contains modest amounts of certain vitamins and more of others. The edible glands are especially good in this respect. It is appetizing, palatable, almost completely digestible, and is a very satisfying food that postpones the feeling of hunger longer than some which are quickly digested. But meat makes no pretense to being a balanced ration; it supplies no carbohydrate, is low in calcium, and cannot be relied on as a sole source of most of the vitamins unless eaten rather raw, and it lacks in indigestible residue. This may seem a long list of failings for one food, but much the same statement can be made concerning any other food. There is no complete and perfect food excepting, perhaps, the mythical ambrosia which the Greek gods were wont to consume. Even milk, except in infancy, has a list of failings which cannot be ignored. If there were a perfectly balanced food human beings would tire of it and so it would defeat its own ends. Meat has enough fine points of which to be proud without claiming more. Its chief claims for preference lie in its supply of fine quality protein and in its appeal to the palate.

In general, both over-eating and under-eating of food should be avoided. Keeping this in mind, the only safe diet for man is the well-mixed, balanced diet, employing meat, eggs, and similar high protein foods, green leafy vegetables, roots, and tubers, fruits, cereals, breads, milk and its products, and other good foods. In such a diet, green, leafy vegetables, fruits, and milk should be stressed because they are too fre-



A Typical Western Range

quently omitted. But meat also will find a place for itself and thus justify the esteem in which it has been held throughout the ages.

THE MEAT-PRODUCING ANIMAL'S PLACE IN AGRICULTURE

The foregoing section of this chapter has dealt with the use of meat as a food and the part the chemist has played therein. Chemistry is also helping to solve the problem of the place of the meat-producing animal in a well-rounded system of agriculture. In primitive days the owner of flocks and herds had little competition from the husbandman of the soil. Fruits and nuts were articles of diet ready for use. Vegetable and cereal crops were found that could furnish food for man. As population increased and the knowledge of agriculture grew, crops were cultivated with greater intensity and relatively more cereal and vegetable foods were produced. This type of food production tended to fix the population and to prevent the wandering about to which all nomad herdsmen were accustomed. Rain, sun, soil, and seed, together with some cultivation on the part of the tiller of the soil, sufficed to yield large returns in the form of cereal and other foods of the vegetable kingdom. Large fertile areas were found adapted to the growing of grain. Others not so easily cultivated were best used for grazing livestock.

The quantity of cereal food produced soon exceeded the demand for use as human food. Parts of the grain-bearing plants accumulated in quantity and had to be disposed of in some manner. In regions where grain growing predominated the burning of straw stacks and corn stalks was common. If these regions

grew no appreciable amount of livestock, and if the practice mentioned were followed the soil soon began to lose its fertility. Then various means were found necessary to augment the decreased fertility and various forms of manures and fertilizers were applied and systems of rotation of crops devised.

This brief sketch serves to indicate that meat-producing animals and livestock in general perform two functions in our present system of agriculture. One is to convert into a relatively rare and valuable product, such as meat or milk, an economic surplus of such feeds as grains which can serve as human food and grasses, forage crops, and those parts of the grain crops which cannot serve as human food. The other function is to return to the soil, in the form of manures and fertilizers, certain valuable ingredients removed by the crops.

SOIL FERTILITY AND ANIMAL FERTILIZERS

The student of agriculture, working in a region where livestock and grain crops were both grown, early noticed that fields in which livestock had been fed were more fertile than those used for crops alone. Chemical analysis of the droppings of cattle and other livestock showed them to contain nitrogen and organic matter as well as smaller quantities of phosphorus and potash. These ingredients, needed by many soils, are removed by crops in amounts relatively large when compared to the supply in the soil. The chief contribution of animal manure to fertility of the soil is in the nitrogen and organic matter content.

There is another side to this fertility question than that just indicated. The animal at best returns to the soil only a part of the material removed by crops.

However, if grain crops are produced and the grain, straw, and other parts are likewise removed, the soil will lose all the material furnished to the crop. Live-stock will return a part in the form of manure. When feeds raised on the farm are fed to cattle, and in addition feeds purchased from outside are also used, much more is returned to the soil of that particular farm. The return to the soil is still greater in case the animal has been born and partly raised on some cheap grazing land and then matured and fattened on a farm in a grain-growing section. In this latter case the animal actually enriches the farm and leaves it more fertile than it was found.

Yet when the meat animal leaves the farm it has not made its last contribution to the fertility of the soil. Manure dropped in the railway cars or cattle pens at the public stock yards may be returned in the form of fertilizers. Then, when the animal is prepared for human food, certain inedible parts will contribute, through tankage, blood meal, or bone meal, to the fertility of the soil. These forms of fertilizer material are rich sources of nitrogen for the soil. In addition, bone meal is a most excellent source of the phosphorus so greatly needed by grain crops. Tankage may also serve as a source of phosphorus, the amount depending upon the proportion of bone in the tankage. Even after the meat has left the packing plant or retail meat shop it may contribute some material to the soil through bones or tankage material collected from the butcher, or garbage collected from the home.

ANIMAL PRODUCTS AS ANIMAL FEEDS

The meat-producing animal contributes in a more direct way than by the fertilizer route to the needs of

man for food. More and more of the parts of the meat animal not used directly for human food are being used as feed for farm animals. This cuts out two steps in the cycle of soil-crop (or animal feed)—animal-fertilizer-soil. The cycle now becomes soil-crop (or animal feed) animal-feed. In other words, a percentage of the animal body (tankage and meat meals, for instance) is used directly as feed for animals, rather than indirectly for fertilizing crops which will be used later for animal feed.

The value of high class or complete protein and its need in the diet of man have already been pointed out. In addition, the necessity of certain minerals has been stressed. These statements apply to animals as well as to man. Therefore, it is not surprising that meat scraps or sour milk greatly increase the production of eggs by laying hens and that tankage is an excellent supplement to corn in the ration of the hog. Bone also helps the hen to produce better egg shells and adds to the mineral ration of the hog.

THE RELATIVE ECONOMY OF FOOD PRODUCTION BY ANIMALS

Rather frequent reference is made to the fact that animals which are grown for food return in the form of human food only a small percentage of the feed consumed by them. It also has been pointed out that the beef animal is less efficient in this respect than the dairy cow or the hog. Armsby, an American chemist, calculated that, of the energy of grain used in feeding the animal, there was recovered for human consumption about 18 per cent in milk, and only about 3.5 per cent in beef. Wood, in England, estimated that the cow returned in milk, veal and beef one-twelfth as



A Fine Beef Steer

A source of the best steaks, roasts and stews

much food as she consumed, while the beef steer returned only one-sixty-fourth. An official Report on the Food Supply of the United Kingdom presented figures interpreted as showing that a good milk cow will return 20 per cent of the energy value of what she consumes, the poor milk cow will return 12 per cent, and the good beef steer will return but 6 per cent. The figures of Wood evidently covered the life history of the animal, while the others probably covered only the period of productive activity.

Before some new evidence concerning the economy of production of human food by animals is presented certain principles should be recognized. First, the laws of the conservation of matter and energy hold for animals as well as for machines. All of the matter and energy consumed by an animal can be accounted for in some form or other. Owing largely to the nature of the feeds eaten, some of this matter and energy is voided unused and becomes available as a fertilizer for the production of food. Another part is consumed in the running of the animal mechanism, the end products being largely water and carbon dioxide. The synthetic processes of the plant are needed to reconvert these into food products. After these losses occur the remainder can be used for production of milk, body substance, or other material product, or work.

This leads to the second principle, that the economy of production of food by animals depends largely upon the proportion of total feed eaten that is available for food production. In other words, a large capacity for consuming feed insures a greater part of the feed being available for productive uses.

A third principle to be considered is that the conversion of available feed into animal products may not proceed without some loss incident to the transforma-

tion. Evidence concerning these possible losses is not large. The Institute of Animal Nutrition in this country, Hansson, a Swedish chemist, and Møllgaard, a Danish chemist, have all contributed valuable data. According to these investigators, the losses are relatively larger in the production of body substance than in the production of milk. They have shown that feed which will produce 1,000 large calories in the form of milk will produce from 780 to 860 large calories in the form of body substance.

The practical point to be considered here is: What proportion of the total feed consumed by a food-producing animal can, in the course of its total life, be returned as human food? Experiments conducted at the University of Missouri yield some new direct evidence on this point. A young beef steer, full-fed from birth, returned 17.7 per cent of the total energy of the food in the form of body substance. Slightly older animals returned 12.6 per cent and mature (3-4-year old) cattle returned but 8.2 per cent. Where the feed had been lighter the returns diminished, being as low as 3 per cent in some cases. Not all of this recovery is in the form of edible product. Most of it is potential human food, but we are not as yet using more than about two-thirds as food. Employing round numbers, it is seen that a beef steer may return 18 per cent of the energy consumed when young and only 9 per cent when old. Reducing these figures to two-thirds, to correct them to edible product, gives 12 and 6 per cent respectively. The efficiency of the younger animal is about double that of the older animal.

Given the grown animal, what is the efficiency of conversion of the feed? Experiments conducted at the University of Missouri by Moulton, Trowbridge, and Haigh furnish an answer to this question. Ten ma-

ture dairy cows of good productive capacity returned during one year 16.9 per cent of the energy consumed. A mature thin beef steer was fattened for the market to a condition of medium fatness. It returned 14.9 per cent of the energy consumed in added body substance, most of which was edible. Another steer fed to a very fat condition showed an efficiency of only 10.2 per cent.

These results indicate, then, that the beef steer is more efficient than some earlier results have shown. The younger beef animal shows a greater efficiency than one allowed to grow to full maturity on full feed. The ratio may be two to one.

OTHER CONSIDERATIONS AFFECTING ECONOMY

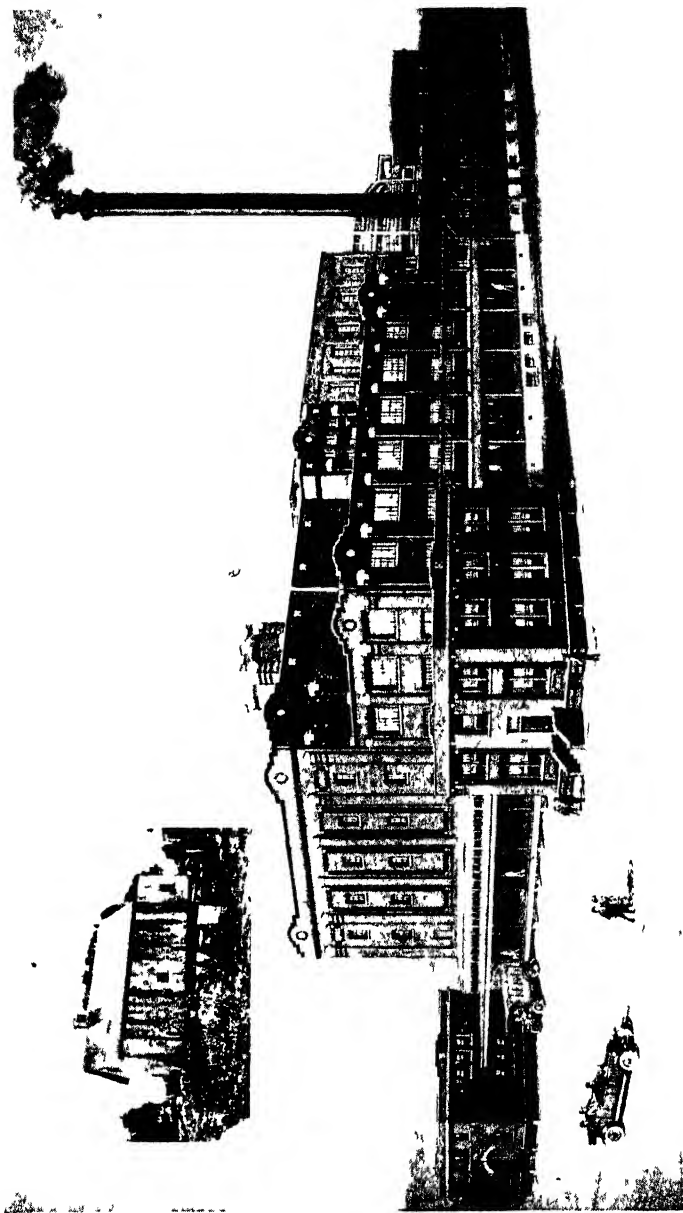
A number of other considerations enter into a well-rounded discussion of this topic. The use, for grazing, of land not fit for cultivation may lead to the production of an animal which will later be a rather efficient producer of human food. According to the National Research Council Advisory Committee of the American Society of Agronomy, two-thirds of all crop land harvested in the United States produced food for livestock rather than for human beings. All forage crops produced in this country in one year will feed 50,000,000 adult cattle. Since there are over 100,000,000 adult cattle in the country, pastures must feed the other 50,000,000. In other words, one-half the cattle are now fed on pasture. Our permanent pastures, although badly abused, still furnish one-third of the feed consumed by all domestic livestock. A good proportion of this pasture land is unavailable for the production of tilled crops. This fact alone would seem to establish a place for meat-producing animals in any economical system of agriculture.

It has been estimated that swine now consume 40 per cent of our corn crop and cattle 15 per cent, only 10 per cent being used for human food. The remainder of the corn plant may serve as stover for cattle, or still better, as silage for cattle and dairy cows. Smaller proportions of other grain crops are used as feed for cattle and other domestic animals.

Max Rubner, a foremost German chemist working in this field, does not believe that animals are really competitors of man for food. He shows that the herbivora, at least, convert, into good protein and fat, substances which man cannot utilize. Haldane, an English chemist, in his book entitled "Daedalus: or Science and the Future," points out that the same acreage which will feed 420 people, if it is used for growing potatoes, may feed only fifteen if it is used to grow grass to be turned into beef. However, this will not eliminate the ox—a mere middleman—as it were. If man does not—and cannot—live by bread alone, still less does he live by potatoes alone. Most plants turn their raw materials, not into sugar or starch which man can digest and use, but into cellulose and other cellular material which he cannot utilize. That is where the hooped animals have the advantage of us. They convert these cellular materials into food for man.

THE EFFICIENCY OF OTHER CONVERTERS OF ENERGY

It is the rule rather than the exception that most of the natural means of converting energy from one form to another are not efficient. Alsberg, an American chemist, has quoted the work of Brown and Escombe, who show that of the total light rays that reach this planet there are available for photosynthesis, or the elaboration of plant substance, only 6.5 per cent of the



An Old Slaughter House typical of conditions a few generations ago
A Thoroughly Modern Meat Packing Plant

total energy of the solar radiation. The plant really uses but a fraction of this, so that only 1.2 per cent of the total solar radiation reaching the plant is actually returned by it in the form of plant substance.

Slosson, that versatile American interpreter of science, states that the wind motor converts into usable energy only 15 per cent of the power of the wind that reaches it. The steam engine returns but 13 per cent of the energy of coal while the water turbine yields 70 per cent of the energy it receives in the water which turns it.

These facts all show that high efficiency is most infrequent. They lead the chemist to hope that he may in his laboratory evolve more efficient methods. There is some evidence that this will sometime be more than a hope. In the meantime the meat-producing animal must, taking all things into consideration, be considered a relatively economical producer of human food.

FURTHER CONTRIBUTIONS OF MEAT-PRODUCING ANIMALS TO MAN'S NEEDS

The story of the chemist and his rôle in adapting the meat-producing animal to man's needs would not be complete without reference to those things other than meats and fats which the meat-producing animal furnishes.

In the early days of the livestock and meat industry the product of meat animals was carcass meat and fats, such as lard. There were no by-products excepting hides. These were used from earliest times for leather to serve man as clothing and later in many other ways. All other offal parts were discarded unused. As the meat packing industry began to develop in centers such as Cincinnati and later Chicago, the chemist be-

gan to find employment in the industry. His influence, together with competition and pressure from the communities surrounding meat packing plants, brought about the utilization of more and more parts of the animal.

