THE FOOD-SUPPLY OF THE FUTURE.

IS the evil time coming when population will exceed the capacity of the earth for production and the ever-fiercer struggle for existence will leave the weakest to starvation? Such is the direful import of the doctrine of Malthus, a doctrine which has weighed heavily upon the minds of philosophers and philanthropists, and which has greatly influenced thought if not legislation. But science to-day seems to offer a different answer to this question. Chemistry and physiology, in defining the laws of plant-growth, show that the old ideas which limit vegetable production by land-area and soil-fertility are incorrect, and imply that the capacity of the earth for yielding food for man is almost unlimited. In this view of the possibilities of plant-production, which the whole tenor of scientific research and practical experience makes more and more certain, the prospect for the future of the race is not one of Malthusian dreadfulness, but full of inspiring hope.

But before entering upon the main discussion I may refer to some of the ways in which we can better economize our present food-supply, and how it can be increased by fish-culture, by better tillage of the soil, and by irrigation.

In an effort towards obtaining information regarding the amounts and composition of the food of the people of the United States I have collated the figures for some fifty daily dietaries of several hundred persons in boarding-houses and private families — factory operatives, mechanics, and well-to-do persons in professional life — from the New England and other Eastern States. While these are insufficient for accurate generalizations, they accord with the impressions current among physicians, economists, and other students of the subject, and I am persuaded that when the needed data are gathered for judging as to the amounts of food consumed by people in the Southern and Western as well as in the Eastern States they will not differ greatly in the general outcome from those already collated. The available statistics of food-consumption in England, France, Italy, and especially Germany, are far more extensive. From these I have selected a number which seem to be fairly representative for comparison with the American dietaries referred to, and with dietary standards proposed by the leading authorities on these subjects.[1] Comparing the American dietaries with the European dietaries and the dietary standards thus brought together, the differences are very striking. The quantities on the American side are very much the larger. This is shown in the figures for the fuel-values, which are taken as the measure of the power of the food eaten to yield heat to keep the body warm and strength to do its work, and are expressed in calories (heat units). The number of the calories in the European dietaries ranges from 3000 to 4200; in exceptional cases of men doing unusually severe muscular work it reaches 4600, and in a single and very exceptional case 5600. In the American dietaries the range is from 3500 to 7800, and in one case of laborers at hard muscular work reaches 8800. Standards by European physiologists for a laboring man at moderate work call for 3050 to 3150, and an American standard for 3500 calories. While men in professional life in Germany, with abundant means, are well nourished with food supplying from 2500 to 2800 calories per day, that of men in similar callings in New England in the cases examined ranges from 3400 to 4500 and more.

We are better fed than the people of Europe, and do more work, and it is doubtless fortunate for us that this is so, but we certainly use much more food than we need. Part of the excess is simply thrown away; the rest is eaten to the detriment of our health. The facts at hand imply that our chief wastefulness is with meats and sweetmeats. This is perfectly natural. People in the United States are generally able to have the kind of food they like and all they wish of it. Sugar is abundant and cheap, and we consume immense quantities, as the statistics of production and importation and our grocers' bills very clearly show. But the worst wastefulness is in the production and use of meats.

WASTE IN THE PRODUCTION AND USE OF ANIMAL FOODS, AND ITS PREVENTION.

FACTS which were briefly cited in previous articles, and which I hope may be given in detail in a later one, indicate that people in this

1 A brief abstract of some of the more important results may be found in Vol. I. of the "National Medical Dictionary," edited by Dr. Billings and published by Lea Brothers & Co. For other facts see articles on "The Chemistry and Economy of Foods," in THE CENTURY MAGAZINE for May, June, July, and September, 1887, and January, May, and June, 1888. More detailed data are to be given in the Report of the Storrs School (Connecticut) Agricultural Experiment Station for 1891.

country buy excessive quantities of meat, and especially of fat meat, that part of the excess is simply thrown away or used for other purposes than food, and that part is eaten to the detriment of health. A moderate amount of meat is, I believe, very desirable. The trouble is in our lack of moderation. We like the taste of meat, we can afford all we want, or at least think we can, we have the idea that we need it or that it is good for us, and we do not realize how much more we use than we actually need. Not only is the excess injurious to health, but the waste it involves is greater than is implied in the actual cost.

The chief use of meats in the nutrition of man is to supplement bread, potatoes, and other vegetable foods; in other words, to supply what they lack for our best nourishment. Our foods, animal and vegetable, furnish us material to build up the framework of our bodies and to repair their wastes on the one hand, and on the other to yield heat to keep us warm and to give us muscular strength for work. Blood and muscle, bone and tendon, are made from the so-called protein compounds, such as the myosin, which is the basis of lean meat, casein (curd) of milk, and gluten of wheat. For fuel to yield heat and muscular strength we use carbohydrates, such as starch and sugar, and fats like the oil of corn and wheat, the fat (butter) of milk, and the fat of meats. Vegetable foods, such as wheat, corn, and potatoes, have relatively little protein, and their nutritive material consists mostly of carbohydrates. Beef, mutton, fish, milk, and other animal foods furnish protein in large amounts, and in easily digestible forms. For our best nourishment we want sufficient protein to build up our bodies and to supply their wastes, as well as carbohydrates and fats to serve as fuel. We use meats and other animal foods to supply the protein, in which vegetable foods are relatively deficient.

Meat is a manufactured product for which a large amount of raw material is required. The manufacture of meat is a process of transforming the vegetable protein, fats, and carbohydrates of grass and grain into the animal protein and fat of beef, pork, and mutton. The same principle applies in the production of milk, eggs, and other animal foods. In the most economical feeding of animals it takes a number of pounds of hay or corn to make a pound of beef or pork. In other words, let the farmer make animal protein and fat from vegetable materials in the best way he can, and still he must consume a large quantity of soil product to produce a small amount of animal food. Hence animal foods are costlier than vegetable. This is the simple explanation of the fact that in most parts of the world meat is the food of only the well-to-do while the poor live almost entirely on vegetable food. Thus ordinary people in Europe eat but little meat, and in India and China they have none at all. It is hard enough for them to get the nutriment they need in vegetable forms. Meats they cannot afford.

