World Sources of Protein

by MARTIN G. WEISS and RUTH M. LEVERTON

PROTEINS are the scarcest and most expensive of all our foodstuffs; millions of people in the world have never had the amount or the quality of proteins they need for nutritional well-being.

Proteins are present in every animal and plant cell, and they have to be made by living cells. All proteins come directly or indirectly from plants, which combine nitrogen, hydrogen, oxygen, and carbon from soil, air, and water as they grow to make these vital substances.

People and animals cannot use such simple materials and must get protein from plants or other animals. Once eaten, the proteins are digested into smaller units and rearranged to form the many special and distinct proteins of the body tissues. These are basic substances in all the body's muscles, organs, skin, hair, and other tissues.

Proteins are made up of different combinations of 22 simpler nitrogen-containing materials, the amino acids. Eight are classed as essential or indispensable because they must be supplied to the animal body in readymade form. The other amino acids are also essential for body tissues and functions, but the body can build them from carbon, hydrogen, oxygen, and nitrogen furnished by food.

The value of any food in meeting the body's needs for protein depends on the amount and assortment of amino acids, especially the essential ones. Also important is the ability of the body to digest and metabolize the food, and what and how much protein the food supplies in relation to what and how much protein the body needs.

The amount of protein needed for health depends chiefly on the person's age, whether or not he is growing or otherwise forming new tissue, and on the adequacy of his supply of energy. Supplying energy needs takes priority over all other uses of food. When there is a shortage of energy sources, proteins are used for that purpose, and their amino acids will not be available for maintaining body tissues.

In the United States and Canada, animal products provide two-thirds of the protein in human food. The proteins in meat, poultry, fish, eggs, and dairy products are ideal for human consumption. They are palatable and are nutritionally complete, as they comprise adequate amounts of each of the eight indispensable amino acids. In fact, gelatin, which is deficient in certain amino acids, is the only protein from animals that is nutritionally incomplete with respect to amino acids.

There are about 6 billion head of livestock and poultry in the world—about two animals for every human being—but the distribution is far from uniform. The world has slightly more than three times as many people as cattle, but major livestock countries, such as Argentina and New Zealand, have about two and one-half times as many cattle as people. Densely populated countries like Pakistan, Burma, Thailand, Ceylon, and Cambodia may have four to six times as many people as cattle.

It is said often that in densely populated countries people and animals may actually compete for proteins: The supply of feed and food there is such that the conversion of plant products to nutritious animal products by animals is too expensive, and animals are too inefficient in converting feed to food.

Animal scientists, however, have made great strides in lowering the feed-to-food ratio, particularly in chickens and swine.

Under efficient management conditions, the following pounds of feed are required to produce 1 pound of animal gain or product: Milk, 1.0; broilers, 2.3; eggs, 3.1; turkeys, 3.5; swine, 3.6; beef, 8.0; and lamb, 8.7. Thus the efficient producer can expect a pound of milk from each pound of feed and a pound of live-weight broiler per 2.3 pounds of feed. He must use 8 pounds of feed to produce 1 pound of live-weight gain as beef. Since poultry dresses out much higher than cattle, the price of steak naturally is much higher than the price of dressed chicken.

Scientists have determined the protein-conversion efficiency for the same products—the amount of protein animals require in their feed to make a pound of crude or total protein in the animal product.

Thus, the pounds of protein required are: Milk, 3.9; eggs, 4.1; broilers, 4.6; turkeys, 6.2; pork, 7.1; beef, 10.0; and lamb, 12.5. That range is as great as the feed-conversion efficiency; the protein-conversion efficiency of the livestock classes falls almost in the same order.

The figures indicate that in milk, eggs, and broilers, under good management, we get 1 pound of protein for the investment of about 4 pounds of protein in the feed. For a pound of protein in beefsteak or lamb chops, however, we must invest two and one-half to three times that much protein.