In addition to carcass meat, there are other parts of the animal which are edible, nutritious, and toothsome articles of food. Beef and calf tongues are used fresh, cured or smoked, and also in certain sausages. Tongue and cheek trimmings also may be used in sausage. The brains of beef cattle are considered delicacies by many. Palate meats and soft palates are used in canned meats and certain sausages. The gullet, or esophagus, and the windpipe, or trachea, have attached to them muscle tissue which can be used in economical canned meats and sausages. Sweetbreads, livers, kidneys, and even the spleen are used directly as food or used in some sausages and canned meats. Hog ears, lips, snouts, and feet are carefully cleaned and used as pickled delicacies or in some sausages. These are all good articles of food and add to the total food produced by the meat animal.

FAT PRODUCTS

In addition to lard, lard compounds, oleo stock, oleomargarine and other edible fats, the fatty tissues of the animal reaching the packing house yield many other products of value. Among these are lard oil, tallow oil, tallow stearin, and other industrial oils, greases, and lubricants. These fats are also a source of soaps of all kinds. Oleo oil from oleo stock serves for use in oleomargarine, as does neutral lard. This oleo oil is richer in Vitamin A than any other animal body fat. These last two fats are very fine in flavor and keep

better than almost any shortening agents known. In addition, they, together with other high-class lards, are unsurpassed as shortening agents.

Oleo stearine, the solid fat pressed out of oleo stock, serves for use in lard compounds and substitutes, pastries, confections, candles, delicatessen products, as well as by tanners. Creams for toilet preparations and cosmetics, illuminating oils, and leather dressings are also made from animal fats. Cracklings, the tissues left after pressing out the fat, are used in chicken feed and occasionally with six times their weight of flour in making a certain kind of bread.

Last but not least, the fats serve as a source of glycerin. The chemist has shown how to separate the glycerin from the fatty acid with which it has been combined in the fat. He uses the glycerin in soap, for toilet preparations, as a solvent for many things and as a source of explosives in the form of nitroglycerin and dynamite.

HIDE AND LEATHER PRODUCTS

The early use of leather has been mentioned. Skins and hides have served man in many useful and honorable ways and in some that were useful but not so honorable. An example of the latter is found in the account of Jacob's deception of Isaac at the time the latter wished to pass his blessing and the leadership of his tribe on to Esau, his eldest son. Esau was a hairy man and to make the deception complete it was necessary for Jacob to cover the back of his hands and arms with hairy goat skin so that his father in blessing him with the laying on of hands would be led to believe that Jacob was Esau.

In addition to the use of hides and skins for leather, clothing, shoes, gloves, harness, books, ornaments, and

so forth, a water soluble hide glue is made therefrom. The basic substance of hides and skins, aside from the hair and epidermis, is a protein known as collagen. When boiled with water a gelatinous substance or glue is formed. Glue was used by the cabinet makers of Egypt over 3,000 years ago. Its use is perhaps of even greater antiquity. The fleshings scraped off the inner side of hides also yield glue. The source here is the connective tissue which also contains much collagen. Hide material and fleshings may be used as tankage and as fertilizer. Some of the better grades of skins are used for gelatin, clean pig skin being a standard source of the best grade of gelatin.

Sheep skins, of course, yield wool and leather, two of our most valuable sources of clothing for man. The wool must be cleansed in the wool house. The scourings, when properly treated and purified, yield lanolin which is much in demand as a basis for cosmetics.

HAIR AND BRISTLES

Hair and bristles of cattle and hogs find many uses such as brushes, carpet sweepers, cushions, pads, mattresses, horse collars, felt, and upholstering, and as a binder and retarder in plastering. Some may also be used for fertilizers. Cattle switches are turned into curled hair and hair products. The fine hair from the ears of cattle serve for art brushes in lieu of camel's hair.

HORN AND HOOF

The outer part of horns and hoofs and the dew claws contain a protein, keratin, which cannot be converted into human food excepting indirectly through the hoof meal used in fertilizers. The larger pieces are steamed and laminated and used for hairpins, combs, brush and

knife handles, snuff boxes, imitation tortoise shell, and novelties and decorations too numerous to mention.

BONES AND SINEWS

Bones and sinews yield many products of use to man. Mention has already been made of the use of bone in fertilizers and feeds. In addition the ash free material of bone, being largely ossein, a protein allied to if not identical with collagen, yields gelatin or glue on boiling with water. The ash that has been removed from the bone by the action of acid is largely calcium phosphate. This is recovered for use in phosphate baking powders and fertilizers. Sinews contain large amounts of collagen and horn piths, being really bone, do also. Therefore they serve for use as gelatin, glue, or fertilizer.

The finer grades of bone serve for knife handles, tooth brush handles, knick-knacks, buttons, imitation ivory, mah jongh sets, mouthpieces for certain musical instruments, and decorations and novelties of sundry kinds. Certain bone preparations are used for case hardening steel and bone black is used for refining purposes. An ink much like India ink is made from charred bones. Shin bones, knuckles, and foot bones also yield bone oil and neat's-foot oil, a valuable leather dressing.

PRODUCTS FROM BLOOD

In addition to its use as a fertilizer and in calf and poultry feeds and even in sausage and blood puddings as human food, blood finds many other uses. It serves as a plastic for buttons and novelties and, when properly prepared, for certain paints. The blood contains

a number of proteins, the one that causes blood clotting being known as fibrin. When blood clots this fibrin removes other materials leaving blood serum which serves as a source of certain blood albumins used medicinally and as a waterproofing for certain fabrics such as leather. A preparation of blood is used to give a certain red shade of leather and a black polish for shoes contains a packinghouse product from a similar source. From blood a waterproof glue is made that finds much use in connection with veneer woods. A high grade glue is made from blood albumin.

STOMACHS AND INTESTINES

The contents of the stomachs and intestines of livestock are sometimes used in fertilizers. The slimes collected when making casings from the intestines are used in high grade fertilizers. The contents of the paunch of cattle, consisting to a large extent of hay and straw, serves as a source of straw board. The first and second stomachs of cattle and sometimes the stomach of the hog, when properly cleaned and prepared, yield tripe which many people consider a delicacy. Stomachs are sometimes used as food containers. Weasands, or trachea, may serve as casings for sausage, or as snuff containers. Bladders are used as sausage containers, putty containers, and in some European countries as containers for lard and butter.

The intestines of the sheep and sometimes of hogs and cattle are carefully prepared and cleaned, freed from fatty and connective tissue and mucous lining, and turned into very serviceable containers for sausage known as casings. The large gut treated similarly may serve as bologna casing or putty containers.

Sheep intestines, in addition, are used in making "cat-gut" and ligatures. Thus they serve mankind in binding up the wounds made by the skilled surgeon in his alleviation of mankind's suffering. This gut material is used in tennis racquets, as drum snares, and as strings for such musical instruments as the guitar, harp, cello, violin, and ukulele. This would seem to cover almost everything from the sublime to the ridiculous.

The bung gut and caecum yield a fine tissue known as gold beater's skin. This tissue is also used in making covers for perfume bottles. The best grade of this tissue serves as a gas-proof fabric for use in air ships as containers of hydrogen and helium. A vast number of these skins were used in lining the gas bags of the Shenandoah and Los Angeles.

PHARMACEUTICAL PREPARATIONS

Perhaps the most interesting and marvelous use to which animal products are put is in the preparation of pharmaceutical and glandular preparations. The chemist has collaborated with the physiologist and physician in developing this field. The subject would make entrancing reading since it deals with the effects of the mysterious materials elaborated by certain glands and their magic effects upon the functioning, growth, and development of our bodies. Space will permit but a short reference to these products.

DIGESTIVE ENZYMES

Animals, such as man and the domestic animals, digest food by means of digestive enzymes. It sometimes happens that a person experiences difficulty in

digesting food, due to a lack of some of these enzymes. The meat packing plant is a never-failing source of material which can be used to supply the enzyme needed. Thus pepsin, a protein digestant, is prepared from the lining of the hog's stomach, and rennin or rennet from the stomach of the calf. The latter curdles or coagulates milk and is used in cheese making and in making a tasty dessert from milk. The pancreas serves as a source of three digestive enzymes: trypsin, which digests protein; amylase, which digests starch; and steapsin, which aids in the digestion of fat.

INSULIN

The pancreas is the source of insulin which is proving such a great aid in helping the physician to conquer diabetes, that disease in man which brings with it the inability to properly use sugar in the body.

OTHER GLANDULAR PRODUCTS

Ox-gall is used in making ox-gall soap and in certain pharmaceuticals such as bile salts for increasing bowel activity. The adrenal glands, located near the kidneys, are a source of adrenaline or epinephrine which is used in surgery to insure a bloodless field for certain operations. The thyroid gland of sheep has long served to cure or prevent certain types of disease resulting from thyroid insufficiency such as Cretinism. In the brain cavity two important glands are located, the pineal and the pituitary. The latter is responsible for abnormal development of men. If the gland does not function sufficiently during infancy a dwarf will result. If it functions too well the individual will turn out to be a giant. Theoretically this gland can be used

to control the size to which one can grow. Alice in Wonderland must have eaten cakes containing this gland when she grew so large that she filled the room. In practice, however, great danger attends the use of this gland and chemistry as well as medicine has much to learn about it.

The pituitary gland is really two glands in one. The above paragraph has dealt with the front part or anterior lobe. The posterior lobe yields a substance which has a tremendous action on the smooth or involuntary muscle. Under the name of pituitrin it is used at times to assist in child birth, to increase the tone of a lazy intestine, or for its effect upon the bladder.

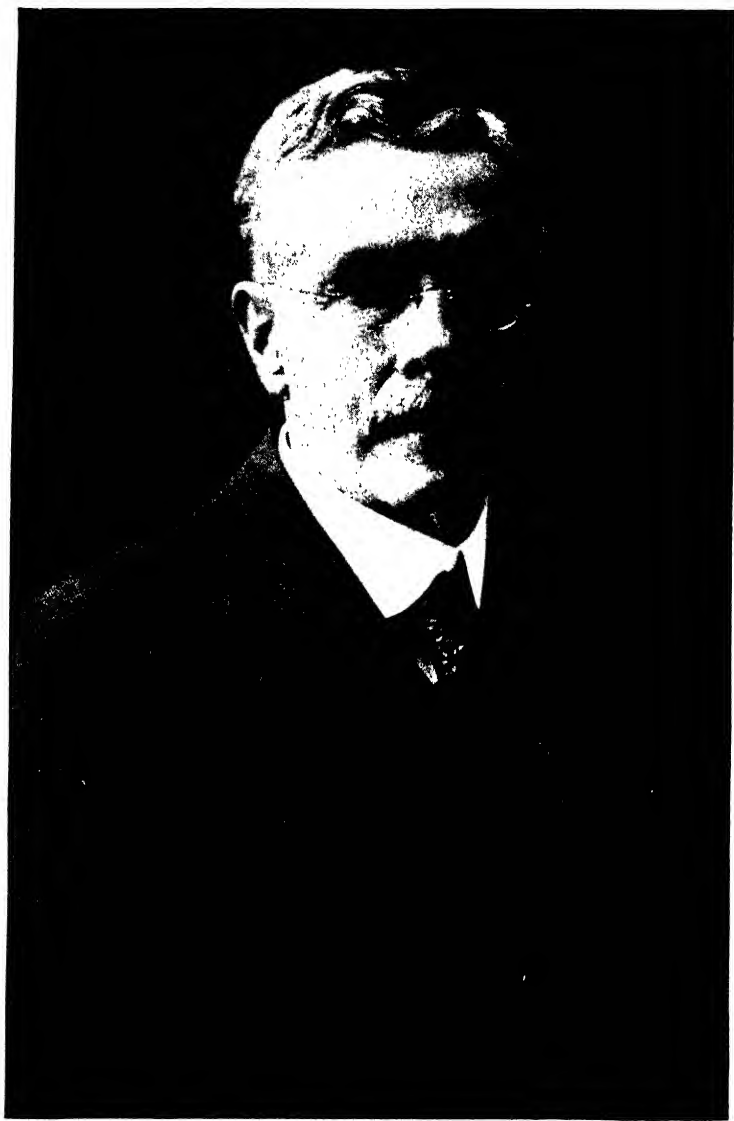
The pineal body is finding some use also. Its exact function is not known, but there appears to be an interrelation between this gland and the sex glands and other glands. In fact most of these glands of internal secretion react upon one another as well as directly upon some one or other of man's functions.

Extracts of the corpus luteum from the ovaries of cows as well as preparations of the ovaries themselves have been used for pharmaceutical preparations. A great stride forward has recently been made by Doisy, a physiological chemist, and Allen, an anatomist, in extracting a substance, or hormone, from ovaries.

THE PLACE OF THE MEAT ANIMAL

In summing up it can safely be written that the meat-producing animal converts food that is inedible for man and also economic surpluses of edible food into nutritious, concentrated foods such as meat, fats, and similar products. It also furnishes shortening, leather, wool, hair, industrial products, lubricants, animal feeds, fertilizers, gelatin, glue, parts of musical

instruments and pharmaceutical products of great usefulness and value. All this could not be done without the aid of the chemist. The chemist has also shown that the meat-producing animal is not an uneconomical producer of food as food producers go. Taking everything into consideration, the human race must acknowledge its indebtedness to the meat-producing animal and to the chemist for his part in making the fullest use of the animal and its products.



DR. HENRY PRENTIS ARMSBY

CHAPTER XIV

CHEMISTRY AS A GUIDE IN ANIMAL PRODUCTION

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THE GENERAL PROBLEM—METHOD AND APPARATUS

Farm animals are produced and maintained for their capacity to convert crude feed products into palatable and wholesome human food, for the work which they perform, and for the hides and wool which they produce.

In the light of the fact that the farm animals of the United States eat about four times as much food—on an energy basis—as the human population it is obvious that the efficient and economical feeding of those animals is of surpassing importance, especially in times of economic stress. The difference between the efficient and the careless feeding of the farm animals might represent an amount of nutriment equivalent to the requirements of the entire human population.

Anyone who knows even a little chemistry will understand that profound chemical transformations of nutrients must take place within the animal body during the conversion of the feed into muscle, fat, milk, eggs, wool and work. Chemistry, therefore, fur-

nishes a natural means for measuring nutritive values of feeds, and nutritive requirements of animals.

But since nutrition is such a vastly complicated process, complete and detailed statements of the nutritive requirements of animals would be so cumbersome as to be utterly useless for any practical purpose.

It is necessary, therefore, that means be found for simplifying such statements, so that they can be readily grasped by the mind, and so that they can be used with convenience and reasonable accuracy in relation to practical animal production.

Various methods have been proposed for evaluating animal feeds, but the most convenient and scientific of these is afforded by what is known as the net energy conception of Armsby.

The late Dr. H. P. Armsby, former director of the Institute of Animal Nutrition of the Pennsylvania State College, was one of the world's foremost students of animal nutrition and from his long and productive career the contribution which promises to be of greatest service is that to which we have already referred as the net energy conception.

In order to grasp this subject let us bear in mind the fundamental fact that when a food substance is burned in the air it gives off a certain amount of heat, the quantity depending on the composition of the food, and called the heat of combustion. When food substances are utilized for energy production in the animal body the process is likewise one of oxidation, the amount of heat produced being exactly the same as when they are burned.

Armsby's idea was, that by measuring all of the expenses and losses of food utilization, in terms of energy, and subtracting these from the gross energy of the food, the remainder would represent the net

value of the food to supply energy, for purposes of maintenance and production, and would also constitute a very useful and significant measure of nutritive value generally.

Such a determination of net energy value involves, essentially, a balancing of outgo against income, as in book-keeping,—but in terms of energy, instead of dollars and it is the simplest, most inclusive, and most scientific of all general measures of nutritive value.