But meat-making in the United States to-day is far more wasteful than it need be, on account of the excessive fatness of our meats. This comes about very naturally. We have a great excess of soil-product in the valleys of the Ohio and the Mississippi and on the ranches of the West. At present the pork-maker and the ranchman convert a large portion of this into very fat meat. The pork-producers of the great corn-growing States select the breeds of swine which, as they say, "will take the most corn to market," and have thus got into the way of growing animals that are little else than masses of fat. The beef-growers of the western ranches, and those in the East as well, produce excessively fat meat. Part of the fat is trimmed out of the meat by the butcher, part is left on our plates at the table to go to the soap-man or garbage-barrel, and part is eaten. Unfortunately very many of us eat much more fat, both in meat and butter, than is needed for nourishment, and thus do injury to our health.

The agricultural production of the United States to-day is one-sided. Our animal and vegetable food-products, taken together, contain relatively too little of the flesh-forming ingredients,—that is, those which make muscle and tendon,—and too much of those which serve as fuel. Or, speaking in chemical language, they have relatively too little protein and too much carbohydrate and fat. The reason for this is simple. From careless culture and insufficient manuring, or other reasons, our vegetable products, and especially the grasses and grains, have come to contain small proportions of protein, smaller by from 25 to 40 per cent. or more than the same products grown in Europe. Furthermore, our great staple grain, corn (maize), is poor in protein at best. This helps to explain the relative fatness of our meats. Animals fed on products poor in protein and rich in carbohydrates tend to excessive fatness.

Our national dietary has likewise come to be one-sided. Our food has relatively too little protein and too much fat, starch, and sugar. This is due partly to our large consumption of sugar, and partly to our use of such large quantities of fat meats. In the statistics above referred to the quantities of fat in the European dietaries range from 1 to 5 ounces per day, while in the American the range is from 4 to 16 ounces. In the daily food of the well-to-do professional men in Germany, who were amply nourished, the quantity of fat was from

3 to 4½ ounces per day, while in the dietaries of Americans in similar conditions of life it ranged from 5 to 7½ ounces. The quantities of carbohydrates in the European dietaries are from 9 to 24 ounces, while in the corresponding American dietaries the carbohydrates were from 24 to 60 ounces.

People in this country eat what is set before them, asking no questions for economy's sake provided it suits their taste. We are a generation of sugar and fat eaters. The one-sidedness of our dietary is a result of the one-sidedness of our agricultural production.

To resume. A large amount of soil-product is required to make a small amount of meat. We eat much more meat than is needed to supplement our vegetable food. Our meat is much fatter than would be necessary anyhow. The sugary and starchy foods of which we consume an excess make the fat still less necessary. It is clear then that by the present method of meat production and use a very considerable amount of the grass and corn of our farms and grazing regions is wasted, and worse than wasted.

A reform must come, but it will come no faster than our farmers learn to produce crops richer in nitrogen, and to make more meat and leaner meat from less vegetable material, and consumers learn to buy and use meats and other foods of the kinds and in the proportions best suited to their actual needs. The agricultural reform will lead to the production of more food from less land. The dietary reform will result in the eating of less food per person and food better adapted to the demands of health, work, and purse.

THE SEA AS A SOURCE OF FOOD FOR MAN. FISH-CULTURE.

AFTER we have used our food, the refuse, which contains material that should serve to nourish plants to be used as food again, is to a greater or less extent wasted. In various ways an immense amount of plant-food ultimately finds it way through soils, sewers, and streams into the sea. What makes the matter worse is that the costliest and most precious of all of the elements of plant-food, nitrogen, is the one which is most carried from the land into this great receptacle. The plant-food thus conveyed to the ocean is commonly looked upon as lost for future use. But we recover it to some extent, and may recover far more. Late research has shown that part of the nitrogen is transformed within the waters of the ocean to ammonia, which is continually evaporated from the ocean's surface and carried by winds to the land again, there to be brought to the soil by rain and to serve as food for growing plants. The nitrogen is thus passing through a ceaseless round, from air to soil, from soil to plants, from plants to animals and men who use them as food, and then to the sea, from which more or less returns to the air again. But this is not all the saving of nitrogen from the sea. There is vegetation in the sea as well as on the land. That on the land yields us bread and meat. That in the sea yields fish. Here is the source for an almost inexhaustible supply of nourishment for man. Such reliable authorities as the late Professor Baird, of the United States Fish Commission, and Professor Huxley, serving in a similar capacity in England, have made calculations of the quantities of fish in the rivers, the lakes, and the sea, and of the possibility of increasing this supply by fish-culture. The conclusion as to the amounts of fish which may be made available for food for man seems almost incredible until we look into the facts and find how well they are founded. But this is only part of the story. Fish is especially rich in protein. This fact is brought out very forcibly in a series of chemical studies of the more important species of fish and shellfish used for food, made under the auspices of the Smithsonian Institution and the United States Fish Commission.[1] In other words, by the culture and use of fish we effect a threefold saving. We obtain the protein which is needed to supplement vegetable products of the soil as food for man. We thus reduce the demand for meat, for the production of which the product of so much land is necessary. And, finally, we bring back from the sea in the protein of fish the precious nitrogen which is needed to restore fertility to our exhausted soils.

Incidentally we have here an argument for fish-culture the force of which is not usually understood. Fish-culture not only supplies most valuable nourishment for man, but does so by utilizing material that would otherwise go to waste. It makes the sea supplement the land by producing the very food-ingredient that is most lacking in the produce of the soil. It helps materially toward both the increasing and the balancing of products for human consumption which are so essential for the welfare of the race.

In short, if we make leaner pork and leaner beef, and thus use less soil-product to make fat, of which we now have an excess, and if we get more protein from the sea in fish, and raise correspondingly fewer animals to produce protein, we shall save large areas of soil for the cultivation of wheat and other vegetables for

[1] A detailed account of this investigation, which was conducted by the writer at Wesleyan University, is to appear in a forthcoming report of the United States Fish Commission.

food. In this way the soil can be made to supply far more nourishment for man than is otherwise possible.