These comparisons must be qualified in several respects. The crude protein of the feed is determined by analyzing for total nitrogen and multiplying by the factor 6.25, which gives a good measure of protein. But this method measures all the protein, much of which would not be digestible by people. In fact, animals can utilize only 30 to 95 percent of the total protein in feeds, the percentage depending on the digestibility of the feedstuffs used. Furthermore, we must keep in mind that the animal uses protein for maintenance as well as for growth or production of meat, eggs, and other products. The conversion ratios would be higher when management conditions are not efficient—when animals have poor rations or forage for themselves and get little supplemental feed, as they do in many feed-deficient countries.

Ruminant animals, such as cattle and sheep, can convert a combination of carbohydrates and synthetic nitrogen compounds to proteins. In fact, nearly one-third of the nitrogen requirements in the ration of fattening cattle may be supplied in the form of urea. In the ordinary feeds, however, nitrogen occurs mostly as proteins. The ability to use nonprotein nitrogen therefore is not thought to be of any great importance when a balanced ration is fed.

We must conclude that large differences in feed and protein conversion exist among animal classes and products. With even the most efficient conversion, however, approximately 4 pounds of crude protein are required to produce 1 pound of animal protein. Some of this crude protein could not otherwise be converted to human use. Finally, in most countries only animals can harvest vast rangelands, woodlands, and wastelands. Also, many plant residues occur as the by-products of the harvested crops. Even though conversion rates may be unfavorable, grazing is the only means of utilizing much of these resources.

SOCIAL, RELIGIOUS, and dietary customs of some countries may reduce the consumption of animal proteins.

India, for instance, pooling cattle and water buffaloes, is estimated to have about one-half animal per person, about the same as the cattle-human ratio in the United States. Since many of these animals are unclaimed and wander about the countryside, statistics are not accurate. Some estimates have been as high as one animal per person.

Even with the large numbers of cattle and buffaloes, animal foods make up a small part of the Indian diet. Bullocks are a major source of farm and transport power. More important is the opposition to slaughter of cattle dictated by religious doctrines. The reluctance to slaughter cattle is an outgrowth of the great famines during the rule of the Mongol emperors in the 14th century, when decimation of breeding stock was threatened. It was incorporated into the Hindu religious philosophy and persists today. Slaughter of cattle is prohibited by law in more than half of the 15 Indian States. As a consequence, India is largely a country of vegetarians, and consumption of animal products is restricted chiefly to dairy products and eggs.

FISH also are a major source of animal proteins. About three-quarters of the annual catch of 41 million metric tons is used for human consumption. On a world basis, this amounts to 22 pounds per person, in comparison with 20.5 pounds of beef and 20.3 of pork.

Fish flour, sometimes called fish protein concentrate, has received increased international interest. It consists of finely ground whole fish and is used as a food additive. It is said to be the world's cheapest, most abundant, and biologically richest source of animal protein. It contains up to 95 percent protein, and all of the essential amino acids occur in adequate quantity. With present systems of processing, however, the meal is not acceptable for human food in some countries because it includes the offal of the fish.

PLANT PROTEINS, particularly in the Western World, have long been considered poor relatives of the animal proteins.

Advances in dietary research and development of refined analytical techniques have done much to clarify the situation. First, the concentration of proteins varies greatly among plants and plant parts. Secondly, plant proteins vary greatly in nutritional quality, which is determined by the ratio or balance of the eight essential amino acids required by people.

Most of the people in the world are fed by relatively few major crop plants. These crops may be grouped into six general classes: Cereals (rice, wheat, and corn); sugar plants (sugarcane and sugarbeet); root crops (potatoes, sweet potatoes, and cassava); tree crops (banana and coconut); oilseed legumes (soybeans and peanuts); and pulses (dry beans and peas, chickpeas, and broadbeans). If high yields of cotton can be combined with the newly discovered glandless (gossypolfree) genetic characteristic, cottonseed also may become a major source of food.

Rice illustrates the importance of these crops in human nutrition. It has been estimated that at least 60 percent of the energy of half the people in the world is derived from rice. More than 30 percent of all human energy on this globe therefore comes from one crop.

Because cereals as a group are the most widely grown crops for human food, they probably contribute as much vegetable protein to the human diet as all other crops combined. But their protein concentration is not high. Rice has a protein content of 7.5 percent; wheat, 13 percent; and corn, 9.5 percent.