The justification for the use of net energy values as measures of food value generally is that, no matter what the purpose for which an animal is fed, several times as much nutriment is used directly and indirectly for energy-production as is used for any other purpose or all other purposes combined.

As for the significance of energy in relation to animal life—the first thing that we notice in regard to a living animal is that it is warm. This elevated temperature, which is essential to the processes of life, is maintained through the expenditure of energy of food or of body tissue. The circulation of the blood, the respiration, and all of the visible movements of the body occur through expenditure of energy.

The source of the energy of the living animal is obviously the food, the utilization of which requires the expenditure of energy,—on account of prehension, mastication, deglutition, rumination, fermentation, secretion, digestion, peristalsis, metabolism, dynamic stimulation, and excretion.

Throughout the development of an individual animal there must be growth—a storage of energy, in anticipation of future requirements; and if the animal's kind is to persist upon the earth there must be reproduction—which is a manifestation of energy in pro-

cesses of a complication exceeding, perhaps, the possibilities of human knowledge.

Life itself, in a physical sense, being but a manifestation of energy, what is more appropriate than that we should measure foods in terms of their capacity to contribute useful—that is, *net* energy? In this sense fat is stored energy; proteins and minerals are building materials for the construction of working parts; and vitamins may be likened, with a partial measure of appropriateness, to lubricants.

It is true that we do not feed animals, except those kept for work, directly for energy production, but nevertheless, the energy-producing value of foods constitutes a most important and practical measure of nutritive value generally.

All of the organic compounds of the feed contribute to its net energy value,—fat, carbohydrate and protein. The energy of nutrients utilized for tissue growth is considered as net energy and these nutrients finally yield energy as the tissues are broken down and oxidized in the course of normal wear. Net energy values, therefore, cover, in a way, protein as well as non-nitrogenous nutrients.

But since the net energy value of a feed expresses its worth for only the one class of requirement implied by its designation (net energy) it is necessary, in making a complete statement of the nutritive requirements of an animal, to consider and to include also protein (in the specific sense), mineral nutrients, and vitamins.

It is well, however, to observe that any measure of nutritive value is but a device of convenience,—that in the most critical sense it is illogical to compare the nutritive values of feeds, since, in this sense, feeds, and rations, being characterized by different attri-

butes, are not logically comparable, the measurement of their nutritive values constituting, therefore, entirely separate problems; but so meticulous a point of view is quite out of place in practical, scientific considerations.

As to constancy, it is known that net energy values of feeds do differ, somewhat, in accord with the individuality of the animal, the plane of nutrition, and the physical conditions of feeds (as related to digestibility and energy-cost of utilization); and, also, the protein, vitamin and mineral nutrient combinations of rations may affect net energy values. While the net energy conception does not necessarily imply a denial of the existence of these factors, the general use of net energy values either considers them apart, or as negligible.

The net energy values of feeds for different kinds of animals, and for different kinds of production, do differ materially, however, and, for consistent use, must be separately determined.

Net energy values stand in an interesting relation to the temperature of the environment. The statement of a net energy value of a feed assumes that the temperature of the environment is sufficiently high, so that the waste heat of feed utilization will maintain the normal body temperature, there being, therefore, no use of feed directly for heat production.

These conditions commonly prevail in profitable practice and constitute the only practicable standard. Under other conditions, that is, when the housing or other protection, and the waste heat of feed utilization, are insufficient to maintain the animal's body temperature, the net energy values (which presuppose "normal" conditions) would not apply.

Since the animal's maintenance requirement of

energy is "net" those effects of treatment which increase or decrease the maintenance requirement alone do not alter net energy values of feeds. Thus, the following factors might affect the quantitative feed (maintenance) requirement of an animal but would not affect the net energy value of the ration: exercise, as affected by fatness, sex, temperament, breed and type; light as a stimulus to metabolism; and age, as affecting intensity of metabolism, especially oxidative functions.

The experimental method employed in the determination of net energy values of feeds is based, as already suggested, on Lavoisier's conception that heat production in an animal is essentially a process of oxidation, or slow combustion, of food material or body tissue, and Rubner's demonstration that this combustion proceeds on the same terms within an animal as without, which is nothing else than a confirmation of the law of conservation of energy.

The total chemical energy of the feed is represented by its heat of combustion. Part of this energy escapes the animal unused in the visible excreta and in the combustible gases. The remainder is available for the needs of the animal. Of this available energy those parts which are used for maintenance, and for that increase of energy expenditure which is always caused by the consumption of the feed, are converted into heat, and are eliminated as such. The balance may be retained by the animal in the form of material increase, such as flesh or milk.

According to the net energy conception all the increased heat production caused by the consumption of feed is considered a waste, since it is not utilized by the animal, either for maintenance or production, and must be subtracted, together with the energy of the

excreta, from the energy of the feed, to obtain its net energy value.

Since the efficiency of utilization of feed for the different nutritive purposes, such as maintenance, body growth, and milk production, has been found to differ characteristically it is necessary to determine separate net energy values for these purposes; thus in order to determine the energy expenditure caused by a feed for maintenance the heat produced by the fasting animal is compared with the heat produced by the same animal while receiving a maintenance ration. This increase in heat production represents the energy cost of utilization of the feed for maintenance. A similar comparison of the heat produced by the animal on maintenance with that produced on a supermaintenance ration gives the energy cost of utilization of the feed for body increase.

For example, a steer while fasting produced daily 6265 Calories of heat. The same steer while receiving 3.51 kilograms of timothy hay and grain (a maintenance ration) produced 8352 Calories, and while receiving 5.72 kilograms of the same feed mixture (a supermaintenance ration) produced 10704 Calories of heat per day. The difference between 8352 Calories (maintenance) and 6265 Calories (fasting), or 2087 Calories, represents the energy cost of the utilization of the feed for maintenance, which is 595 Calories ($2087 \div 3.51$) per kilogram of feed. Similarly, the difference between 10704 Calories (supermaintenance) and 8352 Calories (maintenance), or 2352 Calories, represents the energy cost of utilization of 2.21 kilograms ($5.72 - 3.51$) of the feed for body increase, or an energy expenditure of 1064 Calories per kilogram of feed.

To carry the illustration a little further, if from the

gross energy of the feed, 16000 Calories, are subtracted the losses of energy, in feces, urine and combustible gases (methane), 7158 Calories, and also the energy cost of feed utilization, 2087 Calories, the remaining 6755 Calories (1925 Calories per kilogram) constitute the energy actually utilized by the animal for repair of body tissue, that is, for maintenance.

In a similar manner, by subtracting all corresponding losses of energy while on the supermaintenance ration from the gross energy of the feed, the energy actually utilized by the animal for body increase was found to be 1375 Calories per kilogram of feed.

The apparatus required for the determination of the net energy values of feeds, or, more specifically, for the measurement of the heat produced by the animals, and of the gaseous excreta, is known as the respiration calorimeter. Such an apparatus is in use at the Institute of Animal Nutrition of the Pennsylvania State College, and is the only calorimeter now in use in the world of a size sufficient for the larger farm animals.

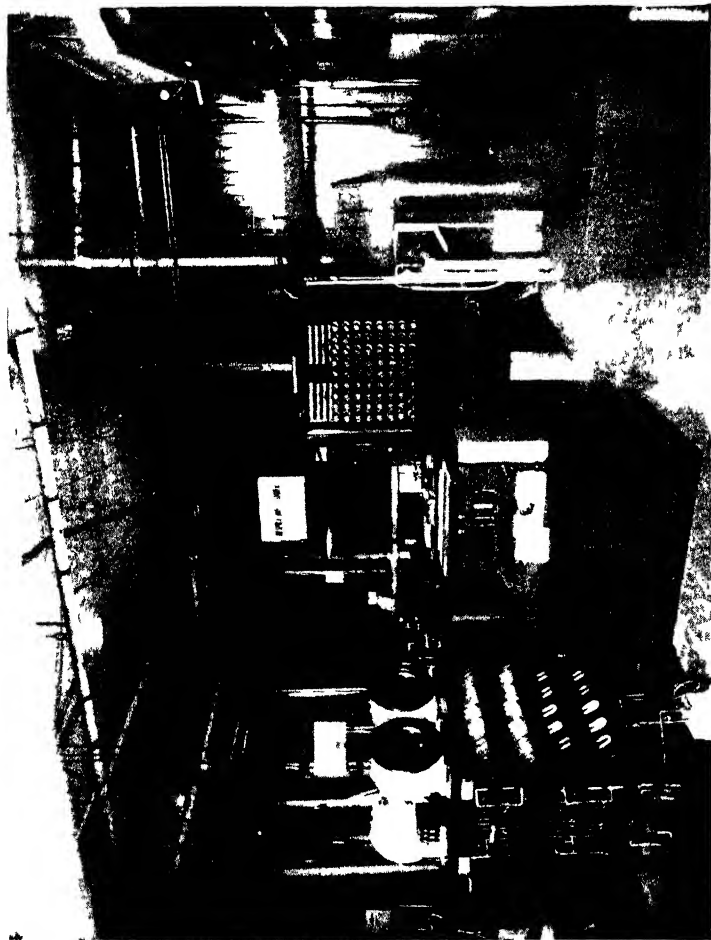
The calorimeter consists of the respiration chamber, in the background, and accessory equipment.

Beginning at the reader's left—the large cylinders are aspirators for taking samples of the air as it leaves the chamber.

The rotary meters for measuring other air samples, both incoming and outgoing, are below the placard. In front of the meters, in a small glass case, is apparatus for registering the number of revolutions of the meters; below the meters are absorption tubes for determining the moisture and carbon dioxide in the air samples; and below these tubes, on the floor, are suction pumps which draw a sample of the incoming air through absorption tubes, and a sample of the outgoing air first through absorption tubes, then through an electrically heated tube furnace, and then again through absorption tubes,—both samples being finally delivered to the air meters.

At the right of the air meters, and lower down, are cylindrical water meters used to measure the water which carries the heat out of the calorimeter; and above these water meters are valves for regulating the flow of cooling water through pipes in the air spaces of the calorimeter walls.

The window in the chamber is at the animal's head, and permits the operator to observe its position and behavior. A thermometer may be seen through this window, hanging inside the chamber.



View in Respiration Calormeter Room.

At the right of the window (not visible) are thermometers for determining the temperature of the water as it enters and as it leaves the heat-absorbing coils inside the chamber.

On the table below the window are electric switches, Wheatstone bridge and galvanometer scale; and at the end of the table is a program machine which rings bells or buzzers as signals that readings are to be taken.

The square of electric lamps in the center of the picture provide resistance in the several circuits which heat incoming air, or the air in the wall spaces.

Behind and to the right of these lamps is the galvanometer; and the cylinder at the right is filled with sand to furnish a solid base for the instrument.

In the lower right-hand corner is the brine tank, cooled by an ammonia coil, and used to lower the temperature of water entering the heat absorbing coils in the chamber.

The vertical pipe above the bank of lamps is the incoming air pipe, surrounded by a cooling jacket, the heating coils being inside this air pipe; and the horizontal pipe at the right of the lamps is the outgoing air pipe as it runs to the air-circulating pump.

Important pieces of apparatus not shown in this view are the air-circulating pump, the tube furnace for burning the methane out of an air sample, the refrigerating machine, the box for freezing the moisture out of the incoming air, the clock which times the experiment and runs the program machine, and other sets of absorption tubes.

The central feature of the apparatus is a chamber within which the animal stands, or lies, in a stall, provided with feed box and drinking cup, and permitting the same freedom of movement as under conditions of stall feeding.

The chamber is closed by air-tight doors, and has three double walls, the inner of metal, and the two outer of wood, each of the double walls being built to inclose an air space; and these three concentric walls being separated by air spaces, so that there are three air spaces within, and two between these insulating walls.

In the spaces between the double walls are electric heating wires, and pipes for circulating cold water by means of which the temperature of these spaces is so controlled as to prevent the escape of the heat given off by the animal, so that it can be taken out in another way, and measured.

The escape of the heat through the walls is pre-

vented by keeping the air spaces between the walls at the same temperature as the air inside the calorimeter. Throughout both the inner and the middle walls are distributed several hundred iron-German silver thermocouples, connected in series with a reflecting galvanometer, and serving to indicate any difference in temperature between the inner and the outer surfaces of these walls. If the temperature inside the calorimeter rises, the operator heats the air in the spaces between the walls; and if the temperature inside the calorimeter falls, the temperature of the air spaces between the walls is lowered. The heating of the air spaces is done by passing an electric current through the resistant wires, and the cooling is done by circulating cold water through the brass pipes. So long as the temperature in the spaces between the walls is kept the same as that inside the calorimeter there will be no flow of heat either in or out.

The temperature inside the calorimeter is measured by means of a series of copper resistance thermometers connected to a slide-wire Wheatstone bridge and is also read on a mercury thermometer which hangs within the chamber, and which is visible through a window. This thermometer is graduated to fiftieths of a degree Centigrade.

Air is supplied to the animal by drawing through the calorimeter a steady stream of 400 to 700 liters per minute, by means of a special pump. The number of strokes of the pump is recorded on a cyclometer, the volume of the air moved at each stroke having been accurately determined.

The loss of heat from the calorimeter, in the air stream, is prevented by maintaining the temperature of the ingoing air the same as that of the outcoming

air, by means of devices similar to those used for regulating the temperature of the air spaces between the walls surrounding the calorimeter; that is, the ingoing air is heated, or cooled, to the same temperature as that of the outcoming air.

By thus preventing the loss of heat through the walls, or in the air stream, it is possible to remove and to measure the heat given off by the animal by passing a stream of cold water through a system of copper pipes inside the calorimeter. Access of air to these pipes is regulated by means of shields which can be raised or lowered, from the outside, by the operator. By raising or lowering the shields, or varying the flow of water through the heat-absorbing pipes, the rate at which heat is removed may be so regulated as to keep the temperature of the interior constant within a few tenths of a degree.

The temperature of the ingoing and outcoming water is read every four minutes by means of two mercurial thermometers, graduated to fiftieths of a degree Centigrade; and the volume of water passing through is measured by means of two copper meters, each containing 100 liters. All the sensible heat emitted by the animal, then, is measured in this water current. In addition the latent heat of the water vapor produced by the animal is estimated from the amount of water vapor as determined in the air stream. The sum of these two factors, after applying certain corrections, is a measure of the total heat production.

In order to control the moisture conditions inside the calorimeter most of the moisture is frozen out of the ingoing air before its entry into the calorimeter.

The analysis of the ingoing air is accomplished by drawing a measured portion through absorption tubes,

(b) Temperature readings of the feed and the feed box, as introduced into the chamber.

(c) Temperature readings of the aspirator used for sampling the residual air in the chamber.

(d) Weight of absorption tubes.

IV. Observations made once a day:

(a) Temperatures of the feces and urine as collected.

(b) Weights of the feces and urine, together with their containers.

(c) Temperatures of the empty urine box and feces box as introduced into the calorimeter.

(d) Temperature of the drinking water.

(e) Weight of water drunk.

V. Observations made immediately before the animal enters the calorimeter, and soon after leaving it:

(a) Rectal temperature.

(b) Weight of the animal.

VI. Observations made at irregular intervals:

(a) Time of filling of the water meters.

(b) Position of the animal and time of changing position, as to lying or standing.

(c) Reading of the pointer on the valve by means of which the water-flow in the heat-absorbing pipes is regulated, and time of moving the pointer.

(d) Number of heat units used in heating the ingoing air.

(e) Position of the shield connected with the copper heat-absorbing pipes.

The determination of the heat production of the animal does not terminate, however, with the end of the calorimeter run. The mass of accumulated data is then subjected to a process of computation which, although simple in principle, is much more time-consuming than the calorimetric measurements themselves. The details of this computation cannot be given here; but suffice it to say that before the final figure for the heat production of the animal is obtained all possible sources of error, for which correction can be made, are considered, and proper corrections are applied. The following is the list of corrections which are usually made.