INCREASE OF FOOD-SUPPLY BY TILLAGE AND IRRIGATION.

FEW who have not studied the subject realize the possibilities of crop-growing by irrigation. The lands of Egypt, which would otherwise be a desert, have been kept in fertility for centuries by the overflowing of the Nile; the irrigated plains of Lombardy can yield nine crops of grass in a single year; the sewage-farms of England, over which is spread the sewage of cities that usually flows direct into the streams, yield almost fabulous produce. In the geographies that were used in our schools a generation or two ago a large portion of the territory between the Mississippi and the Pacific was designated as the Great American Desert. The largest yields of corn in the United States, now and for years past, have come from the midst of this region and without increase of water-supply, except that which comes with tillage; by irrigation portions of it are made to rival the plains of Lombardy and Egypt. Already our Government is preparing the way for a vast system of irrigation. It is proposed to build dams and to make reservoirs in the mountains of the West to hold the waters of winter until the time arrives for them to bring their store of food for the nourishment of plants and to enable them to withstand the summer's drought. In the belief of those who have studied the matter most thoroughly such an enterprise put into effect will make the region which covers two fifths of the whole United States include the garden of the continent, and capable of sustaining a population as dense as that of Italy or Spain.

There are those who prophesy that the agriculture of the future will be carried on largely by irrigation, and the more one looks into the matter the more plausible the idea appears. But tillage and manuring work wonders in farming. The produce which the Prussian farmer gets from his sandy plains excels that of our virgin prairies. Countless illustrations of this could be cited. Prince Kropotkin describes a case in point.[1]

Is it possible that the soil of the United Kingdom, which at present yields food for one half only of its inhabitants, could provide all the necessary amount and variety of food for 35,000,000 human beings when it covers only 78,000,000 acres, all told—forests and rocks, marshes and peat-bogs, cities, railways, and fields? The current opinion is that it by no means can; and that opinion is so inveterate that we even see a scientist like Mr. Huxley, who is always so cautious when dealing with current opinions in science, indorse that opinion without even taking the trouble of verifying it. It is accepted as an axiom. And yet, as soon as we try to find out any argument in its favor, we discover that it has not the slightest foundation, either in facts or in judgment upon well-known facts.

. . . . . .

If we want, however, to know what agriculture can be, and what can be grown on a given amount of soil, we must apply for information to the market-gardening culture in this country, in the neighborhoods of Paris, Amiens, and other large cities [in France], and in Holland. There we shall learn that each hundred acres, under proper culture, yield food, not for forty human beings, as they do on our best farms, but for 200 and 300 persons; not for 60 milch cows, as they do yield in the island of Jersey, but for 200 cows, and more if necessary. . . . They [the gardeners there] have created a totally new agriculture. They smile when we boast about the rotation system having permitted us to take from the field one crop every year, or four crops every three years, because their ambition is to have six, nine, and twelve crops from the very same plot of land during the twelve months. They do not understand our talk about good and bad soils, because they make the soil themselves, and make it in such quantities as to be compelled yearly to sell some of it; otherwise it would raise up the level of their gardens by half an inch every year. They aim at cropping, not five or six tons of grass on the acre, as we do, but from fifty to one hundred tons of various vegetables on the same space; not £5 worth of hay, but £100 worth of vegetables, of the plainest description, cabbage and carrots. That is where agriculture is going now.

Of this *culture maraîchère*, the distinctive feature of which is replanting, Prince Kropotkin says:

In such a culture the primitive condition of the soil is of little account, because loam is made out of the old forcing-beds. . . . No less than 2125 acres are cultivated near Paris in that way by 5000 persons, and thus not only the 2,000,000 Parisians are supplied with vegetables, but the surplus is also sent to London.

The above results are obtained with the help of warm frames, thousands of glass bells, and so on. But even without such costly things, with only thirty-six yards of frames for seedlings, vegetables are grown in the open air to the value of £200 per acre, and even, with some most successful gardeners, £200 on the half-acre. . . . In fact we are totally unable to realize what the soil can give, unless we have seen its liberality with our own eyes. Let me add also that all this wonderful culture is a yesterday's growth. Thirty years ago the *culture maraîchère* was quite primitive. But now the Paris gardener not only defies the soil,—he would grow the same crops on an asphalt pavement,—he defies climate. His walls, built to reflect light and to protect the wall-trees from the northern winds, his wall-tree shades and glass protectors, his frames and *pépinières* have

[1] In an article on "The Coming Reign of Plenty," in "The Nineteenth Century" for June, 1888.

made a real garden, a rich southern garden, out of the suburbs of Paris. He has given to Paris the "two degrees less of latitude" after which a French scientist was longing; he supplies his city with mountains of grapes and fruit at any season; and in the early spring he inundates and perfumes it with flowers. But he does not only grow articles of luxury. The culture of plain vegetables on a larger scale is spreading every year; and the results are so good that there are now practical *maraîchèrs* who venture to maintain that if all the food, animal and vegetable, necessary for the 3,500,000 inhabitants of the departments of Seine and Seine-et-Oise had to be grown on their own territory (3250 square miles), it could be grown without resorting to any other methods of culture than those already in use, methods already tested on a larger scale and proved to be successful.

The essential features of this system are the selecting of vigorous plants, providing them with proper warmth and moisture, especially in their earlier growth, transplanting them so as to give them the best opportunity for development, and supplying them with abundant food. All this is simply the practical application of the principles which modern science is coming to explain. It is improvement of varieties of plants and the economizing of plant-food and energy.