The man of average weight requires about 70 grams of protein a day. If he were to get it from rice, he would need to eat more than 2 pounds daily. He would need 1.75 pounds of corn or 1.25 pounds of wheat.

The sugar crops, sugarcane and sugarbeet, are processed almost entirely for sugar, which contains no protein when refined. The residues, sugarcane bagasse and sugarbeet pulp, contain protein, but they are not used for human food. Sugar that is produced by noncentrifugal means usually is consumed in an unrefined condition and is sticky and doughy. The product, known as gur in India, panela in Latin America, and jaggery in Africa, contains small amounts of proteins as impurities, but they are not of dietary significance.

Potatoes, sweetpotatoes, and cassava are largely starch crops. Cassava is grown only in tropical and subtropical countries. The processed product with which we are most familiar is tapioca. On a fresh basis, both types of potatoes contain only about 2 percent protein; cassava roots contain even less. In fact, to supply the required 70 grams of protein, a man would need to eat 8 pounds of potatoes or 25 pounds of processed tapioca.

The protein concentration in bananas is low and is similar to cassava root in this regard. Coconut, on a dry-weight basis, is similar to rice in total protein content.

We should not infer that those major crops that are low in protein are undesirable food. Most are important sources of energy-rich starches, and many contain important mineral constituents of the diet.

OILSEEDS in general are first-rate sources of protein. The protein contents of most oilseeds are much higher than in cereals. Many varieties of soybeans contain more than 40 percent protein, peanuts fall in the range of 25 to 30 percent, and cottonseed contains about 16 to 18 percent.

Extraction of oil and removal of seedcoats concentrate the protein in the remaining oilmeal and oilcake. The protein in the meal and flour produced therefrom exceeds 50 percent. Concentrates that contain 72 to 74 percent protein, which is higher than that in meat on a dry-weight basis, can be made through additional processing.

High-protein soybean concentrates have been used to supplement diets in countries where nutrition is inadequate. One cup of soybean concentrate, approximately 170 grams, will supply the daily requirements of protein, vitamins, and minerals for an average adult.

The quality of protein in the oilseed crops generally is good. All are slightly lower than ideal in methionine. The quality of protein in soybeans, however, compares favorably with that of animal products.

Dry beans and peas are a major source of food throughout the world. All of the edible beans and peas are legumes. Internationally, they are collectively referred to as pulses and sometimes as grain legumes. They include a goodly number of crops and species. In the Western Hemisphere, Europe, and Africa, dry edible beans consist mostly of beans belonging to the same botanical species as snap or wax beans. They include navy, great northern, pinto, red kidney beans, and others. In the United States, we also grow lima beans, dry peas, cowpeas, lentils, and mungbeans.

The grain legume produced to the greatest extent in the Far East is chickpeas. Pigeonpeas, mungbeans, urdbeans, and dry peas also are produced in large quantities. Others include moth beans, broadbeans, hyacinth beans, and the twinflower Dolichos.

The protein contents of pulses fall within the range 22 to 26 percent on a dry-weight basis. The quality of protein in chickpeas, pigeonpeas, lima beans, and twinflower Dolichos is exceptionally good and comparable with that of animal proteins. Proteins in most of the other pulses have excellent quantities of lysine but are slightly low in the sulfur-bearing amino acids, methionine and cystine.

The full possibilities of the pulses of the world have not been realized. Grain legumes generally have not been improved as much as many other crops, partly because emphasis has been placed on the improvement of crops that are exported extensively, such as cotton, tea, and coffee.

In tropical countries, most pulses are grown largely during the dry period, with little or no irrigation. Yields are much less than optimum. The development of improved varieties and systems of culture that would give maximum production would greatly increase the potential of this important class of protein-bearing crops.

THE PLANT COLLECTION program of the United States Department of Agriculture was intensified several years ago. Cultivated plants and the plants from natural stands in their native, uncultivated habitat have been sought in many lands. The primary objective is to find new crops to provide raw materials for industry. Principal attention is given the composition of seeds, particularly their content of proteins, special oils, gums, and waxes.

The total proteins of seeds vary among plant families. Proteins in species within families vary, but not so much as some other constituents, such as oil content. For example, the species of the legume family may have 12 to 55 percent of protein; members of the grass family may have 2 to 33 percent. Despite such variations, one would expect search among the legumes to yield more high-protein species than among the grasses.