(a) Corrections for difference of pressure on the bulbs of the two thermometers in the ingoing and the outgoing water of the heat absorbing system.

(b) Correction for friction of the water in the heat absorbing pipes.

(c) Correction for lag in the rise or fall in temperature of the water from that at the inlet to that at the outlet of the heat absorbing system.

(d) Correction for change in temperature of the heat absorbing system during the experiment.

(e) Correction for heat developed by the blades of the fan used to stir the air in the calorimeter.

(f) Correction for change in temperature of the walls of the chamber during the experiment.

(g) Corrections for heat introduced into the apparatus or withdrawn from it, in feed, drink, excreta, and vessels containing these materials.

(h) Correction for the metabolism of anyone entering the chamber during the experiment, if this is necessary, for instance, in experiments on milk production, to milk the cow.

(i) Correction for storage of heat in the platform upon which the animal lies, which is applied when the animal is in a different position, as to standing or lying, at the end of the experiment from that at the beginning.

(j) Correction for condensation of water on the heat absorbing system.

(k) Correction for storage or loss of heat due to gain or loss of substance by the animal during the experiment.

In addition to the above corrections, in order to render the values for heat production of the different experimental periods comparable in respect to position of the animal, a special correction is applied, which has been experimentally determined, and which has for its purpose the correction of the heat production to uniform time of standing, per day, a standard day of 12 hours standing and 12 hours lying having been arbitrarily adopted.

After completing the necessary analytical work, and the computation of the heat production for the several experimental periods, we are then ready to proceed with the computation of the net energy value of the ration. The routine of this computation is, briefly, as follows:

(1) The available energy of the ration, usually referred to as the metabolizable energy, is obtained by subtracting from the gross energy of the ration the energy of the urine, feces and methane.

(2) The heat production of the fasting animal is regarded as the net energy requirement for maintenance.

(3) The energy expenditure, or the energy cost of utilization of the feed for maintenance, is obtained by comparing the heat production of the animal on a maintenance ration, with the heat production of the fasting animal.

(4) The energy cost of utilization of the feed for body increase is obtained by comparing the dry matter of the ration and the heat production of the animal in a supermaintenance period with the dry matter and heat production in the maintenance period.

(5) The net energy value of the feed for maintenance is obtained by subtracting from its metabolizable energy the energy cost of utilization, as obtained in (2).

(6) The net energy value of the feed for body increase is obtained by subtracting from its metabolizable energy, the energy cost of utilization as obtained in (3).

RESULTS

The investigations thus far conducted by means of the respiration calorimeter relate to many different aspects of the general problem of animal nutrition, but have had to do mainly with the following problems:

How do different feeding stuffs compare as to their content of energy, as to the proportion of this energy which is available to the animal, and as to the proportion which is actually utilized for maintenance and material production?

Resulting from numerous studies on this general problem are a series of net energy values of a variety of feeding stuffs, including roughages and grains. These net energy values have been determined with steers as the experimental subjects.

The work has shown, with roughages, such as timothy, clover and alfalfa hay, a distribution of the energy, in general, as follows: from 55 to 56 per cent of the total energy of the feed was passed off in the excreta; from 17 to 30 per cent was lost in heat production; and only from 15 to 27 per cent was net, and was utilized for maintenance and body increase. In case of grain rations from 25 to 35 per cent of the

total energy was lost in the excreta; from 23 to 27 per cent was lost in heat production; and from 36 to 46 per cent was net.

While energy used for maintenance is all loss, in a sense, it is of vital importance to know what the maintenance requirement is, because this must always be met, and variation in the amount so spent directly affects the amount available for material production.

The results of fasting studies have shown that the energy requirement for maintenance of cattle is about 1.4 Therms per square meter of body surface, or 7.6 Therms per 500 kilograms live weight.

How do pure-bred and "scrub" steers compare as converters of feed energy into body increase? A study of this subject showed that, fundamentally, the scrub steer was just about as efficient in its utilization of the energy of the feed as was the pure-bred steer, that is, the losses and expenses of feed utilization were about equal, but from a practical point of view the pure-bred animal was the more economical, first, because its maintenance requirement was less, and, second, because it consumed more feed.

The relative efficiency of utilization of feed energy by farm animals for different uses, as for maintenance, growth, and milk production, is also being investigated by means of the respiration calorimeter. The results thus far obtained on the fundamental question of relative utilization of feed energy for body increase and milk production show that in the latter process feed energy is 21 per cent. more efficiently utilized. The results also indicate that it will be possible, by applying the rations established between the efficiencies of utilization for these purposes, to utilize the net energy values of feeds for one purpose in the com-

putation of net energy values and rations for the other uses.

The influence of various external factors on the heat production, and hence on the feeding economy, is being investigated. The importance of the coat of hair of a steer, and of the temperature of the environment, in relation to the use of feed has been measured; and it has been found that the energy cost of maintaining an animal in the standing position is materially greater than when it is lying down—a fact of obvious significance in connection with the conditions of housing or confinement of fattening cattle.

All of the above studies and many others intimately connected with the net energy conception have as their ultimate aim the furnishing of a scientific basis for the feeding of farm animals, and thus for the economical conservation for man's use of the energy of agricultural products.

A question which naturally arises in the mind of anyone who is interested in this subject is as to the applicability of the results of respiration calorimetric studies to the conditions of feeding practice.

Opportunities having presented themselves for obtaining evidence on this question it has been found that the results of these laboratory studies do apply under conditions of stall feeding.

The net energy conception, therefore, has given us a new point-of-view from which to regard and to investigate the subject of animal feeding, and is leading to the establishment of new, interesting and educating facts of the highest degree of scientific and practical significance.

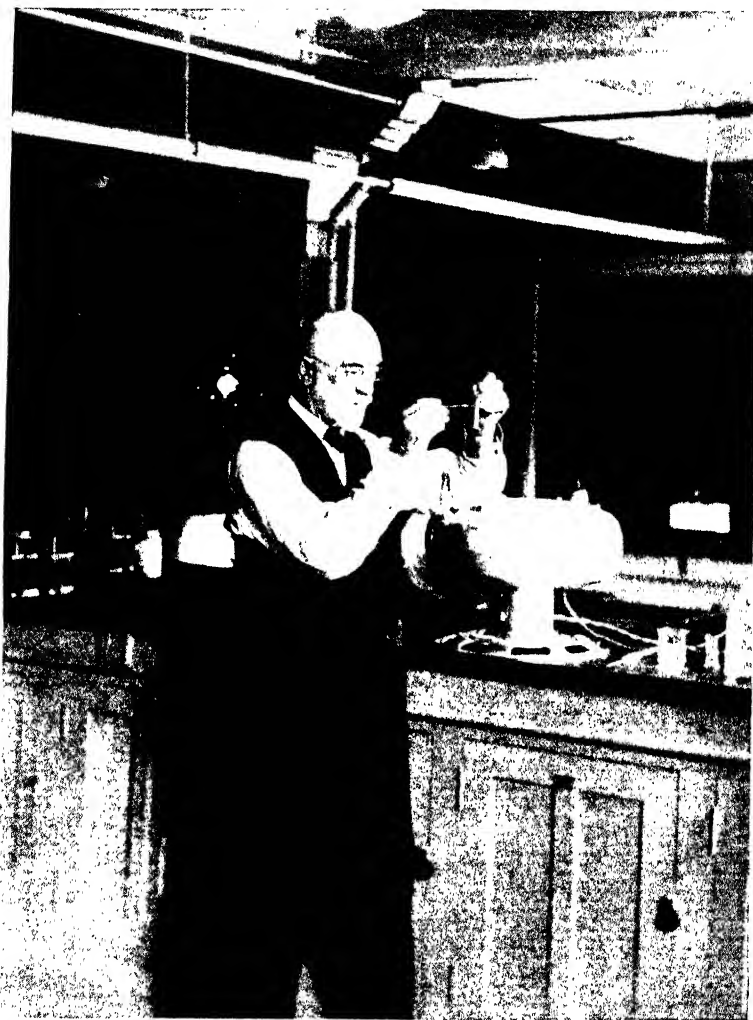


Photo by University Photographic Laboratory, Madison, Wis.

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CHAPTER XV

THE CHEMISTRY OF MILK AND ITS PRODUCTS

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IMPORTANCE OF THE DAIRY INDUSTRY

In 1924 the amount of milk produced in the United States was about 115 billion pounds¹ (equivalent to 57.5 million tons, or 13.4 billion gallons or 53.6 billion quarts). This product came from 26.25 million cows, giving an average annual yield of 4380 pounds per cow. The approximate value of these cows was 1.3 billion dollars and, of the product, 2.75 billion dollars, equal to \$24 for each person in the United States.

The milk was distributed, roughly, in equal parts between that consumed daily for household purposes (so-called market-milk) and that made into dairy products. The amount of market milk averaged annually per person 470 pounds or 220 quarts, equivalent to a daily individual consumption of 1.3 pounds or 0.6 quart.

¹U.S. Dept. of Agr., Bureau of Agr'l Economics, Division of Dairying.

The following table gives the amounts and percentages of milk used in each of the ways indicated:

Table 1. Distribution of Milk in Different Forms of Use.

How Used	Amount of Milk Used, Billion Pounds	Percentage of Total Milk
For household purposes.....	52.8	46.00
For butter.....	41.2	36.00
For cheese (all kinds).....	4.2	3.65
For condensed and evaporated milk.....	4.3	3.70
For ice-cream.....	3.9	3.40
For miscellaneous products (powdered milk and cream, malted milk, etc.).....	0.3	0.25
For feeding to calves.....	4.7	4.00
For losses in handling.....	3.4	3.00
Total.....	114.8	100.00

The rapid growth of the dairy industry in the United States is shown by the fact that the number of cows increased from 10 million in 1870 to over 26 million at the present time.

It is interesting to notice briefly the general way in which the dairy cows are distributed. We find nearly one-half of them in seven States, each having more than one million cows, ranking in the following order: Wisconsin, New York, Minnesota, Illinois, Iowa, Texas, Pennsylvania. The distribution of cows, as well as the character of the industry, is determined by several factors. For example: conditions favoring the production of market-milk and ice-cream, are (1) a large center of population, (2) efficient transportation facilities, and (3) cows with good production; as found in the Eastern, Middle, and Middle-Western States. Production of butter, cheese and concentrated forms of milk thrives, especially, where (1) the population is less dense, (2) grazing conditions are favorable and (3) grain is economically grown. These conditions hold in the Central-Western States, in which two-thirds of our creameries are located.

THE COMPOSITION OF MILK

Before methods of chemical analysis were developed, the composition of milk could be known only in the crudest way. Common observation indicated that milk contains: (1) *fat*, for butter could be made from it; (2) *curd*, the white substance separating when milk sours, which was associated with cheese; and (3) *whey*, the yellowish liquid remaining when the curd of sour milk is removed. It was not known what chemical compounds made up fat, curd and whey.

The application of chemistry to the study of the composition of milk has revealed the fact that normal milk contains more than twenty individual compounds, which can be distributed in the following classes: (1) water, (2) fat, (3) protein or nitrogen compounds, (4) milk-sugar or lactose, (5) salts, (6) gases and (7) miscellaneous compounds.

The amount of each of these constituents in milk is found to vary widely, depending on such conditions as individuality of cow, kind of breed, stage of lactation, age, character of food, amount of water drunk, state of health, care, etc.

WATER in milk varies in amount from about 86 to 88 per cent., in the case of the milk of herds of cows, while, in case of single milkings of individual cows, it may range from 82 to 90 per cent.

Under the general term, *total solids* or *milk solids*, are grouped the constituents of milk other than water.

MILK FAT (less properly called butter fat) is not a single chemical compound, but is a somewhat variable mixture of about ten different compounds called *glycerides*, in which glycerin is combined with different organic fatty acids. Milk fat contains about 12.5 per cent. of glycerin thus combined in these different

glycerin-acid compounds. The proportions of these individual glycerides vary and this variation affects the quality of the milk fat, such as hardness or softness, and, in the case of the combined acids present, solubility in water and volatility when heated. These differences are made use of in distinguishing pure from artificial butter, because milk fat contains a larger proportion of the volatile soluble acids and a smaller proportion of the non-volatile insoluble acids than those other forms of animal fat commonly used in making imitation butter.

Milk fat is present in milk, not in solution, but suspended in the form of very small transparent globules, most of them varying in diameter between one-twenty-five hundredth ($\frac{1}{2500}$) and one-fifteen thousandth ($\frac{1}{15,000}$) of an inch. In one drop of average milk there are estimated to be more than one hundred million fat globules. The size and number vary with the same conditions that influence the percentage of fat in milk. These minute globules have no membranous covering, as was once believed, but are simply very small particles of fat floating free in milk in the form of an emulsion. Each globule is surrounded by a very thin layer of protein condensed on the surface by surface attraction or adsorption.

Normal milk varies greatly in fat content, going below 2 and over 8 per cent. in case of single milkings of individual cows. In the case of milk from herds of cows, the milk fat varies usually between 3 and 5 per cent. The percentage of fat in milk is influenced by individuality, breed, age, lactation, time between milkings, portion of milk drawn from the udder, etc. The following figures illustrate the variation of percentage of fat in the normal milk of some different breeds of cows.

Table 2. Milk Fat in Milk from Different Breeds of Cows.

Name of Breed	Per cent of Fat in Milk		
	Average	Lowest	Highest
Holstein-Friesian.....	3.36	2.88	3.85
Ayrshire.....	3.60	3.20	4.24
Short-Horn.....	4.44	4.28	4.56
Devon.....	4.60	4.30	5.23
Guernsey.....	5.30	4.51	6.13
Jersey.....	5.60	4.96	6.09

Milk first drawn from a cow's udder contains 1 to 2 per cent. of fat; that last drawn, from 8 to 9 per cent.

Proteins in milk consist mostly of *casein* and *albumin*.

MILK CASEIN is the most important protein or nitrogen-containing compound in milk, because (1) it is the one present in largest quantity; (2) its presence makes it possible to convert milk into cheese; (3) it has a high value as human food; and (4) it has numerous valuable commercial uses.

Milk casein is most familiar to us in the form of the solid white substance, called curd, which appears in milk when it sours. It is a very complex chemical compound, containing the elements, carbon, oxygen, hydrogen, nitrogen, sulphur and phosphorus. Casein is present in milk, not in solution, but in the form of extremely small, solid, gelatinous particles in suspension. The slime found in the bowl of a centrifugal separator, after milk has been passed through it, in the process of removing fat, consists, to a considerable extent, of milk casein.

When milk sours in the ordinary way, lactic acid, formed by the action of certain bacteria, causes the casein to separate in a solid, white mass. Any dilute acid added to milk has the same effect. Solutions of alkali compounds, such as sodium bicarbonate, ammonia, caustic soda, etc., form compounds with casein

that dissolve easily in water. Some of these and other compounds of casein have important commercial applications.

The formation of a peculiar skin on the surface of milk, heated above 140° F. (60°C.), is largely due to the casein in the milk.

One of the most characteristic properties of milk casein is its coagulation by the chemical ferment, *rennin*, contained in rennet extract, which is prepared from the mucous membrane of a calf's stomach. This property furnishes the basis of the process used in making most kinds of cheese.

Commercial casein is prepared mostly from skim-milk, but, to some extent, from buttermilk also. It is separated by means of a dilute acid, drained from the whey, washed with water and, after more or less drying, goes to market. It finds increasingly extensive use in a great variety of ways, as in paints, glues, imitation ivory and celluloid, food and medicinal preparations, paper sizing, photographic materials, water-proofing cloth, imitation leather and linoleum, imitation mica, etc., etc.