The selection of the better and the rejection of the poorer individual plants are means for breeding better varieties. Of the variations of animals and plants under domestication Darwin and others have given us notable examples, and the utilizing of the underlying laws constitutes one of the great features of the advance of modern agriculture. Manures, sewage, and other waste products contain the chemical elements of the food of plants that are so precious, because essential for their growth. By the use of glass the direct heat of the sun otherwise reflected from the earth and lost is saved to soil and plant. In the fermenting of waste matters bacteria bring about the union of their carbon and hydrogen with the oxygen of the air, and in this combustion the heat which came from the sun to the plants of whose material the waste matters are composed is made available again. And in the warming by steam-pipes the heat of the sun which was stored in coal in past geologic time is turned to use once more. The power used to carry the water for moistening the soil, whether that of machinery fed by coal, or of animals and men fed by the product of the soil, is part of the energy which the sun supplies.

Thus provided with the proper conditions of growth the plants avail themselves of the stores of material in the air. The product is many times greater than is realized in ordinary farming.

Prince Kropotkin adds "that in the hands of men there are no unfertile soils; that the most fertile soils are not in the prairies of America, nor in the Russian steppes; that they are in the peat-bogs of Ireland, on the sand-downs of the northern seacoast, on the craggy mountains of the Rhine, where they have been made by man's hands." The experience of tillers of the soil past and present, explained by modern science, upholds his statement. More than this, there is valid ground to expect that the food-production of the future may far exceed anything that these statements can even suggest.

Toward the realization of all these things that agency which is the fruit of rationally interpreted experience, and to which we give the name of science, is an indispensable and most efficient aid.

About the middle of the last century, a lighthouse, known as the Dunston Pillar, was built on Lincoln Heath, in Lincolnshire, England. It was erected to guide travelers over a trackless, barren waste, a very desert, almost in the heart of England; and long it served its useful purpose. The pillar, no longer a lighthouse, now stands in the midst of a rich and fertile farming region, where all the land is in high cultivation. For many years no barren heath has been visible, even from its top. Superphosphate of lime, a chemical invention first applied to land by the British chemist Murray, and brought to the notice of reading farmers by Baron Liebig, has been the chief means through which this great change was effected. Superphosphate over great stretches of English soil makes, or once made, the turnip crop. Turnips there support sheep, and with sheep the English farmer has been able to get rich on the poorest light lands.

Had not chemists busied themselves to find out what makes plants grow, and had practical farmers not been ready to use their discoveries, Lincoln Heath would perhaps still remain a waste. What is true of this bit of English soil is true in greater or less degree of wide areas of our own and other lands. Whether poor by nature or exhausted by cropping without return of the plant-food taken away, soils can be made fruitful by proper treatment. How to do this, science helps us to find out. The veteran agricultural chemist Professor Johnson of Yale University, Director of the Connecticut Agricultural Experiment Station, who cites the above instance, tells the exact truth in saying further:

Agriculture, as well as other industries, has received large benefits from the systematic investigations of science. Chemistry, for example, has taught agriculture how to utilize the refuse of slaughter-houses and fisheries — the bones, the flesh, the blood, which but a few years ago were waste, a nuisance, and a peril to the public health. It has found vast mines of fossil phosphates in

England, Norway, Spain, France, Germany, Russia, in Austria, Canada, and many parts of the United States; and has shown how they may be quickly and profitably converted into a precious fertilizer.

Chemistry, by discovering and actually defining the food-elements of vegetable growth, and by revealing their sources and realizing the means of making them cheaply available to the farmer, has triumphantly overcome one of the previously insuperable obstacles to the development of national wealth.

Italy, Germany, France, Britain, and the United States have seen or are seeing the productiveness of thousands of their fields decline to a profitless minimum, until lands once beautiful with harvests are desolate and abandoned. But the artificial barrenness and exhaustion, like the natural barrenness of the heath or sand-down, yield to the touch of science; and in all the older countries I have named the work of reclamation is in full progress, and, barring some great calamity of politics or nature, we are confident that the producing power of their soil will never again be less than now, but will increase manyfold in the future, until they become gardens in all their breadth and to the very hilltops.

THE DOCTRINE OF MALTHUS AND THE FOOD-SUPPLY OF THE FUTURE.

THIS last statement promises wonderful things. It also brings us to the gist of the whole matter.

The doctrine of Malthus regarding the future food-supply of the world and the ultimate starvation of a portion of the race has been greatly misrepresented, but even the most favorable interpretation is a gloomy one. Briefly stated the theory is that population increases in a geometrical and food-supply in an arithmetical ratio; and hence the time must come when there will not be food enough. Perhaps the simplest and most correct reply to this theory is that the assumption that the race increases and will continue to increase in geometrical ratio is not borne out by observed facts. The theory that the food-supply increases in only arithmetical ratio, and must ultimately reach its limit, is doubtless nearer the truth. But while there is a limit to the possible production of food, it transcends all the ideas that ever occurred to Malthus or to the people of his time. It has always been assumed that the capacity of the soil to produce plants is measured by what is popularly called its fertility — that is to say, the amount of production possible under ordinary conditions of culture. The science of to-day, however, shows this measure to be incorrect, and the practice of agriculture is already beginning to add its testimony to the same effect. And remarkable as is the story told in market-gardening, in the reclaiming of the desert, and in irrigation, it is only the first chapter of a tale the already attested wonders of which almost rival those of the Arabian Nights.

The fundamental mistake out of which grew the gloomy doctrines of the older theorists was in measuring the possibilities of production by what they knew of soil-culture. Science had not revealed to them that, aside from proper temperature and moisture, the essential factor in vegetable production is plant-food; that this may be given to the plant without the aid of the soil; that what they understood by soil-fertility is a comparatively unessential factor of agricultural production; that, in short, the possibilities of the food-supply in the future are measureless. Since some of these facts are of comparatively late discovery and not very generally understood, and their bearing upon the present question is not always appreciated, they demand, perhaps, a few words of explanation here.

