THE NEXT HUNDRED YEARS . . . II

As population increases, the need to obtain more food becomes more pressing. A noted plant physiologist considers some of the ways we might increase our food supply.

by HARRISON BROWN, JAMES BONNER AND JOHN WEIR

This article has been extracted from the book, The Next Hundred Years: Man's Natural and Technological Resources, *by Harrison Brown, James Bonner and John Weir, copyright 1957 by The Viking Press, Inc., to be published in June. Dr. Brown is professor of geochemistry at Caltech; Dr. Bonner, professor of biology; Dr. Weir, professor of psychology.*

This extract, the second in a series of three, has been drawn largely from Dr. Bonner's evaluation of our agricultural resources. Next month, Dr. Weir discusses technical manpower sources.

THE POPULATION of the world has climbed with extraordinary rapidity during the course of the last century and has now reached a level of about 2.6 billion persons. Between 1850 and 1900 the world society grew by about 0.7 percent per year; this rate would produce a doubling of population every century. Between 1900 and 1950 the average annual rate of increase was 0.9 percent, shortening the doubling time to about 75 years . . . If we were to assume that the increase of population during the next century would average 1 percent per year, we would foresee a world of nearly 7 billion persons by the middle of the next century.

Such rapid rates of population growth can, in the long run, be maintained only if the production of food can keep pace with this growth . . . Thus, in our forecasts concerning the future, we must examine the problem of feeding this number of persons adequately.

Increases in food supply are attainable by wider application of present technology. Agricultural productivity can be increased by the use of more irrigation, more fertilizer, more insecticides; by the application of more plant-improvement technique; and by practicing more intensive agriculture. The rate at which such increase can be achieved is between 2 and 4 percent per year and should thus suffice to take care of our increasing world population.

True, to spread this technology will be a long, hard task, since it must diffuse to so many people, but theoretically it can be done. And, meanwhile, new technological developments may increase the rate of growth of our food supplies, or raise the maximum amount of food which can ultimately be produced, by the introduction of new methods of management of crops and of human diets.

A most effective method of increasing the amount of food available to people would be to decrease that fed to animals. Animal protein forms an important part of the human diet today, particularly in the Western countries. The American, for example, consumes about one-third of his diet calories in the form of such things as meat, milk, and eggs; the Western European about 20 percent; the Asian only about 5 percent. We consume animal protein not only because it tastes good to us, but also because it provides a plentiful supply of the amino acids essential to human nutrition, in the most favorable proportions. Yet these same amino acids are

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present in the protein of plants, from which the animal product has derived them, and with proper preparation can be effectively used.

The animal is a relatively inefficient converter of plant material to food for human beings, as is shown in the following table.

Production of Protein per Acre by Different Methods of Land Management (All values for cultivated crops on arable land)

METHOD OF LAND MANAGEMENT	METHOD OF RECOVERING PROTEIN	EDIBLE PROTEIN (pounds, per acre per year)
Planted to forage, grain, fed to steers	as beef	43
Planted to forage, grain, fed to cows	as milk	77
Planted to soybeans	as soybeans	450
Planted to alfalfa, U. S. average crop	as extracted protein	600
Planted to alfalfa, Western U. S. irrigated	as extracted protein	1500

The production of protein by conversion of plant substance to beef, which supplies about one-half of the world's meat, has an efficiency of only 5 to 10 percent, both in terms of food calories and in terms of protein. The production of milk protein is considerably more efficient than is the production of beef. Both of these procedures are, however, much less efficient than it would be to use our crop area for the production of soybeans, which produce seeds rich in protein, and to eat the soybeans ourselves. And the plant which produces seeds rich in protein is, again, less efficient as a protein producer than is a plant such as alfalfa, which is rich in protein in all its vegetative structure.

Alfalfa is, of course, grown to supply protein for animal diets, and there is no reason in principle why it cannot be used to supply protein directly in the human diet. If we are to use plant protein on a large scale as food for people, however, it will be necessary to devise methods by which the plant may be ground and the protein extracted. We will also have to find ways of fabricating the protein thus extracted into materials resembling such things as meat, eggs, and milk. But these are merely technological problems and are certainly soluble. This modification of our food technology would permit us to supplement human diets with the needed amino acids at a fraction of the cost in acres that characterizes our present system.

A second modification of our agriculture which could provide an important increase in the world's food supply is the replacement of crops which are less efficient in food production by crops which are more efficient. This raises the question of the efficiencies of different crop plants. Wheat yields less food per acre than do rice, potatoes, or sugar beets, but this is in part because the land sown to wheat is often less favored by rain or temperature than are the lands chosen for the other crops. Similarly, yields are often low in the underdeveloped areas because of limited supplies of fertilizer.

Let us, then, compare the efficiencies of crop plants as producers of food when each crop is grown under conditions as nearly ideal as possible.