MILK ALBUMIN resembles casein in being a protein but differs from it in various ways, especially in that the albumin, (1) is in solution and (2) is not coagulated by acids at ordinary temperature or by rennet extract, and (3) is coagulated by heat. As a by-product from the manufacture of milk sugar, it is used as a poultry-food.

MILK SUGAR, also called *lactose*, is present in milk in solution. In its general composition, it resembles ordinary sugar, but it is less sweet and less soluble in water. The amount of sugar in cow's milk varies between 4 and 6 per cent. and averages about 5.

In its relations to dairy products, especially butter

and cheese, the importance of milk sugar is due to the ease with which it is converted into lactic acid by certain kinds of bacteria. In the ordinary souring process, the amount of milk sugar decreases by bacterial action somewhat more than one-fourth and there is formed a maximum of nearly one per cent. of lactic acid.

The milk sugar of commerce is usually prepared by evaporating whey obtained from cheese-making or from preparation of commercial casein and then purifying the crude product. It is used principally in food preparations for infants and in mixing with drugs for powdered medicinal preparations.

SALTS of milk, commonly included under the statement of analysis as "ash" or so-called mineral constituents, are present, on an average, to the extent of about 0.90 per cent., equivalent to about 0.70 per cent. of ash. The salts of milk include such compounds as sodium and potassium citrates, sodium chloride, potassium, calcium and magnesium phosphates, etc. These salts have important relations to milk and its products, especially in the feeding of children.

GASES of milk include carbon dioxide, together with some oxygen and nitrogen carried into the milk mechanically from the air in the process of milking. In the normal milk contained in the udder, there is present by volume about 10 per cent. of carbon dioxide, existing in part as gas and in part as sodium bicarbonate. In the process of milking, a considerable portion of the gas escapes under ordinary conditions, leaving between 3 and 4 per cent. in the drawn milk. This is further decreased by heating.

MISCELLANEOUS COMPOUNDS. There are several other compounds normally present in milk in small amounts, which have little or no known practical interest; but

among these there is an exceptional group of substances, called "*accessory food factors*" or "*vitamins*," the presence and value of which have been discovered only recently. The accessory most prominent in milk is known as "*fat-soluble*" because it is more concentrated in cream and butter. This substance is necessary for the normal growth and reproduction of animals. In its absence, children have a tendency to develop rickets and also, in some cases, a certain form of bacterial eye disease may appear, probably due to a weakened resistance of the tissues. These facts have served to emphasize the value of milk and its products as a food.

METHODS USED IN TESTING MILK AND MILK PRODUCTS

The word "*testing*" has come to be used in the dairy industry in the general sense of quantitative estimation of certain constituents, both normal and abnormal, in milk and milk products. Previous to 1890, the methods available were chiefly such as could be used only by a trained chemist.

It was known in a vague and limited way that milk varied greatly in the percentage of its constituents and that different milks had different values both as food and as a source of dairy products; but accurate, practical methods for learning these differences in value were not available.

Attention was first given to a method for finding the amount of fat in milk and, out of the various attempts, was evolved the "*Babcock Test*" in 1890, which was devised by S. M. Babcock, Ph. D., Chief Chemist of the Wisconsin Agricultural Experiment Station. This method is based on the action of two agents: (1) the chemical action of sulfuric acid upon the constituents

of milk-serum (proteins, sugar, etc.) and (2) the mechanical action of centrifugal force. The sulfuric acid changes the solids of the milk-serum to such an extent as to destroy the strongly adhesive effect which these compounds have in holding the fat globules in the form of the milk emulsion. This action of the acid enables the fat globules to collect in a mass. The application of centrifugal force in a machine designed for the purpose completes the separation of the fat from the other milk constituents. A definite amount of milk (17.5 cubic centimeters, equal to 18 grams) is measured by means of a special pipette into a test-bottle of particular design with a graduated neck, so that, when the test is completed, the percentage of fat can be read directly from the graduated scale. The sulfuric acid (17.5 cubic centimeters, of 1.82 to 1.83 specific gravity) is measured in a special cylinder and added to the milk in the test-bottle and carefully mixed. The mixture is then centrifuged, the fat rising to the surface. Enough hot water is now added to the liquid in the bottles to bring this fat into the graduated neck. After another centrifuging the per cent. fat can be read at once.

The details of the Babcock Test have been worked out so completely that the results are accurate, provided the simple directions are followed with reasonable care. This test, modified to meet special conditions, is applicable to the determination of fat in butter, buttermilk, skim-milk, cream, ice-cream, cheese, condensed milk, etc.

The Babcock Test solved the problem calling for a rapid, inexpensive and simple method for accurately testing milk and milk products for fat. It has found extensive application in many lines of dairy work, as may be shown by mention of the following important results coming from its use. (1) The payment for

milk on the basis of its fat content, its most valuable constituent, has been made commercially practicable. (2) Makers of butter and cheese have been able to detect and then prevent abnormal losses of fat in the process of manufacture. (3) Milk producers have been enabled to discover unprofitable cows, thus being furnished an intelligent guide in improving the output of milk fat by their herds. (4) The test has surpassed all other means in preventing the watering and skimming of milk, especially that taken to creameries and cheese-factories. (5) It has been of invaluable service in scientific dairy research and has, in general, been a source of educational inspiration.

Numerous other methods, mostly chemical, have been utilized for the following purposes: (1) The estimation of total solids in milk and its products, (2) the determination of water, salt and casein in butter, (3) the finding of the amount of casein in milk, (4) the determination of the amount of acid in milk and milk products, (5) estimation of the keeping quality and sanitary condition of milk, (6) the testing of milk by the use of rennet extract in the process of cheese-making, (7) the detection of adulterations in milk products.

CONTROL OF MILK AND ITS PRODUCTS

The different tests mentioned above have a practical application in making it possible to ascertain the value of milk for different purposes and to exercise control of milk and its products with reference to certain relations, such as legal, sanitary and operative.

I. *Legal Control* has in view primarily the prevention of adulteration. For this purpose, certain so-called standards have been established by laws, which

prescribe definite limits in relation to the chemical composition of milk and its products. These standards vary somewhat in different States. For example, in New York, legal milk must contain not less than 3 per cent. of milk fat and 11.50 per cent. of milk solids. The government of the United States has provided legal definitions or standards for milk and its products for application to interstate commerce. For illustration, its standard or definition of butter is that it contains not less than 80 per cent. of milk fat and not more than 16 per cent. of water.

The forms of adulteration most commonly practised are the following:

(1) *In milk*: (a) Addition of water, (b) removal of fat, (c) addition of any preservative, such as a solution of formaldehyde, borax, benzoic acid, etc., (d) addition of sodium bicarbonate to neutralize acid, and (e) addition of yellow coloring-matter.

(2) *In cream*: The same as in milk, and, (f) the addition of gelatin and sucrate of calcium, which are used to increase the consistency of cream and make it appear richer.

(3) *In butter*: The most common form of adulteration is the use of some animal fat (usually tallow), or vegetable oil (most commonly cocoanut oil), in place of milk fat, either in whole or in part, making the products known as oleomargarine, nut-oleo, etc.

(4) *In cheese*: Two kinds of adulteration are known, (a) the removal of fat, in varying degrees, from the milk used, producing so-called skim-cheese, and (b) the use of fat or oil, other than milk fat, making what is known commercially as filled cheese.

II. *Sanitary control* has for its object the production of pure, clean milk, by which is meant milk that is free (a) from disease-producing germs, (b) from

germs that cause milk to undergo any undesirable chemical change which makes it unfit for domestic or manufacturing purposes, and (c) from an excess of germs that cause milk to sour. The most effective means of sanitary control is *pasteurization*, that is heating milk to a temperature of 145° F. (63° C.) for not less than 30 minutes. In large cities, pasteurization of market-milk is required.

III. *Operative control* has reference to conditions affecting chemical composition and changes relating to milk and the manufacture of milk products. In the sale of market-milk or of milk sold to creameries, cheese-factories, condenseries, etc., on the basis of its fat content, the percentage of fat is determined by the Babcock Test. In the production of cream, for whatever purpose, it is important to know the fat content. In the manufacture of butter, the percentage of fat in skim-milk, buttermilk and butter should be known in order to control losses of fat that may be found, on testing, to occur to an abnormal extent in any stage of the process. Similarly, in cheese-making, the percentage of fat lost in the whey must be ascertained. Operative control is also illustrated in butter-making by the regulation of the acidity of cream, previous to churning, and, in cheese-making, by the control of the acidity in the various stages of the process.

CREAM

Cream is a mixture of milk fat, in variable concentration, with the other solids of milk. It is formed naturally when milk is allowed to stand undisturbed, the fat globules, which are lighter than water, rising to the surface by gravity. Formerly all cream was prepared by the gravity process, commonly called

“setting,” but the invention of the centrifugal separator has replaced the old method in all commercial operations. The centrifugal separation of cream has several advantages over the gravity process, because, (1) the richness of cream can be accurately controlled, (2) loss of fat in skim-milk is greatly lessened, (3) much time is saved, (4) the cream is more free from dirt and (5) the skim-milk is fresh. Skim-milk from the gravity process seldom contains less than 0.50 per cent. of fat, and, by the separator process, rarely more than 0.10 per cent. The sale of milk fat in the form of cream for domestic use is the most profitable form of dairying. By means of the homogenizing process, mentioned below, it is possible to produce good imitation cream by the use of vegetable oils, such as cottonseed, peanut and cocoanut.

The minimum legal standard for cream is usually 18 per cent. of milk fat. Cream for ordinary table use generally contains 18 to 20 per cent. of milk fat. Cream for whipping contains 35 per cent. or more.

ICE-CREAM

The ice-cream industry is of distinctly American origin and one of comparatively recent development. Between 1909 and 1924, the annual output increased from 80 to 285 million gallons. The methods of manufacture have been revolutionized and standardized by the application of mechanical refrigeration, the invention of new machinery and the development of new processes. Practically all frozen delicacies are included under the general term of ice-cream and comprise not only plain ice-cream but the various mixtures (containing nuts, fruits, confections, egg-yolk, etc.), frozen whipped cream (mousse) and various kinds of ices (sherbet, frappé, punch and soufflé).

The milk fat in ice-cream is the most important constituent and usually varies between 8 and 16 per cent. The source of the milk fat is cream, more or less diluted with milk or skim-milk. To an increasing extent, however, the cream is prepared by melting unsalted butter and mixing it with milk or skim-milk by means of the *homogenizing* process. The homogenizing machine breaks any liquid fat or oil into very minute globules by forcing it, under high pressure, through a minute opening against a hard surface. The melted butter, after being homogenized, is intimately mixed with skim-milk by spraying so as to form a well-emulsified cream. The use of butter in this way enables the manufacturer to store it and use it whenever the cream supply is not available.

The next important constituent of ice-cream is the "filler," consisting of milk solids and other solids, which may be supplied in the form of condensed milk, skim-milk powder, egg powder, corn-starch, etc. These materials are used to give the ice-cream so-called body, keeping it from melting too quickly into a watery mixture and enabling it to "*stand up*" for some time at ordinary temperatures.

Gelatin is used in most commercial ice-cream and is technically known as a "*binder*," its function being to hold the constituents of the ice-cream together and give the product a smoothness of texture, and a richness of taste or feeling on the tongue, especially in cases where the amount of milk fat is deficient.

The flavoring materials used in ice-cream are many, including various familiar flavoring extracts, fruits, fruit juices, nuts, chocolate, coffee, maple, etc.

Modern methods have developed, on a commercial scale, apparatus for mixing, hardening, packing, etc.,

as well as recipes for many new combinations of constituents. The most intimate mixture of materials is secured by passing the whole through the homogenizing process before freezing.

The details of the process of ice-cream making involve little or no chemical change in the materials used, the various steps being mechanical procedure.

BUTTER

Butter consists of a mixture of milk fat, water and casein, usually with added salt and coloring matter. The butter-making process comprises four steps: (1) separation of cream, (2) "*ripening*" the cream, (3) churning the "*ripened*" cream, and (4) working, salting and finally packing the finished butter.

The process of "*ripening*" cream is the only one involving chemical change, the other steps being purely mechanical. The ripening of cream is a bio-chemical process, induced by the action of certain lactic acid-producing bacteria which are added to the cream in the form of a "*starter*," which is simply clean-flavored sour milk or skim-milk. The more important results of chemical action are of two kinds: (1) The lactic acid formed by the bacteria changes the composition of calcium caseinate in such a way as to keep the casein from holding the fat globules in emulsion in the cream, thus enabling the globules, under favorable conditions of temperature, to come together in the process of churning and gradually accumulate into butter granules, decreasing the loss of fat in buttermilk. (2) In the ripening of cream, there is formed some compound which gives to good butter its characteristic delicate flavor or aroma, upon which depends, in large degree, its commercial value. Butter is made, also, to a

limited extent, from sweet or unripened cream, but such cream churns with less ease, and more fat is apt to be lost in the buttermilk. In an increasing degree, cream is pasteurized previous to its being made into butter. Pasteurization makes it possible to control those forms of fermentation that produce undesirable flavors. More than half the butter in the United States is made in creameries and is generally of better quality than that made on farms. One of the results of the war was an increased use of butter substitutes, such as oleomargarine, nut-oleo, etc.

The distribution of fat in butter-making can be shown, as in the following table; taking 1000 pounds of milk containing 4 per cent. of fat and indicating the amounts of skim-milk, buttermilk and butter, with the amount of milk fat in each.

Table 3. Distribution of Fat in Butter-making.

	Pounds	Fat, Pounds
Milk.....	1,000	40
Skim-milk.....	870	1
Cream.....	130	39
Buttermilk.....	83.5	0.2
Butter.....	46.5	38.8

On an average, about one and one-sixth pounds of butter are made from each pound of fat in milk.

CHEESE

Cheese consists largely of milk fat, casein and water, with small amounts of other milk constituents and added salt, with or without coloring matter. The percentages of constituents vary widely in different kinds of cheese.

The chemistry of cheese is far more complex than that of any other dairy product. Until quite recently very little was known of the relation of milk constituents to cheese in their effect upon either yield, quality

or composition, and even less about the chemical changes occurring during the cheese-making process.

About 400 varieties of cheese are known. These can be grouped into about 20 distinct types, since many varieties differ only in name. Most of the names originated in some locality, such as Edam (Holland), Emmenthal (Switzerland), Camembert (France), Cheddar (England), Limburger (Belgium), Gargonzola (Italy), etc. Most of the cheese made in the United States is known as American cheddar, but there are also made cottage cheese and a few of the European varieties (Neufchatel, Camembert, Limburger, Emmenthal).

On the basis of water content, cheese may be roughly classified into soft, medium and hard, or, on the basis of the material used in making cheese, as cream, whole-milk, skim-milk and whey cheese.

So many and so varied are the processes in cheese-making that it is possible to consider here, in brief outline only, some general features that are more or less common to all. There are four stages in cheese-making (1) The milk casein is coagulated or solidified into a mass of curd by means of an enzyme contained in rennet, in the presence of dilute lactic acid (formed from milk sugar by the action of bacteria). This coagulation serves to hold most of the fat and some of the other milk solids. (2) In the second stage the curd is gradually heated and manipulated for the purpose of separating from the fat and casein a sufficient amount of whey (water, milk sugar, albumin and salts). (3) In the third stage, the curd, much reduced by removal of whey, is salted and compressed into a characteristic form. In this condition, it is known as "*green*" cheese and in most cases is not suitable for eating. (4) In the last stage, the cheese

is kept for a period of time, varying from a few weeks to several months, under certain conditions of temperature and atmospheric moisture according to the variety of cheese, for the purpose of ripening or curing, during which the cheese undergoes marked changes in chemical composition, under the action of enzymes and micro-organisms. Chief among these chemical changes are (1) those that change the proteins derived from milk casein into more digestible compounds and (2) those that develop characteristic flavors.