Modern research, in discovering the laws of nutrition and growth of plants, has shown that they can flourish on the most barren soil or even without any soil at all. Of the materials that make up the plant only a very small proportion — say two per cent. or thereabouts of the weight of grass when ready to be made into hay, and a still smaller proportion of the ripened grain of wheat or corn, for instance — has come from the soil, the rest having been supplied by the air from its stores, which are inexhaustible. If we heat a wisp of hay, a grain of wheat, or a piece of potato in an oven long enough it will be dried. The water thus driven out originally came from the air, though the plant obtained most if not all of it from the soil through its roots. If we put the dried material into the fire, the bulk of it will burn away, and only ashes will remain. The combustible portion consists mainly of four chemical elements, carbon, oxygen, hydrogen, and nitrogen. The carbon was obtained by the plant from the air, mainly through its leaves. Oxygen and hydrogen are the constituents of the water, which the air also furnished, and the nitrogen likewise came from the air, though a large part of it — until lately it has been claimed that practically all — was first accumulated in the soil and taken up by the plants. The only food which the soil supplies to plants from its original sources is the small quantity of mineral matter which we call ashes when the plant is burned. Of every hundred pounds of the flour we use for bread, or of the pasture grass from which cattle feed and our meat is made, only a little over a pound in the case of the flour, and about two pounds in the case of the grass, was furnished by the soil on which the wheat and the grass were grown. And that small quantity which the soil contributes from its own original stores is made up of a certain list of chemical elements the majority of which are contained in ordinary soils in such abundance that the cropping of ages would not begin to exhaust them.

It is hard to think of anything more barren, more destitute of fertility, than sea-sand. In connection with some studies of the chemistry of vegetable production in the laboratory of Wesleyan University we have been growing plants in just such sand, brought from the shore of Long Island Sound. To divest it of every possible trace of material which the plants might use for food except the sand itself, it was carefully washed with water and then heated. The young man who prepared the sand for use, in his zeal to burn out the last vestiges of extraneous matter, heated the iron pots in which it was calcined so hot that they almost melted. The sand was put into glass jars, water was added, and minute quantities of chemical salts, which plants take from the soil, were dissolved in it. In the sand thus watered and fertilized dwarf peas were grown. Peas of the same kind were cultivated by a skilful gardener in the rich soil of a garden close by, and grew to a height of about four feet, while those in the sand with the water and the minute quantities of chemical salts reached a height of eight feet.

This is an old story. For that matter, plants will thrive without even the sand. Experimenters have devised the method of water-culture, by which plants are grown, not in soil at all, but with their roots immersed in water in which are dissolved the ingredients of their food, which the roots ordinarily gather from the soil. The stems and branches are upheld by appropriate supports. Thus cultivated, they are in every way healthy, and attain a more than tropical luxuriance, a development rarely equaled in field-culture. This method of growing plants by water-culture, as it is called, has been developed in Germany more than anywhere else. Professor Wolff, of the Agricultural Experiment Station in Hohenheim, raised four oat plants in this way with 46 stems and 1535 well-developed seeds. Professor Nobbe, of the Experiment Station in Tharand, thus grew in jars of water a Japanese buckwheat plant nine feet high, weighing when air-dry 4786-fold as much as the seed from which it was produced, and bearing 796 ripe and 108 imperfect seeds. Wheat, maize, and other plants, and even trees, are grown in this way. Professor Nobbe now has some trees produced by water-culture from seeds of others which also had never been in soil at all, but had grown with their roots immersed in water. The requisites for such plant-growth are proper temperature, water, and certain elements of plant-food, of which very minute quantities suffice. Given these, and the air will supply the rest, and, if other conditions are right, abundant yield is sure.

The experimenters have found just what are the chemical elements that plants take up by their roots. The list includes phosphoric acid, sulphuric acid, chlorin, iron, lime, magnesia, potash, and, for many plants, at any rate, some compound of nitrogen. It happens that the most of these substances exist in abundance in even the most barren soils. Iron and chlorin never, magnesia rarely, and sulphuric acid and lime seldom, fail to be supplied in abundance. The elements most frequently lacking in our ordinary soils are phosphorus, which is contained in phosphoric acid, potassium, the basis of potash, and nitrogen. These soil-elements are quickest exhausted in our ordinary farming. They, more than any others, are wanting in poor and worn-out land, and they are the most precious constituents of manure. With plenty of these, and proper water-supply, we need have no fear for the agriculture or the world's food-supply of the future.

Although it has been reserved for the science of the present to show that warmth, water, and plant-food are the prime factors of successful crop-growing, the principle has been acted upon from time immemorial. It is at the basis of the irrigation that has been practised since the most ancient times. It is as actually applied in market-gardens about Paris, where such surprising results are obtained; on the sands of Belgium and Holland, that yield food for a dense population, and on the soils of North Germany, which, though they are naturally poor, and have been in cultivation for many centuries, excel to-day the rich soils of our new West in their produce. Not the natural fertility of the soil but its rational culture is what brings the largest, the surest, the most enduring harvests.

THE FUTURE SUPPLY OF PLANT-FOOD.

In discussing "The Economy of Nitrogen" from the standpoint of the then prevalent view, a writer in the "Quarterly Journal of Science" some fourteen years ago said:

> To economize nitrogen, phosphorus, and potash, to recover these bodies from waste, and to find substitutes for their present profligate applications is the most sacred task which the chemist can take in hand. The reforms which may shield us from occasional pestilence sink into insignificance compared with those required to guard posterity, in a not very remote future, from chronic scarcity, from recurrent famine, and from a wolfish struggle for food, in which man must relapse into a worse savagery than that from which he has emerged.

But can we obtain the phosphoric acid, the potash, and the nitrogen? It seems to be a law of human progress that when a great want is defined, the discovery of its supply soon follows. When advancing science had revealed the need of phosphoric acid in poor and exhausted soils, mines of phosphate were found in England, France, Germany, Spain, the islands of the Caribbean Sea, Canada, different parts of the United States, and elsewhere, and the already visible supply, that which has been discovered in the present century, is sufficient for the agriculture of untold thousands of years to come.