Efficiency of Various Crops in Production of Food in Varied Regions

REGION	CROPS	FOOD PRODUCED (millions of calories per acre per year)
United Kingdom, moderately intensive farming	cereals (wheat)	2.9
	potatoes	6.7
	sugar beets	7.3
Northern Europe (Denmark, Holland), intensive farming	wheat	4.5
	potatoes	8.0
	sugar beets	13.0
Japan, intensive farming	rice	6.5

It is clear that the cereals compare unfavorably with potatoes or sugar beets, since high-yielding crops of the latter produce up to twice as many or more edible calories per acre as do the cereals. This is due to two principal factors. For one thing, the potato or sugar-beet crop takes longer to develop than does the cereal. Leaves that are exposed longer to the sun's energy have more opportunity to gather and store that energy. And in the second place, 50 to 60 percent of the potato or sugar beet plant is edible and digestible by man, as contrasted to 30 percent or so of the cereal.

To look at it in another way, the energy which is stored in plant material is energy the plant has captured from the sun's rays. Plants as we know them appear to be very similar in the efficiency with which they store solar energy in chemical form. Given favorable temperature, plenty of water, and abundant fertilizer, our crop plants uniformly capture about 2 percent of the incident energy.

High yields of food material per acre are attainable if we use a crop which remains active in the field for a long time. Thus the tropical sugar cane, which captures the sun's energy the year round, readily produces twice as much sugar per acre as does the sugar beet, which grows for but five months or so. And, in addition, the chemical equivalent of 2 percent of the sun's energy must be divided among the varied portions of the plant. The grain is a smaller portion of the cereal than is the sugar of a sugar beet.

These considerations are clear enough and provide us with a clear-cut goal in plant improvement. We want a plant which grows over a long season and of which as high a proportion as possible is edible. The commer-

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cial sugar beet is in fact a product of genetic improvement by which the original low-sugar plant has been bred for high sugar content and high per-acre yields. We know how to breed crop plants high in other constituents, such as fat and protein. It is not at all impossible that we might be able to alter our sugar-producing plants by genetic means to cause them to accumulate fat, protein, or other dietary necessities in higher yield. Thus, we might breed a meat beet or a fat plant.

Inedible residues

There is still another approach to the problem presented by the fact that only a relatively small portion of the cultivated plant is edible to the human being. We can convert the inedible residues to food. Such residues are abundant. In the United States, for example, in which the human being yearly eats about 0.37 ton of food, we produce each year about 1.75 tons per capita of the inedible residues of corn and wheat—stalks, stems, corn cobs.

The technology of the conversion of these woody materials to material digestible by man is well worked out. It is possible to treat the woody plant material with hot acid and produce a molasses-like syrup of roughly 50 percent of the weight of the original material. The present estimated cost of molasses from this source is roughly ten times that of molasses from sugar beet or sugar cane. It is further possible to convert the molasses by yeast fermentation to a protein-rich material. The yeast obtainable from the molasses in 50-percent yield is also potential food for man.

If the need for food in the world were great enough we could theoretically convert the bulk of our woody residues to sugar or protein by this method, a measure which by itself would increase our food supply by perhaps 50 to 100 percent. The food increment would be costly, since it would require the expenditure of a great deal of energy and investment in much new technology, but it could be done, should it become necessary.

The step which appears, however, to be most practical for the ultimate augmentation of our world's food supply has to do with the management of water. Water availability is today a major limiting factor in crop production and in determining crop areas. There are in addition vast areas of steppe and desert which would be suitable for agriculture if water were available.

At the present time about 11 percent of the world's cultivated acres are supplied with water by conventional irrigation schemes. This amount is rapidly increasing, particularly in Asia and Latin America. It has been estimated that if the waters of the rivers of the world are appropriately conserved and distributed it should ultimately be possible to irrigate 14 percent of the world's cultivated acres at current prices of water and of farm products. This amount could undoubtedly be increased still further, perhaps to as high as 20 percent of the world's cultivated acres, by the building of expensive conventional irrigation projects. There is nonetheless just not enough water in the streams to irrigate any substantially greater portion of the earth's surface than this, by conventional methods.

We cannot hope, therefore, to water the steppes and deserts, which together constitute over twice as large an area as the land now under cultivation, by conventional irrigation projects. If we are to irrigate this area we must acquire water from other sources, and this means in the long run the reclamation of sea water. What are the economic prospects for the reclamation of sea water and for the irrigation of the deserts of the earth in this way?

It is now economical to carry on agriculture in the United States in regions in which irrigation water from conventional projects costs as much as $10 per acre-foot and in which from 2 to 5 feet are applied per acre per year. It is proposed to intensify this practice within the next 20 years with irrigation water that costs up to $40 per acre-foot. Supplementary irrigation in the southeastern United States, the application of relatively small amounts of water to enable plants to survive through drought periods, is already being carried out with water which costs as much as $75 per acre-foot.

Reclamation of sea water

The cost of reclamation of ocean water has been investigated by various groups. These forecasts agree in suggesting a probable cost for fresh water from the sea of from $100 to $200 per acre-foot. To this we must add the cost of building canals and pipelines to carry and distribute the water. And so, if we are to irrigate the arid areas of the earth with reclaimed sea water, we will do so at great expense. To supply irrigation water alone will cost more per acre per year than the average value at present prices of the crop produced on such an acre.