Functions of milk constituents in cheese.—The fat, casein, water, milk sugar, and salts, which go from milk into cheese, perform each a function peculiar to itself.

(1) *Fat* affects the quality of cheese by giving it palatability as a result of imparting smoothness, richness, and delicacy of taste.

(2) *Casein* makes possible the manufacture of cheese from milk because of its coagulating reaction with a solution of rennet extract. The coagulated casein holds the fat and other solids of milk, giving the finished cheese firmness of body, under a wide range of temperature. It also furnishes the protein material, which is changed into soluble nutritious compounds, adding largely to the food value.

(3) *Water* helps give smoothness to cheese and furnishes conditions favorable to the work of enzymes and micro-organisms, resulting in solubility of protein and production of cheese flavors.

(4) *Milk sugar* furnishes to bacteria the material for making lactic acid.

(5) *Salts of milk.* Lactic acid, as fast as formed, reacts with insoluble calcium phosphate in milk to

form soluble calcium salts, which are necessary for the coagulation of calcium caseinate by rennet.

Relation of milk constituents to yield of cheese.—The chief solid constituents in cheese are fat and casein-derived compounds, which are over 90 per cent. of the cheese solids. The other constituents are (1) calcium salts of phosphoric, lactic and citric acids, (2) added salts, (3) traces of albumin, (4) small amounts of milk sugar, most of which is soon changed to lactic acid.

The yield of cheese depends primarily upon the amount of fat and casein in milk. Milk richer in fat is also richer in casein and hence more cheese is made from richer milk, as shown in Table 4.

Table 4. Cheese Yield from Milk of Different Breeds

Breed	Per Cent of Fat in Milk	Per Cent of Casein in Milk	Pounds of Cheese Made from 100 Pounds of Milk
Holstein-Friesian.....	3.26	2.20	8.90
Ayrshire.....	3.76	2.46	10.14
Short Horn.....	4.28	2.79	11.52
Devon.....	4.89	3.10	13.02
Guernsey.....	5.38	2.91	13.51
Jersey.....	5.78	3.03	14.36

In this connection it is interesting to see what becomes of the milk constituents in the process of cheese-making. We use, for illustration, milk containing 4 per cent. of fat and show how much of each constituent goes into cheese and into whey for each 100 pounds of milk.

Table 5. Distribution of Milk Constituents in Cheese and Whey.

	Pounds	Water, Pounds	Milk- solids, Pounds	Fat, Pounds	Casein, Pounds	Albumin, Pounds	Sugar, Salts, etc., Pounds
Milk.....	100.00	87.00	13.00	4.00	2.50	0.70	5.80
Whey....	89.40	83.10	6.30	0.28	0.10	0.67	5.25
Cheese...	10.60	3.90	6.70	3.72	2.40	0.03	0.55

The following table gives the average composition of various kinds of cheese.

Table 6. Composition of Some Kinds of Cheese.

Kind	Water, Per Cent.	Fat, Per Cent.	Casein and Albumin, Per Cent.	Sugar, Salts, etc., Per Cent.
Cheddar, from average milk	36.80	35.10	22.65	5.45
Neufchatel.....	44.45	14.60	33.70	7.25
Roquefort.....	31.20	27.60	33.15	8.05
Edam.....	36.30	24.00	30.20	9.50
Swiss.....	35.80	24.45	37.40	2.35
Stilton.....	30.35	28.85	35.40	5.40

CONCENTRATED FORMS OF MILK

Concentrated milk products, such as condensed and evaporated milk, milk powder, malted milk, milk chocolate, etc., use about 4.00 per cent. of the milk produced in the United States. These products have the advantage of prolonged keeping quality, and reduced cost of transportation owing to decreased bulk, and they find extensive use in tropical and arctic regions, on ships, in remote camps, as well as at home for ordinary domestic purposes, in bakeries, in ice-cream and candy making, etc.

Evaporated and condensed milk products are prepared by heating the milk in a vacuum pan to about 135° F. (47° C.) to reduce the percentage of water. Only clean milk, with a low degree of acidity, makes a satisfactory product.

Evaporated or unsweetened milk is condensed milk containing no added sugar. It contains about 70 per cent. of water, 8 per cent. of milk fat and 26 per cent. of milk solids.

Condensed milk, sweetened, contains about 40 per cent. of added cane sugar, 25 per cent. of water, 8 per cent. of milk fat and 28 per cent. of milk solids.

This product is heated in sealed cans at 226° to 245° F. (108°—117° C.) for complete sterilization.

Milk powder is much more concentrated, one pound representing about eight pounds of normal milk, while one pound of the evaporated or condensed milk represents only two to two and one-half pounds of normal milk. For convenience in handling and reduced cost of transportation, and for better keeping quality, milk powder is a superior product. Further, it can be made into milk of any consistency or richness by adding water. The process of preparation affects the properties of the milk less than that of condensing.

Milk powder is made either by evaporating milk in a thin layer on hot cylinders or by spraying it into a current of hot air. Whey powder is also prepared for use in the diet of invalids and infants. Milk powder is prepared from whole milk, half-skimmed milk and skimmed milk. Cream powder is also prepared by the spray process. The composition of milk powder is approximately given below.

Table 7. Composition of Milk Powders.

	Whole Milk, Per Cent.	Half-skimmed, Per Cent.	Skimmed, Per Cent.
Milk Sugar.....	36.50	39.70	47.00
Milk Fat.....	29.20	15.10	1.00
Casein and Albumin.....	26.90	33.30	37.00
Salts.....	6.00	6.90	8.00
Moisture.....	1.40	5.00	7.00

Malted milk is prepared by drying in a vacuum a mixture of whole milk with wheat flour and the extract of fermented barley. It finds extensive use as a food for invalids and infants, being of special value in warm countries.

Milk chocolate is prepared by condensing, in a vacuum pan, a mixture of milk, concentrated chocolate extract and sugar.

SPECIAL MILK BEVERAGES

An increasing amount of milk, both whole milk and skim milk, is being used for the preparation of special beverages, such as kumiss, zoolak, artificial butter-milk, kefir, Lacto-Bacilline, Bulgaricus milk, Acidophilus milk, etc. These preparations are the result of some form of fermentation in the milk. In most cases, the fermenting organism is one of the lactic acid formers. The ordinary lactic bacteria produce about one per cent. of acid, while the Bulgaricus yields two per cent. or more. In the case of American kumiss, the fermentation is caused by ordinary yeast. Sugar is added to the milk and from this a small amount of alcohol is formed, but there is little or no acid present in the fresh product. The different lactic organisms are found on sale at drug-stores in the form of tablets and capsules, with instructions for their use. These fermented drinks are palatable and usually more easily digested than ordinary milk. They are used extensively especially by invalids with digestive and other ailments. A pleasant unfermented drink is made by bottling fresh milk with carbon dioxide gas under a pressure of about 70 pounds per square inch.

FOOD VALUE OF MILK AND MILK PRODUCTS

Of all natural foods, fresh, clean, normal milk is of the highest value. (1) It is palatable. (2) It contains the necessary food nutrients (proteins, fat, carbohydrates and salts) usually in proportions that make a well-balanced food. (3) The compounds in milk are readily digested. (4) It is rich in important food accessories or vitamins. (5) It is ready for immediate use without special preparation. (6) It

contains no waste and is a food with many different uses in the household. (8) It is cheap in comparison with other foods.

The various products of milk contain one or more of the compounds of milk in concentrated form and they have the following general advantages: (1) Greater keeping quality, (2) easier distribution at decreased cost, (3) increase in the variety of available palatable foods, many with special flavors making a wider appeal to different tastes.

The statement has been made, and with a large measure of truth, that the health of a nation is influenced more by the amount of milk used than by any other food, and that, therefore, the welfare of a people is largely in proportion to the milk consumed by its individuals, and especially its children.

CHAPTER XVI

THE CHEMIST AS DETECTIVE AND POLICEMAN OR "FERTILIZER, FEED AND INSECTICIDE CONTROL"

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Other chapters have told of the importance of the above mentioned commodities in the economy of the farm, but if the best results are to be secured from the use of these products, the consumer must be assured in advance of their use as to the quality of the goods which he is purchasing.

Fraud and adulteration in the production of the various materials and articles used by man in the various occupations and endeavors in which he has been engaged are almost as old as the industries and manufactures of which the historian tells us; as is evidenced by the mention of such fraudulent practices in ancient times by Dioscorides, Vitruvius, Pliny and other writers of that early period. Indeed one author recounts the incident of an adulterator of wines, who was compelled to drink a large amount of his own product, with fatal results to the luckless culprit.

Just as many other articles and products of utility have from time immemorial been made the vehicles of fraud and deception in connection with their manufacture and sale, so have fertilizers, feeding stuffs



Dr. HARVEY W. WILEY

and insecticides, from time to time, since becoming important articles of commerce, been subject to adulteration, misbranding or other forms of deception practiced by unscrupulous manufacturers or dealers. This has necessitated the enactment of stringent laws for the protection alike of the unsuspecting consumer and the honest manufacturer.

Just as the chemist has played an important part in the working out of formulas, the selection and proportioning of ingredients, the manufacture of the final product, and also in prescribing how and under what conditions some of these products are to be employed; so, likewise, the chemist plays a most useful and essential role in the detection and punishment of violations of laws protecting the consumer against the adulteration and misbranding of these products.

FERTILIZER CONTROL

The manufacture of fertilizers upon a commercial scale owed its inception chiefly to the publication and dissemination of the results of Liebig's investigations in the field of plant nutrition, in connection with which he suggested the use of artificial fertilizer mixtures so proportioned as to supply appropriate quotas of nitrogen and phosphoric acid, and the alkalies (potash and soda) to meet the needs of a given soil or crop. He also demonstrated the possibility of converting the insoluble phosphate of lime into the water-soluble phosphate by treatment with sulphuric acid and this led to the gradual development upon a large scale of the process of the manufacture of "superphosphates" or "acid phosphates" from bones and mineral phosphates.

The development of the commercial fertilizer industry along lines of the greatest service to the farmer

was, indeed, in harmony with the following prophecy made by Liebig, himself, embodied in a letter addressed to the American farmers in 1845. Therein he gave expression to his belief in the efficacy of chemical control in determining and regulating the quality and value of the product to be offered to the consumer.

* "Manufactories of manures will be established in which the farmers can obtain the most efficacious manure for all varieties of soils and plants. Then no artificial manure will be sold whose exact amount of efficacious elements is not known, and this amount will be the scale for determining its value. Instead of the uncertainty of mere empiricism, all the operations of agriculture will be carried on with certainty, and instead of awaiting the results of our labors with anxiety and doubt, our minds will be filled with patience and confidence."

The progress of the artificial fertilizer industry in this country received a great impetus with the discovery of the phosphate deposits of South Carolina in 1862, while the later discovery of the natural phosphates of Florida and Tennessee contributed to the further growth and expansion of this important branch of manufacturing chemistry. The admixture of superphosphates with a nitrogenous material and a potash salt resulted in the production of the complete mixed fertilizer, the higher grades of which were brought into competition with the Peruvian Guano and other sea fowl guanos, which commenced to find their way into this country about the middle of the last century.

With no effective legal restrictions regulating the sale and distribution of natural guanos, or manufactured fertilizers, there were of course, to be found here and there manufacturers and dealers who were ready

*U. S. Patent Office Report, 1845.

to make use of the opportunities offered them to foist upon the farmer adulterated and fraudulent products having in many cases a value representing only an insignificant fraction of the selling price of the goods. The uncertainty existing in the mind of the consumer as to the quality and agricultural value of the fertilizers offered to him led to a demand upon the part of the more progressive and intelligent users of these products for the chemical analysis and valuation of these materials; this demand being expressed through the medium of the agricultural press, as well as through some of the agricultural societies which were actively functioning in a number of the States even at that early period.

As early as 1849, Dr. Julius Adolph Stöckhardt, Professor of Agricultural Chemistry in the Königliche Frost—Akademie at Tharandt in Saxony, proposed a method of estimating the values of fertilizers, based upon unit values for the several essential fertilizing constituents and this method was soon thereafter adopted by the chemists of the agricultural societies of Great Britain.

In both Germany and Great Britain, as well as in some of the individual states in this country, the demand for inspection or control in the fertilizer trade was met originally by means of analytical work conducted by chemists employed by the various agricultural societies, and this system of analysis and control continued for many years. Fertilizer inspection work was finally taken over in Germany largely by the Experiment Stations and in this country by the Stations or Special State control organizations. In England, after the lapse of many years, acts of Parliament provided for official government control of fertilizers, as well as other commodities of utility in agricul-

ture, analyses of the products being made largely by District Analysts.

In England, Dr. Augustus Voelcker, Chemist of the Royal Agricultural Society for many years, was a pioneer in calling attention to the frauds practiced upon the agricultural public through the sale of fraudulent or adulterated commercial manures. In a report made in 1855 he declared "that if ever there was a time when the agriculturist had need to exercise special caution in the purchase of artificial manures, that time is the present, for the practice of adulterating standard fertilizers such as guanos, superphosphates, etc., has reached an alarming extent."

The following are the results of analysis of a sample of a product sold as "Essence of Guano" and reported by Dr. Voelcker in the year above mentioned:—

Ammonia.....	.643	per cent.
Phosphoric Acid.....	1.088	" "
Sulphate of Lime.....	15.179	" "
Carbonate of Lime.....	8.008	" "
Sodium Chloride.....	15.803	" "
Insoluble Silicious Matter (principally sand and brick dust).....	34.297	" "

This material was said to have been sold at a price of eleven pounds (\$55) per ton, while at the same time good Peruvian Guano was obtainable in the markets at about 15 pounds (\$75.00) per ton.

The calculated value per ton of the above product, based on the approximate average unit values adopted in several of the large fertilizer consuming states, would be slightly above \$3.00 per ton, while the calculated value of a high grade Peruvian Guano would be in excess of \$72.00 per ton. It thus appears that the purchaser of the above goods was mulcted for the sum of \$69.00 per ton, a loss which could have been avoided by securing advance information through a

chemical analysis as to the composition and value of the material. No doubt many prospective purchasers were protected from loss by the exposure of this fraud by Dr. Voelcker.

An analysis of a so-called "Superphosphate" reported by Dr. Voelcker at a somewhat later date showed the presence of

Water soluble phosphoric acid. . . 3.05 per cent.

Nitrogen. 1.11 percent.,

whereas a good raw bone superphosphate should contain about 12 per cent. of available phosphoric acid and about 2.50 per cent. of nitrogen.

A number of other analyses reported from time to time by Voelcker showed striking disproportions between the selling price and the actual calculated values of the products analyzed.

In this country, Prof. Samuel W. Johnson,* Professor of Agricultural Chemistry at Yale University for forty years and for many years Director of the Connecticut Agricultural Experiment Station, led the way for the introduction of fertilizer analysis and control in nearly all of the states of the Union. As early as March, 1853, he published analyses showing the difference in composition of a number of samples of raw bone superphosphates, both the imported English and American product being included in the samples analyzed. A marked difference between the analyses and values of some of these samples was shown and Prof. Johnson's report concluded with the following words,—“the farmer can only be fully protected from unprofitable expenditure by the frequent publication of analyses made upon different samples.”