For the potash there was for a time no adequate promise. The soap-maker long ago outbid the farmer for the potash of wood-ashes; that of saltpeter is very limited in quality, and wanted for making gunpowder, for salting meat, and for other purposes. A process was invented for obtaining potash from sea-water, which contains a very minute percentage, but the cost of extraction was too great to make it feasible. But some years ago it was discovered that this costly process of evaporation had been carried out on an immense scale, in past geologic time, over an area of some sixty square miles in the region of Stassfurth in Germany, and that in this almost inexhaustible bed of sea salt the potash compounds were on the top. The use of the German potash salts speedily became common in European agriculture, and has extended to the United States and to the coffee-fields of Brazil and Ceylon. The results have been remarkable. Muriate of potash, mined and refined in Germany, brought to this country, and applied at the rate of 150 pounds, costing $3.50, per acre, on the worn-out soil of a Connecticut farm within a mile and a half from where I am now writing, has made the difference between corn so poor as to be hardly worth the husking, and a crop of sixty bushels per acre of the finest shelled corn, and a most excellent growth of stalks. Even if, in the far-distant future, the Stassfurth potash mines should be exhausted, it is by no means improbable that others may be found. It is evident then that we need not be troubled about the phosphoric acid or the potash.

With the nitrogen the case has, until lately, been somewhat different. Although four-fifths of the air are made up of this element, and over every acre of land there are hundreds of tons of it, crops often fail for lack of it. The prevailing doctrine has been that plants do not avail themselves of the nitrogen of the air to any extent, but are dependent solely on that which has accumulated in the soil in past time or is supplied as manure. The scientific interest of the subject and its incalculable importance have made the question of the acquisition of atmospheric nitrogen by plants one of the hardest fought in the annals of biological and agricultural chemistry. That plants should be without this power appears strange, and many observed facts in agricultural practice imply very decidedly that leguminous plants, such as clover, vetch, beans, and pease, somehow succeed in getting hold of the free nitrogen of the air and in using it for their growth. But the experiments of the most noted investigators have seemed to bring positive evidence to the contrary, and the prevalent doctrine has been that atmospheric nitrogen is not available to vegetation.

The evidence against the assimilation of atmospheric nitrogen by plants came from experiments in which the conditions differed considerably from those of ordinary plant-growth. In a series of experiments by the writer, the results of which were published in 1881–84, plants (pease) were grown in sand to which water with plant-food in solution was applied, but under conditions otherwise normal. They were found to contain, when ripe, much more nitrogen than was supplied in the nutritive solution and seed. The only possible source of this extra nitrogen was the air. A conclusion so opposed to the commonly accepted belief was received with hesitation, and very naturally so. But in the years following a number of other experimenters obtained similar results. Furthermore, several others, among whom is Professor Berthelot of Paris, have found evidence that soils as well as plants acquire nitrogen from the air to a much greater extent than was formerly supposed, and that they get this nitrogen very probably by the aid of microbes. And what is still more to the point, Professor Hellriegel of Germany has within the past six years made several hundred experiments and not only found that the leguminous plants — pea, lupine, and serradilla — which he has grown acquire large amounts of the free nitrogen from the air, but has brought very strong indications that microbes in the soil are the agents by which it is done. On the table where I write are the figures for somewhat over 250 experiments carried on during the last three years. They not only confirm to the fullest extent the conclusions published in 1881–84, and those of Hellriegel and others since, that the leguminous plants obtain large quantities of nitrogen directly from the air, but show in a no less convincing way that the amount of nitrogen acquired is more or less directly proportional to the number of nodules on the roots, called root tubercles, in which Hellriegel and others believe the microbes to act. With other plants, alfalfa is here found to obtain very large supplies of atmospheric nitrogen. Considering the great importance of alfalfa in a large part of the country, and especially in the irrigated regions of the West, its power to acquire nitrogen is certainly a weighty matter. Professor

Wolff in Germany has reported experiments which indicate that clover has this power of drawing its nitrogen from the air. His results are confirmed by Messrs. Lawes and Gilbert in England, who were formerly, with M. Boussingault in France, the leading exponents of the opposite doctrine, but who, to-day, in the true scientific spirit, heartily accede to the conclusions which later research is bringing. Kindred results are being obtained by numerous other investigators, and it now looks as though the leguminous plants in general, at any rate those most commonly cultivated, are possessed of this remarkable faculty. Just what species of plants acquire nitrogen from the air, and how they get it, are problems still to be settled.

The connection of microbes with the supply of nitrogen to plants is very interesting. It has been long understood that the nitrogen of animal and vegetable matter in the soil is somehow made available to plants for food. Several years ago two French chemists, Messrs. Schlössing and Münz, discovered that the change is brought about by a ferment. Just what the organism is that performs this most beneficent office of transforming the effete matters of the earth so that they may again become food for plants and man, biologists have sought to learn, but without success, until a short time since, when Herr Winogradsky in Zurich, Switzerland, by a most ingenious series of experiments found evidence that bacteria are the agents. He has given to the group which he finds to cause the nitrification, as the change is called, the name Nitromonas. Still more remarkable is the action of microbes in helping plants to utilize the nitrogen of the air. What the species are and what is their exact connection with the process are questions which bacteriologists in Europe and the United States are now studying with the most eager activity. New facts are continually being brought to light, and we may hope for more definite answers to the problems before many years. But the interesting and withal inspiring thing is that these organisms, whatever they shall be found to be, are thus constantly providing for our welfare, that they are necessary and efficient ministers to our very existence. We are wont to think of microbes as only the germs of fever and cholera and consumption, the agents of disease and death; but they are no less truly the means of providing us with what is indispensable to life. The microbes that help plants to their nitrogen thus become, in the light of modern research, part of the beneficent system by which the earth is enabled to give its nourishment to man.

The practical bearing of all this is evident. As the store of nitrogen in the soil is reduced, the soil is exhausted and refuses to yield its harvests. Nitrogen eludes the husbandman, in being leached out of the soil by drainage waters, and in escaping to the air. He supplies it in manures, of which it is the costliest ingredient. Farmers throughout the older portions of our country pay from ten to twenty-five cents per pound and more for nitrogen in guano and nitrate of soda from South America, in sulphate of ammonia from Europe, in dried blood and meat-scraps from slaughter-houses, and in other commercial fertilizers. For these materials millions of dollars are expended every year in the United States, and the supply of some of them is being gradually used up. By raising leguminous crops, which are in many ways the most valuable for fodder, and which make the richest manures, the farmer may obtain his nitrogen from the air without money and without price. This farmers do and are learning to do more and more.