But as our world becomes more populous, and as the need to obtain more food becomes more pressing, we have available to us this straightforward means of extending an otherwise conventional agriculture to a very large area indeed. It would probably be possible to double or quadruple the world's ultimate food production by supplemental irrigation of the less favored portions of our present crop land and by extending irrigation to the areas which are now arid.

It has been shown that although nine-tenths of the photosynthesis of the earth's surface occurs in the oceans, still, only a small portion of the resulting material finds its way into the human diet. We harvest sea produce primarily in the form of fish, which contribute a negligible fraction of the diet calories that today support the world's human population. We know too that we cannot greatly extend the fish harvest without bringing

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about the depletion of the ocean's fish populations.

Why is it that the ocean's potential contribution of fish is so small, even though the ocean's yearly crop of algae is so large? The answer to this question seems to be that it takes a lot of algae to make even a little bit of fish. It has been estimated that about 100,000 pounds of algae will produce only 1 pound of codfish. The algae is first consumed by some microscopic animal, which retains about 10 percent of the calories. This small animal is next eaten by a larger one with another energy recovery of 10 percent, and so on and on. The food chain from algae to fish involves three, four, or five steps. Only a food contribution of from 0.001 to 0.1 percent of the original plant material is eventually available as fish for the diet of human beings.

By and large, then, the fish is an inefficient converter of plant to human food. If we wish to use the ocean efficiently as a source of food, we must apparently make unconventional approaches to the harvesting of plant material from it. We could of course strain the algae from ocean water directly by some mechanical means, but we would have a lot of straining to do, since 1 cubic meter of sea water contains on the average about 1 cubic centimeter of plant material. We might, however, contemplate the possibility of using the ocean as we do grazing land. We might domesticate an ocean-going vegetarian beast—a sea pig.

Algae as a food crop

The cultivation of algae as a food crop has been widely discussed in recent years. In principle it should be possible to cover an area with large tanks, fill these tanks with an appropriate nutrient solution, inoculate them with a suitable type of alga, and harvest the algae periodically.

If the tanks were covered with transparent plastic or glass, the carbon-dioxide content of the atmosphere could be enriched, thus leading to a production of larger crops for a given area than would be obtainable in the open. At the same time, however, such closed tanks must be cooled in some way, since they act as heat traps when the sun shines upon them. Conventional crop plants as well as algae respond to increased carbon-dioxide concentrations by increased yields. The advantage of algae lies principally in the fact that it is technically rather simple to supply them with extra carbon dioxide.

The investment in preparation of land for the culture of algae is, however, ten to one hundred times greater than that for conventional agriculture. Yield of plant material per unit area of surface exposed to sunlight and under equivalent carbon dioxide concentration is the same for algae and for conventional crop plants. And when the algae have been finally grown and harvested, we have merely a nasty little green vegetable, the consumption of which presents the same sorts of technological and psychological problems as are associated with the utilization of, for example, alfalfa as food for man. It seems logical to conclude that expansion of our food supplies by the more familiar agricultural techniques will precede expansion of our food supplies by the cultivation of algae.

Chemical synthesis of food

The chemical synthesis of food would also appear to be an exceedingly remote possibility, at least so far as provision of general diet calories is concerned. The human being requires in his nutrition chemical compounds which are complex and exceedingly various. Although we do know how to use simple compounds as the starting materials for the chemical synthesis of the sugars, fats, amino acids, and vitamins required in the human diet, it is still a complicated chemical job.

Perhaps the most elaborate large-scale efforts to produce human-diet calories by synthetic means was undertaken by the German government during the Second World War. In order to cope with a severe shortage of edible fats, factories were made to synthesize fats, starting with the hydrogenation of coal. The process was extended with major effort until it supplied about 2,000 tons of fat per year, about one-thousandth of the amount yearly consumed in Germany.

Chemical synthesis of food is a big job. We should bear in mind, too, that it cannot be based permanently on the use of petrochemicals (chemicals obtained from coal and petroleum) as starting materials but must ultimately be based on the reduction of carbon dioxide, as is agriculture itself.

Although the chemical synthesis of bulk dietary calories appears to be impractical for the foreseeable future, that of dietary supplements is a practical matter even today. It is possible to supply a human being with his required rations of vitamins, all synthetically produced, at a cost of between 25 cents and a dollar a year. The vitamins, although complex to manufacture, are required by human beings only in minute amounts.

It is also possible to supplement diets with synthetically produced amino acids, although this is still of questionable practicality from an economic standpoint. Populations in underdeveloped areas who live primarily on cereal diets sometimes suffer from amino-acid deficiencies, probably through lack of the amino acids methionine, lysine, and trytophane. A year's supply of these three amino acids, synthetically produced, costs approximately $40 per person today, so that it is hardly feasible economically for most of the world's population to supplement diets with them.

It may well be, however, that in the future we can enrich our diets with an increasing variety of synthetically produced materials, devoting our agriculture to the business of supplying the bulk of the calories we need.