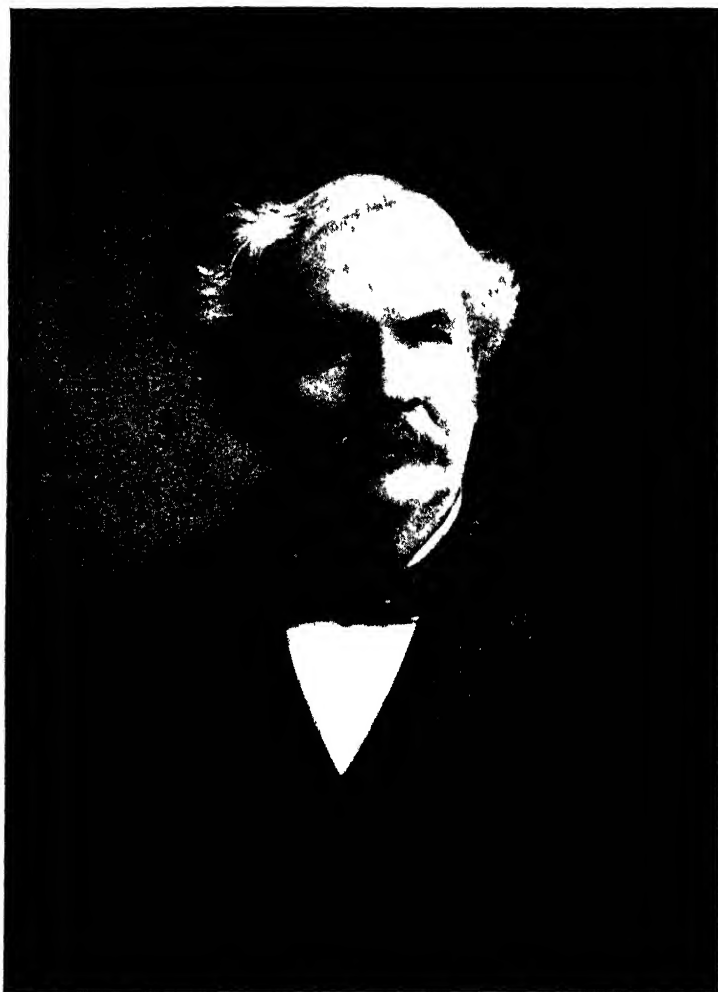
In 1855, Prof. Johnson, after two years of study abroad, returned to New Haven and again took up his

*See Frontispiece.

work of analysis and valuation of fertilizers and the information thus secured was given publicity through the medium of the agricultural press, as well as through addresses delivered to gatherings of farmers and land owners. In his addresses, as his biographer states, he endeavored to impress upon his audiences the following main facts: "The necessity of employing chemical analysis as the only basis upon which to form an intelligent opinion about the suitable composition of a fertilizer; the reliability of accurate analyses as a guide to the estimation of value; and the importance to the community of a regular system of analysis of all commercial fertilizers as a safeguard against fraud, as well as against the self-deception of ignorance,—ideas, which, novel at the time, are now universally accepted and adopted, both by manufacturers and consumers, as the basis of the trade in commercial fertilizers."

The exposure by Prof. Johnson of fraud and deception in the sale of fertilizers in the State of Connecticut, led the Connecticut State Agricultural Society to follow the example set by the Agricultural Societies of Great Britain and Germany in securing the services of a capable chemist to analyze and to fix values for fertilizers offered for sale to the consumers of that State, and Prof. Johnson was elected to fill the position of Chemist of that Society. In an address delivered immediately thereafter, he stated that of all the superphosphates analyzed in the preceding year, "not one came up to a reasonable standard of quality. One was an absolute misnomer, it contained no superphosphate of lime."

The good results of this action by the State Agricultural Society are evidenced in the following excerpt from the Secretary's report a year later:—"The



Professor CHARLES ANTHONY GOESSMANN

action of the Society at the last annual meeting, in securing the services of a chemist, has proved efficient beyond the expectations of the warmest friends of the measure. . . . During the past year scarcely one very inferior or worthless commercial manure could be found in Connecticut. Manufacturers or dealers who could not with safety warrant their manures have sought other markets."

Another pioneer in the field of fertilizer control through chemical analysis was Dr. Charles A. Goessmann, Professor of Chemistry in the Massachusetts Agricultural College and for many years Director of the Experiment Station and Chemist in charge of fertilizer control. Immediately after his election to the chair of chemistry in 1868, the President of the college stated that: "It is confidently expected that under his supervision, analyses of commercial fertilizers will be made, and suitable experiments instituted, to determine for what purposes and at what prices the farmers of the State should employ them." Suffice it to say, the results of the work of Prof. Goessmann at Amherst were such as to more than justify the expectations of the President along the above mentioned lines.

Both Prof. Johnson in Connecticut and Prof. Goessmann in Massachusetts were earnest and active in their advocacy of fertilizer control laws in their respective States, but the first laws enacted in each state in the year 1869, were ineffective, no definite provision being made to carry out the requirements of the laws.

In a report published in 1872, Prof. Goessmann presented the results of his analyses of fertilizers found upon the markets of the State and called attention to the urgent need of a law regulating the sale of fer-

tilizers in Massachusetts. On May 26, 1873, a law was enacted by the Massachusetts Legislature which provided for the official inspection and analysis of fertilizers in the State, it being required that all fertilizers offered for sale have a guarantee of composition attached. It is believed that this is the first effective fertilizer inspection law enacted in the United States, although fertilizer inspection laws were enacted both in Alabama and Delaware in 1871, the provisions of the Alabama law, however, being unworkable and the operation of the law being abandoned.

With the enactment of the law establishing an Experiment Station in Connecticut in 1875, followed by a further law in 1877, changing the location of the Station and providing more effectively for its support, fertilizer control in Connecticut became an established feature of the Experiment Station work in that State, and this control work, both in Connecticut and Massachusetts, has maintained during all the years since a high standard of efficiency and of effectiveness in excluding low grade and misbranded fertilizers from the markets of these States.

During the first year of the conduct of the fertilizer control work at New Haven, Prof. Johnson reported the results of analysis of a mixed fertilizer containing a total plant food content (nitrogen, phosphoric acid and potash) of 0.71 per cent, and having an estimated value of only \$1.03 per ton, while the actual sale price of the goods was \$32.00 per ton.

Such exposures as this of the fraud and deception practiced in the sale of commercial manures led to a demand on the part of fertilizer consumers in other states for the enactment of similar fertilizer control laws, and in many of the states the fertilizer trade co-

operated with the farming interests in seeking the passage of such laws.

Georgia in 1874 followed Massachusetts with a regulatory law for fertilizers, while Virginia and North Carolina followed next in order in March 1877 with the enactment of similar legislation, to be followed in turn by South Carolina, whose fertilizer control law was adopted in 1880.

Other states at varying intervals from 1880 up to 1920 proceeded to enact legislation along similar lines and at present all states of the Union have fertilizer control laws except a few of the thinly settled far Western states.

A provision found in all of the control laws of the country requires the yearly registration of the various brands of fertilizers offered for sale by the manufacturers or manufacturers' agents in the respective states. Such registration must be accompanied by a statement of the guaranteed minimum proportions of each fertilizing constituent in each brand, while in many states it is also required that the sources from which the various ingredients of the fertilizer are derived shall also be included in the statement. Many of the control laws require that the amounts of the several forms of phosphoric acid (water soluble, reverted and insoluble) shall be set forth in the guarantee and that the relative proportions of organic nitrogen and of the several forms of inorganic nitrogen shall also be stated.

Without proper and efficient chemical control, the provisions of these regulatory laws would be entirely ineffective and of no protective value to the consumer and, as a matter of fact, the earlier fertilizer laws enacted in Massachusetts, Connecticut, Alabama, New York and some other states proved to be abortive and

of no value and effect in excluding fraudulent and low grade fertilizers from the market, chiefly because these laws made no adequate provision for the chemical analysis of the products offered for sale.

In most of the states, the fertilizer laws or regulations provide for the sampling, by official inspectors, of fertilizers from stocks in the hands of manufacturers or dealers, and samples are also sometimes taken of goods in transit, or in the possession of the ultimate consumer. In a number of the states, provision is also made for the sampling of fertilizers in the hands of the consumer, or at the time of purchase, the samples being taken by disinterested parties in the presence of the purchaser and seller, or of their representatives. The samples, by whatever method taken, are usually properly labeled or numbered and are generally transmitted under seal to the laboratory of the official chemist, where analyses are made for all constituents embraced within the guarantee of the fertilizer.

The laws of the various states fix penalties for misbranding and for fraud and deception in the sale of fertilizers, and in many of the states penalties are also applied where deficiencies in the plant food supplied by the fertilizer exceed the limits of the tolerance allowed in the several states. In some states also a marked deficiency in the plant food contained, as compared with the guarantee, penalizes the seller by making impossible the legal collection from the purchaser of more than a certain percentage of the selling price of the goods.

The publication in official reports and bulletins of the results of analyses of samples collected under the provisions of the fertilizer laws of the various states also tends to promote the maintenance of a high

quality in the goods offered for sale in those states. Furthermore, honest and reputable manufacturers throughout the country are striving, through the aid of chemical control maintained in their factories by their own chemists, to keep their product up to the standard of the guarantees claimed for their goods.

In the early days of fertilizer control in this country, there was frequent lack of agreement between the analyses of fertilizers made by official chemists of the several states, the manufacturers' chemists and the commercial chemical laboratories, the discrepancies in analyses of the same sample being due, in many cases, to a lack of uniformity in the methods of analysis employed.

The fact that methods of analysis, differing essentially in detail, were employed in many of the state laboratories, while a like divergence in methods employed was noted also in the laboratories of commercial and manufacturing chemists, soon led to a demand for the adoption of official methods which should be uniform throughout the various states having fertilizer control.

The first step in the direction of attaining this much desired end was taken in 1880, at the instance of Commissioner J. T. Henderson, of the Georgia State Department of Agriculture, and as a result of a letter sent by that official to a number of official chemists and other chemists interested in uniform methods of analysis, a convention was held at Washington on July 28th of that year which adopted methods of analysis for the several fertilizer constituents as recommended by committees which had been studying different phases of the subject.

The convention voted to organize a sub-division of Agricultural Chemists in the Section of Chemistry of

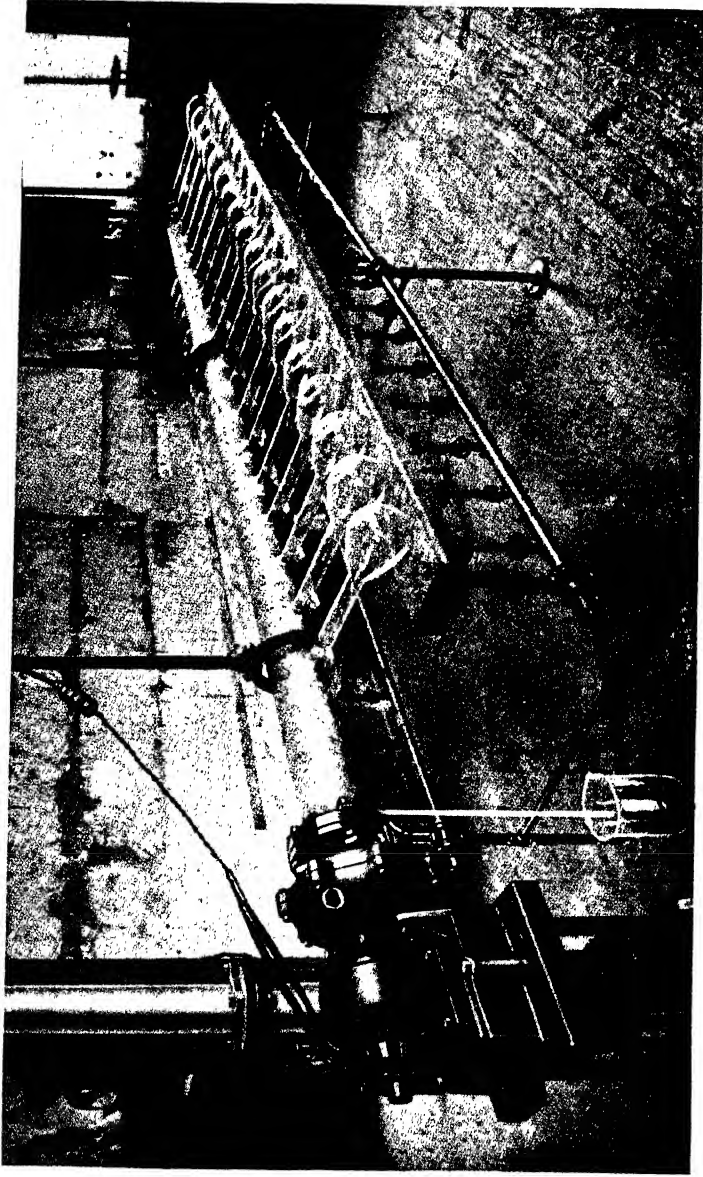
the Association for the Advancement of Science and adjourned to meet at Boston a month later under the Chairmanship of Dr. Charles A. Goessmann of Massachusetts.

Meetings were held at Boston on the appointed date and at Cincinnati the following year, at which time the question of uniform methods was further considered. Following the latter meeting, no further meetings of Chemists, interested in the question under consideration, were held until a meeting of Official Chemists assembled in Atlanta on May 15, 1884, at which meeting provisional methods of fertilizer analysis were adopted.

The convention adjourned to meet at Philadelphia in September, 1884, on which date the members present voted to form an association to be known as "The Association of Official Agricultural Chemists," Dr. Samuel W. Johnson of Connecticut being elected President. A constitution and by laws were adopted and plans were made to conduct co-operative tests of methods of fertilizer analysis during the ensuing year.

The second meeting was held in the Library of the U. S. Department of Agriculture in Washington in September, 1885, at which time reports were received from committees to which had been assigned the study of methods for the determination of phosphoric acid, potash and nitrogen in fertilizers.

At this meeting Dr. H. W. Wiley, Chief of the Division of Chemistry of the U. S. Department of Agriculture, was elected President, beginning at that time an official connection with the Association which has continued for forty years, during which period he has served as President, Secretary and Honorary Life-President of the organization. A large measure of the success attained by the organization, in carrying out



Kjeldahl Digestion Battery.
(A typical example of apparatus used in fertilizer and feed analysis.)

the purposes for which it was formed, has been due to the earnestness, diligence and fidelity which have characterized his connection with the Association and to his wise counsel during the early formative period of the existence of that body.

The committees to which was originally delegated the study of methods of analysis of the various fertilizer constituents were after a few years replaced by Referees, to whom was assigned the task of conducting investigations of methods of determining some single constituent. This resulted in co-operative and collaborative work, by chemists throughout the country, in testing out the methods under consideration, with uniform sets of samples sent out by the referees. In this way, a thorough and systematic study, as well as a practical trying out, of the analytical processes was accomplished, and as a result of this careful and comprehensive scrutiny and test of the methods, these methods, once adopted, received wide acceptance in this country, as well as abroad, and the Association of Official Agricultural Chemists attained a position of marked and enviable prominence among the chemical organizations of like scope and purpose throughout the world.

In this connection, the fact should also be noted that fertilizer control chemists have not only developed and perfected reliable and satisfactory methods for determining the several fertilizer constituents in commercial manures, but have also studied and worked out, through both field and laboratory tests, methods which can be applied in the laboratory for the approximate determination of the availability of certain forms of the plant food elements found in fertilizers. Such methods have been applied to particular advantage in the case of some of the forms of

nitrogen in fertilizers; for the ascertainment of the relative availability to the plant, of some of the forms of organic nitrogen is especially important. It is not simply necessary to know, for example, that a mixed fertilizer having a guarantee of 3 per cent of nitrogen is found to contain the total guaranteed amount of that constituent, but laboratory tests should show that a large proportion of that nitrogen is in a form readily appropriated or assimilated by the plant. Such materials, for instance, as ground leather, hair and wool waste, horn meal, hoof meal, peat, etc., may, by admixture with other forms of plant food, yield a mixed fertilizer having a total nitrogen content equal to or exceeding the guarantee, and yet, owing to the low availability of the above forms of nitrogen, the consumer may receive only a very inadequate return from his investment in nitrogen derived from these sources.