ENERGY AND FOOD-PRODUCTION.

THE supply of plant-food thus seems to be assured. But the population of the earth may become so dense that very general irrigation will be necessary. The rivers, the lakes, and the sea will furnish water, if it can only be transported. This requires power, energy. Will the energy be forthcoming? Is it at hand?

We are accustomed to think of burning wood and coal as the chief sources of power. But their energy is nothing in comparison with that of moving wind, rivers, and tide, and even that fades into insignificance in comparison with the energy of the sun's heat, a source of power so great that we can scarcely conceive of its vastness. When we reflect that remarkable as are the uses we already make of the different forms of energy, our knowledge of them is still in its infancy; that we are apparently much nearer the storage and transport of the energy of stream and wind and sun than our grandfathers were to what we realize to-day in the use of steam and electricity, it takes no great faith to believe that science and invention will, in due time, supply the need. And with this use of mind to make the forces of nature do what has before been either done by the labor of our hands or left undone, the natural order of events will continue to bring what the progress of the past has brought — more product and larger profit with less manual toil.

Instead of the yield of a dozen bushels of wheat from the poor or exhausted soil of an acre, which was, a comparatively few years ago, a common average in England, and is to-day in a large portion of the United States, thirty bushels of wheat per acre has come to be an average with better culture in England, and will come with us when the demand calls for it. It is not to such increase as this, however, that we must look for the food-supply of the future, but to such yields as come with sand- and water-culture. We are not restricted to the thirty or sixty or one hundred fold of the New Testament parable, but may look for the thousand fold that is realized with abundant supply of plant-food and water without any regard to soil.

Nor is there anything abnormal in such vegetable production. That a single plant should produce a thousand seeds, as Professor Nobbe's buckwheat plant did, when fifty would be a large yield in ordinary practice; that the produce of a given area should be scores or even hundreds of times what we ordinarily see; that half a dozen crops should be grown on the same area every year instead of one, is not what we are accustomed to, but is not at all unnatural. What we call natural growth is really stunted growth. Our plants are subject to fluctuations of temperature; they have too much or too little moisture; their food-supply is scant or one-sided; and these very hindrances to their growth have had the further effect of preventing the development of varieties capable of producing the largest amount of the most valuable material. Let plants be trained by selection and cultivation to do their best, let them have the opportunity which comes with proper regulation of temperature and moisture and food, then perhaps we shall see what nature can and will do for us. As well say that the philanthropist is the abnormal, and the untutored child of nature the normal man, as that there is anything abnormal in such large vegetable production.

ARTIFICIAL PRODUCTION OF FOOD. CHEMICAL SYNTHESIS.

But even if there were no such probability of almost unlimited vegetable production, there is still possibility for food-supply in artificial manufacture by chemical process. Plants take the elements carbon, oxygen, hydrogen, and nitrogen, and combine them, in the forms of starch, sugar, oils, fats, gluten, and other compounds which serve to nourish animals and man. Within the memory of many chemists now living it was believed to be impossible to build up such compounds from their elements by artificial means. But chemistry has found means to imitate these processes of combination. Within the past few years many such compounds have been produced in the laboratory by synthesis. A few months ago, in reply to an inquiry from a friend as to the probability of thus making the nutritive ingredients of food, I wrote: "The advance of science in this direction is not enough to warrant any prophecy of the synthesis of food-material,—indeed such a feat seems almost visionary,—but it is hardly safe to say that it is impossible, and there are those who are confident that it will be done."

Chemists distinguish between various kinds of sugars. To one class belongs cane-sugar, which is formed in the sugar-cane, sorghum, beet, and maple, and which we use at the table; to another class belong the glucoses, of which the fruit-sugar that occurs in grapes and other fruits, and the glucose which is manufactured on a large scale from the starch of corn are samples. Some time since Professor Fischer of Würzburg, Germany, succeeded in the synthesis of several sugars closely allied to fruit-sugar. The news has just come that he has found a way to transform glucose into a sugar of the type of cane-sugar. We have long known how to convert starch and cane-sugar to glucose; the process is one of changing a more complex compound to a simpler one. But the possibility of reversing the process was long doubted. Yet just this is what Professor Fischer has now accomplished.

Still more remarkable, I was going to say,—but the time for calling such things remarkable seems to be past,—is the account which has come to hand within a few days of the preparation of an albuminoid compound by synthesis. How carbohydrates and fats may be prepared artificially we have come to understand. But the albuminoid compounds contain more chemical elements, and are far more complex; they are indeed the highly organized material of vegetable and animal life. That these substances could be made in the laboratory has been hard to believe. Yet Professor Schützenberger of Paris has just reported to the French Academy of Science the synthesis of a compound similar to the peptone into which the albuminoids of our food are transformed in the process of digestion.

Farming by water-culture, or the artificial manufacture of food-compounds, would not be feasible or profitable to-day. The growing of a buckwheat plant with a thousand seeds and the synthesis of sugar and protein are now only curious and costly experiments. But will they always be so?

A few years ago an interesting but troublesome lecture experiment consisted in providing a large galvanic battery and causing the current to pass from one piece of carbon to another. A bright light was produced, and there were persons with faith enough to predict that electric lighting would at some time in the distant future be made a practical success. The light of the electric lamp at every street-corner suggests most forcibly that we may be nearer the realization of other triumphs than we think. What we know of these things to-day more than the Romans knew sixteen centuries ago has nearly all been discovered within the last sixty years. The rate of discovery far exceeds the rate of increase of population. Long before population becomes dense enough to demand such production as I have been suggesting we may hope that the details will have been worked out to make it easily feasible.