For this reason, fertilizer control laws or regulations in many states require that laboratory tests of certain classes of materials shall indicate a certain high percentage availability of the nitrogen in the raw material, or in the mixed fertilizer, in order to permit the marketing of such goods in those states. In passing, it may be of interest to note that several of the above mentioned low grade organic materials can be so treated by processes, developed by the industrial chemist, that much of the originally worthless or inactive nitrogen may be converted into forms readily available to the plant.

Agricultural chemists also, through investigations carried out both in experimental plots and in the laboratory, have shown that such a hitherto supposed waste product as basic slag, obtained as a by-product in steel making, can be used to excellent advantage as

a phosphatic fertilizer. They have, thus, aided the steel manufacturer to find a market for a formerly valueless by-product, while at the same time the farmer is supplied with still another manurial material of great value and utility to certain of his crops.

Control chemists in some of the states have also made an investigation of some of the fillers or "make weights" employed in the manufacture of mixed fertilizers and have called attention to the fact, that some of these materials, as for example, pyrites cinder, are objectionable on account of the reversion of the soluble phosphoric acid which they bring about. Accordingly regulations or rulings have been made against the use of such materials.

The fertilizer control chemist has also rendered important and useful service to the consumer in protecting him from fraudulent or worthless fertilizer recipes or formulas, which from time to time have been offered to the farmer at extortionate prices, the sale of such formulas being promoted by the use of circulars of the most misleading character.

Some of these formulas offered for sale in some of the cotton growing states prescribed small amounts of such substances as Ammonium Nitrate, Soda Ash, Saltpeter, Caustic Potash, Phosphoric Acid, Bluestone, Lime, Salt, Sulphur, etc. Some of these ingredients are highly incompatible, while nearly all of the materials, in the form prescribed, are quite expensive. In one of the formulas, less than a total of 50 pounds, of the several chemicals specified, were to be mixed with a small amount of ashes and enough dirt or lot scrapings to yield 2000 pounds, thus producing a ton of alleged fertilizer of pretended high quality at a much less cost than the market price of a commercial mixed fertilizer.

A number of official chemists promptly issued circulars warning the farmers of their respective states against such frauds and the sale of such formulas was soon suppressed.

The importance of the proper chemical control of the fertilizers produced and consumed in this country will be realized when it is considered that the total production of fertilizers in the country reached the large figure of 7,549,288 tons in 1923, having a total trade value of \$177,226,967. Also, the desirability of keeping this large fertilizer tonnage up to the standard will be fully recognized, in view of the further fact, that the increased value of the crop produced often amounts to several times the cost of the fertilizer applied.

FEEDING STUFF CONTROL

The manufacture of commercial feeding stuffs is an industry of much later origin than that of the manufacture of fertilizers, and hence feeding stuff control had its beginning at a much later date than fertilizer control, though the immense tonnage of such products marketed each year and the great value of the same, made such supervision all the more necessary.

Massachusetts was one of the pioneer states in the inauguration of feeding stuff control, just as it had been in fertilizer control legislation, though Maine put feed stuff control into effect almost simultaneously with its sister New England State.

Connecticut did not enact special feed stuff control legislation until a much later date, but its food law, enacted in 1895, made provision for the analysis of foods for animals as well as for man, and much work was done in connection with the examination of com-

mercial feeding stuffs in that state prior to the enactment some years later of a law providing specifically for feeding stuff inspection and analysis.

Since 1900, there has been a gradual extension of feeding stuff control until practically all of the States of the Union have laws regulating the distribution and sale of such products. On June 30, 1906, the enactment of the Federal Food and Drug Act, which embraced foods for both man and animals, made possible co-operation between the general government and the several states in the supervision and control of commercial feeding stuffs.

Great Britain provided for official control of the feeding stuff trade through an Act of Parliament in 1893, the analytical work being done chiefly by District Analysts as in the case of fertilizer control.

As an illustration of the need of such control in England, there was reported in the Journal of the Royal Agricultural Society, in the very year in which the Feed Inspection Act was enacted, the analysis of a sample of linseed cake which was found to contain 17 per cent of rice meal and only 1.5 per cent of actual linseed meal, the remainder of the product being made up of foreign materials. On the other hand, in Germany and some other continental countries, there has been in effect for many years, a voluntary form of control, many of the large manufacturers and dealers selling their goods on a guaranty as to certain constituents and agreeing to pay an indemnity or rebate to consumers in case the Experiment Station laboratories find their products to show any marked deficiency.

Prior to feed stuff control in this country, and in the immediate time thereafter, instances of adulteration and misbranding of feeding stuffs were all too

common, and the consumer was defrauded of large sums by unscrupulous manufacturers. Effective control of the feed stuff traffic being once established in any state the quality of feeds showed a marked improvement, and from time to time the feed control laws have been amended and strengthened, often with the co-operation of progressive and fair minded manufacturers.

In making a chemical analysis of feeding stuffs, the analyst determines what are termed the proximate constituents, including water, ash, protein, fat or oil, fiber and carbohydrates other than fiber. This last mentioned group of bodies is embraced under the term "Nitrogen-free-Extract," starch, the sugars, gums and some allied bodies being included under this designation.

What is termed "crude protein," in reporting analyses of feeding stuffs, embraces the nitrogenous bodies occurring in the material, and the amount of this proximate constituent largely determines the cost of the product. Protein is used in the animal economy chiefly in producing muscle and tissue, while fat and carbohydrates are chiefly of value in producing energy and heat. The fat is estimated to have a value two and a quarter times as great as carbohydrates, for this latter purpose.

What is termed the "Nutritive ratio" is the ratio between the digestible protein and the digestible carbohydrates and fat, the fat being multiplied by the proper factor and added to the carbohydrates. A feeding ration, designed to meet the requirements of a farm animal for a particular purpose, which supplies such proportions of protein and of carbohydrates and fats, as conform to the conclusions reached by accepted authorities in the field of animal nutri-

tion, is said to be a properly "balanced ration." The results of analyses, by the control chemist, of a mixed feed, will furnish information as to whether or not the feed will supply a balanced ration for the animal for the particular purpose for which it is being fed, there being considerable variations in the nutritive ratios for work animals, dairy animals and those intended for meat production.

As in the case of fertilizer control, the feeding stuff control laws in the various states usually require a guarantee as to the proximate constituents of the feeding stuffs. In many of the states, however, this guarantee is restricted to a statement of the minimum percentages of protein and fat and the maximum percentage of fiber which the manufacturer claims for his product. In a number of states it is also required that the ingredients of the mixed feed shall also be stated.

Many of the concentrated feeding stuffs are by-products of industries whose main products are used for other purposes than animal food. Such materials as Gluten Meal, Gluten Feed, Cotton Seed Meal, Linseed Meal, Brewers' and Distillers' Grains, Malt Sprouts, Milling by-products, etc., are included under this designation. By reason of their high protein content, these concentrated feeds or "concentrates," as they are often termed, are employed, by the farmer, for feeding along with lower grade feeds produced on the farm, and by feed stuff manufacturers, for admixture with low protein materials in properly adjusting the nutritive ratios of commercial mixed feeds which they are planning to market.

Before effective State and Federal control of feeding stuffs had been established throughout the country, the practice was all too frequent of mixing waste products or materials of low feeding value and high

fiber content with concentrates and thus supplying the consumer with feed stuffs containing an excessive amount of indigestible and unassimilable material. Among the materials thus employed were ground peanut hulls, ground cocconut shells, rice hulls, oat hulls, ground stems and stalks of forage plants, ground corn cobs, ground cotton seed hulls, etc. Excessive amounts of mill screenings and weed seeds have also been used as adulterants of commercial feeding stuffs.

As a rule some member of the feed control laboratory staff is also a skilled microscopist and is thus prepared to detect more readily the presence of adulterants whose occurrence in the feed is often indicated by some abnormal or unusual results of the chemical analysis.

Where proper protection is not given, the consumer may not only be defrauded by the presence of excessive amounts of some material of low feeding value and digestibility, but occasionally there may be present, in appreciable amount, foreign materials such as wild mustard seed, castor croton seed, etc., whose occurrence in the feeds may produce serious harm or even death to farm animals, as a number of official reports have shown.

Commercial mixed feeds have also been the medium of the distribution of weed pests which have proved to be of great damage and detriment to a number of the staple crops and so the members of the control staff must constantly be on the alert to detect the presence in feed stuffs of the seeds of objectionable and harmful weeds. Even in a product sold as wheat bran, the North Carolina Station reported the detection of the presence of about 11 per cent of unground kernels of wheat, oats, cockle, chess and various other weed seeds. The results of the timely examina-

tion of this material was, no doubt, most helpful in protecting prospective purchasers against such a product.

The so-called "condimental" feeds for farm animals, which have been offered for sale throughout this and other countries for so many years, have been commonly sold at prices out of all proportion to their true value.

These materials often contain a considerable proportion of salt, or some other mineral ingredient, and sometimes some substance or substances of alleged medicinal value, fenugreek, especially, being found in many of these feeds. The manufacturers often make exaggerated claims as to their health giving qualities as well as to their feeding value, and in the case of condimental feeds for dairy animals, their use is urged for the purpose of securing a greater milk production.

The feed control chemist has been of great service to the consumer in warning him against the purchase of such products, whose use is seldom followed by results at all commensurate with the amount paid for such materials.

The methods employed in the analysis of feeding stuffs are those officially adopted by the Association of Official Agricultural Chemists, which had indeed begun the study of methods of analysis of such products some years in advance of the inauguration of feed stuff control.

In the administration of the provisions of feeding stuff control laws, there is close co-operation between the state control agencies and the Federal authorities who carry into effect the feed control provisions of the Federal Food and Drug Act. Inspectors and Chemists connected with State Control report to Fed-

eral officials cases relating to inter-state shipments of misbranded and adulterated feeds which have come under their observation, and in like manner, Federal control officials report to the proper State authorities similar cases of inter-state violations of control laws which may have come to their attention. In some instances, control officials of the State from which a shipment is made, officials of the state of delivery of the shipment, and federal officials have all collaborated in the detection of fraud or misbranding of feeding stuffs and have co-operated in the prosecution in the Federal courts of cases against the offenders.

INSECTICIDE CONTROL

In a similar manner, there has also been effective co-operation between the State and Federal control officials in detecting, and prosecuting in the courts, violations of insecticide and fungicide control laws, the Federal control law involving this class of products having been enacted April 26, 1910.

The annual report of the Secretary of Agriculture for 1905, urged the enactment of such legislation, calling attention to the results of investigations by the Bureau of Chemistry which showed that many of the insecticides upon the market in this country were of little value, while the prices of the product were in many cases excessive. Another report of the same bureau in 1908, gave results of analyses of insecticides collected and analyzed by the various Experiment Stations and State Laboratories, and also published copies of state laws for insecticide control which were then in effect; only the States of California, Louisiana, New York, Oregon and Washington having enacted such laws prior to that time.

Louisiana enacted the first insecticide control law in this country in 1890, but this law provided only for the inspection and analysis of Paris Green, at that time in great demand for use as a poison for the cotton caterpillar, which frequently wrought serious injury to the cotton crop.

A few years later, unsuccessful attempts were made to enact a similar law in Alabama, the State Chemist having found, from an investigation, that there was fraud and misbranding in the insecticide trade in that state, notably in the case of a product sold as Paris Green, two samples of which collected at different times and in widely separated localities were found to contain neither copper nor arsenic, the product consisting of a mixture of Prussian Blue and Chrome Yellow, together with chalk and Kaolin. It is needless to say that purchasers of this product secured no appreciable benefit from its application to plants threatened with insect depredations.

The need for the enactment of the Federal insecticide law as well as state control laws will at once be seen in the results of analysis of samples collected under the first year's operation of that act. Of 293 domestic samples collected and analyzed, 131, or nearly 45 per cent of the whole number, were found to be adulterated, or misbranded, and of 25 foreign samples, 14 were recommended for detention at the ports of entry.

Less than two years after the Federal law became effective, the Bureau of Chemistry reported that "The chemical examination of insecticides and fungicides has been a potent factor in improving the purity of products now sold on the market." Some idea of the value of such work to the farmer is gained by consideration of the loss occasioned by the ravages of

plant diseases and insects. Experts have estimated that there is a loss of 20 per cent from these two sources, which, when applied to the farm crops of 1911 valued at \$5,367,000,000, would indicate a loss of about \$1,000,000,000. Probably one-third of this enormous sum could be saved by the proper application of insecticides and fungicides of the requisite strength and purity. Any inferiority in the quality of these materials means the additional loss of the labor in applying them.

The early studies of this subject showed that many of the insecticides on the market were of practically no value whatever, owing to the fact that they contained little or no active ingredients. Other insecticides which contained some active ingredients were adulterated by the addition of inert substances for the purpose of increasing the bulk to such an extent that they were of no value whatever.

As a result of the data secured by these investigations an insecticide and fungicide law was passed and approved April 26, 1910, which has greatly improved the conditions. . . . A farmer in buying a supply to protect his crops can be reasonably sure that he is getting exactly what he asks for and what he pays for.

A number of the states have adopted insecticide control laws within the past decade or more, but many of the states have failed to enact such legislation owing to the protection secured to consumers throughout the country from the effective operations of the Federal law.

The control chemist has devolving upon him not only the task of ascertaining whether an insecticide comes up to the guarantee as regards the total content of the chief important constituent, but, in the case

of the arsenical insecticides, must determine also the amount of water soluble arsenious oxide present, an excessive amount of this constituent being quite injurious to the foliage of the plant. At the laboratory of the New York Station, a sample of Paris Green, which was apparently up to the standard as to total arsenic content, was found to contain as much as 15.69 per cent of water soluble arsenious oxide, thus rendering its use as an insecticide entirely prohibitory.

In some products which are to be applied by dusting, as for example in the case of calcium arsenate, the effectiveness of the insecticide is in quite a measure dependent upon its physical condition, and tests must be made of the density, or bulk, of the product.

Not only are the inorganic insecticides susceptible of adulteration, but many of the organic materials offered for sale as insecticides and fungicides have likewise, from time to time, been found to carry varying proportions of inert foreign materials. A notable case of this kind was the detection, in the Bureau of Chemistry Laboratory, of the adulteration of Pyrethrum with the pulverized flowers of a plant related botanically, but of little or no value for the purposes for which the Pyrethrum is intended.

Much fraud is perpetrated upon the consumer through the sale of proprietary insecticides, which are sold under misleading trade names, the cost of these products being far above the value of any possible return from their use.

A product of this kind offered for sale a number of years ago laid claims to being not only of great value and efficiency as an insecticide and fungicide, but also of utility as a fertilizer. An analysis made by the New York Station showed a total of only .07 per cent of plant food and practical tests carried out

at the Maine Station showed it to be highly inefficient as an insecticide, although sold at an exorbitant price.

Guarantees as to the content of the active constituents of the insecticides are required both under the State and Federal control laws, the rulings and standards relating to inter-state trade in these products being made and promulgated by the Federal Insecticide and Fungicide Board.

Upon control chemists, not only devolves the task of analyzing fertilizers, feeding stuffs and insecticides, but also of conducting a large share of the investigational work required in the fixing of standards and definitions for the several classes and in deducing conclusions from the results of such investigations.

The results of the work of the control chemist is seen in higher standards for the various products and a greater freedom from adulteration and misbranding of these products as time goes on. In attaining these results, the control officials have, in a large measure, the co-operation and support of the progressive and reputable manufacturers, and quite a proportion of the cases of low grade products, found upon the market, are due, not to intentional fraud, but often, in the case of the smaller producer, to careless and slipshod methods of manufacture, carried out frequently in the absence of effective chemical factory control.

While cases of serious adulteration or misbranding diminish from year to year with effective chemical control, the consumer must still remember the truth of the old adage that "eternal vigilance is the price of safety," and in assuring the safety of the purchaser, the control chemist is, as it were, a sentinel on the watch tower, prepared and ready to warn the consumer of the danger which confronts him.

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PHARMACEUTICS