A German chemist, Professor Knop, wrote a book on agricultural chemistry. When it was done he gave it the title *Der Kreislauf des Stoffs* (The Circulation of Matter). He realized that he had been simply describing the ways in which the elements pass through a ceaseless round of changes, by which they are made parts of air and earth, then of plants, and animals, and man, then of air and earth again. In this round our food is made, our bodies are built up, and then both are resolved into their elements again. Chemical elements are combined by natural forces into starch and protein, into bread and meat, into muscle and brain. The supply of the elements is limitless for the simple reason that none is ever lost. Like the water which after moistening the soil and nourishing the plant passes away to sea or sky only to come again as rain, the elements of food are resolved into their simpler forms only to be made into food again. How much food mankind may have is not a question of area of arable land or of soil-fertility at all, but of man's control of the forces of nature. That control increases with the increase of human knowledge.

In the past man has had the strength of his hands, and that of the beast which he has subjected to his will, to do his work. In the present he uses the power that came from the sun and is stored in coal. This makes possible the industrial advancement, the lessening of the hours of labor, the rise of the scale of living, and the spread of knowledge. The material and intellectual progress of the nineteenth century is the using of potential energy.

With a supply of material exhaustless and enduring, with power to utilize it unbounded as the energy of the sun, with prospect of new discovery unlimited as the sphere of human knowledge, what bound dare we set, what fear need we entertain, for man's future sustenance?

The rôle of the political economist is hardly fitting for the chemist. But one inference continually occurs to me. To make manufactured products abundant and cheap large demand has been necessary. With the hand-loom of the past a given number of people living in a given area could weave a small amount of cloth. In the factory of the present each operative produces many times more than the weaver of the olden time, many more work in a given territory, and cloth is produced at a much lower cost. The agriculture of the future will perhaps be a manufacturing process with correspondingly increased product. It may seem paradoxical to say that the dense population which the older economy told us was to be the precursor of starvation will be actually the antecedent condition of a cheap and abundant food-supply; but is this anything more than the reassertion of a principle which has proved itself true in the manufacture of cloth in the factory, of machinery in the machine-shop, and in countless other ways?

IN CONCLUSION.

To resume briefly. In the light of our present knowledge the problem of the world's future food-supply is conditioned upon two things. One is plant-food, the other is energy, power to manufacture and transport plant-food, and to transport water. The visible supply of plant-food is such that the only element about which there has for some time been any question is nitrogen. Late research implies that this can be easily derived from the atmosphere in unlimited quantity. With the unmeasured energy of the wind, flowing water, and tide, to say nothing of the immensely greater energy of the sun's heat, and the possibility of storage, transfer, and use of energy by electricity and other agencies, we may hope that the science of the future will provide the power. The amount of vegetable growth that is possible within a given area is entirely outside our ordinary calculations. The old way of estimating possible food-production by land-area and soil-fertility is wrong. We have only to assume that as the population of the earth increases there will be a corresponding improvement in the use of plant-food and energy, of which the supply is practically inexhaustible, and the problem is solved.

So strangely yet simply it comes about that in the providing of what is essential for the best welfare and highest happiness of mankind in the future, the things which have seemed farthest from our reach, nitrogen and energy, are the very ones which Providence places about us at all times and in utterly inexhaustible amounts. To make them available requires only the pushing of discovery a little farther along the lines in which it is now moving rapidly and surely. To make a practical use of them requires only the demand for the product. If it is conceivable that population should become so dense as to demand more food than can be thus produced by natural growth of plants, there still remain the resources of artificial production. And if it be allowable to reason from analogy, what is needed to make food more abundant and more cheap is enough population to make sufficient demand.

The capacity of men to consume food is limited. The possibility of its production is almost limitless. The very increase of population which the Malthusian doctrine makes the cause of starvation will thus become the condition of cheap and abundant sustenance. So the use of man's brain transforms the prospect of dire calamity, of misery ineffable, into the promise of inexpressible blessing.

The doctrine of Malthus is the product of a time when men's thoughts ran in gloomy channels, when a stern logic, arguing ruthlessly from premises which to-day we cannot accept, led to conclusions at utter variance with the kinder teachings of nature and revelation, and the gentler aspirations of the human soul.

War, pestilence, and famine will not be needed to remove part of the people of the earth in order that the rest may be kept from starving. Instead of using the sword to kill, it may be turned into the plowshare to help abundant harvests. Pestilence, once thought to be the visitation of divine wrath, we now know to be the work of the microbes of disease. Not only are we finding how to prevent the ravages of these creatures, but we are learning that they are the upholders as well as the destroyers of life, and may be made the agents to protect our children from the very starvation our fathers so much dreaded. In place of the rule of famine which has been prophesied, we have the promise of a reign of plenty.

The doctrine here maintained is optimistic, decidedly so. But what was the earth made for? Is it governed by a beneficent power, or is it not? Are mankind the creatures of Almighty malevolence, or are we the children of a loving as well as omnipotent Father? Are we placed here in a world which is bad and ever growing worse, or is there a continual evolution toward higher and better and happier things? Faith has always had its reply to Malthusian pessimism, though that reply has been vague. The Science of to-day makes it clear. So Faith and Science rightly joined ever lead us to the light.

W. O. Atwater.

FOLKSONG.

"THIS work must give me lasting fame;
Immortal shall it make my name.
Forever live, my monument.
Indeed these years I deem well spent
The while its fabric I have wrought
With web of fancy, woof of thought."

The poet threw aside his pen.
His book was praised awhile by men,
And now it lies on dusty shelves
In corners where the bookworm delves.

Kind Fortune brought some leisure days.
The poet wrote some casual lays:
Songs with smiles and tears together,
All moods of man, like April weather;
"Frail and fleeting fair," said he,
"Their fate is quick obscurity."

But nature's breath inspired their art
And Mankind took them to its heart.
They grew into the people's life,
They marched with soldiers into strife,
Were lullabies for babyhood,
Were whispered low where lovers wooed,
Were sung at weddings to the bride,
Were chanted open graves beside.

The songs have won immortal fame,
And no man knows the singer's name!

Sylvester Baxter.