Families of plants also reveal certain patterns in the quality of the proteins in their seed. Amaranthaceae, the family to which pigweed belongs, and Umbelliferae, the parsley family to which dill and carrots belong, are moderately low in total proteins but are high in lysine. Leguminosae in general also are good sources of lysine, but a few species, such as peanut, are low. Most legume species are low in methionine. Species of Gramineae, the grass family, tend to be very low in lysine but high in methionine. The family to which sesame belongs has similar protein quality. Combinations of corn and soybeans or sesame and soybeans therefore make a good source of balanced proteins.

In quantity and quality of protein, the four most promising families for sources of seed protein for man and nonruminant animals are Leguminosae (soybeans, alfalfa, clover, and others); Compositae, to which safflower and sunflower belong; Cruciferae, which includes rape, mustard, and cabbage; and Cucurbitaceae, of which melons, cucumbers, and gourds are members.

Man's principal sources of vegetable protein are seeds. Other parts of plants, particularly of vegetables and fruit, are eaten but do not constitute major sources the world over.

Bearing in mind the growth of the world's population, we must take a fresh look at all possible sources of protein that might be available to man. We know that huge amounts of proteins exist in certain plants that have never been used very much for human food.

PROTEINS occur abundantly in the leaves of many plants. They usually are considered to be animal feed and are used directly by people to only a limited degree.

On good land in the North Central States, an acre of soybeans may yield 700 pounds of protein. Alfalfa, however, harvested or grazed from a similar acre, may readily contain 1,200 to 1,400 pounds of protein. Most of this protein could not be digested by people.

Animals can convert leaf protein to nutritious and palatable animal protein—although man could expect to recover only one-fourth to one-twelfth of the protein eaten by animals. From the more efficient animal conversions, such as milk, we can at best expect to obtain only half as much protein from an acre of alfalfa as from an acre of soybeans used directly as human food. If we prefer our protein in the form of lamb chops, we are realizing only one-seventh as much protein as from soybeans. There is no question that we prefer milk or lamb chops to some form of plant protein. If expanding populations, however, required a change, the question must be raised as to whether we can use alfalfa protein directly as human food.

Research on the processing of protein from leaves has been conducted in Great Britain. The protein is extracted by a pulping process, which consists of breaking open the leaf cells by cutting or rubbing. The juice is pressed out, and all coarse particles eliminated with fine sieves. The starch grains and chloroplast fragments, which contain the green coloring of leaves, are removed by a high-speed centrifugation. The protein in the juice is separated from the water-soluble components of the leaf by acidification to approximately pH 4 or by heating to 70° to 80° C. About 75 percent of the protein in young, succulent leaves—but only 15 to 20 percent of the protein in leaves nearing maturity—can be extracted.

The product is dark green and does not have a desirable flavor. Flavoring, of course, can be added, and the color can be masked by encasing the protein, as in ravioli. Some experiments indicated that leaf protein has a nutritive value only slightly below that of milk protein. In feeding experiments with swine and other animals, it compared favorably with fishmeal. The economic feasibility of the process had not been demonstrated in 1964.

MANY PLANTS lower on the evolutionary scale also can combine nitrogen with compounds containing carbon, hydrogen, and oxygen and thereby synthesize the basic components of proteins. In fact, the capacity of ruminant animals to make proteins from urea and corncobs or straw is really the synthesizing of proteins by microorganisms in the digestive tract of the animal.

Lower plants that have been investigated as sources of protein include the algae, yeast and other fungi, and the bacteria.

The algae include thousands of species. Some are single-celled, microscopic plants, such as those that cause green color in water allowed to stand uncovered in sunlight for a few days. Some are the giant kelps of the ocean, which may be more than 100 feet long and have leaflike structures several feet across. They have different forms, colors, and conditions of growth. Algae flourish in ponds, lakes, streams, and oceans. Some grow on trees and in soil—even on snow.

Nearly all algae bear chlorophyll, which permits them to combine carbon dioxide and water to form sugars, a process called photosynthesis. Sunlight is the source of energy for the process. The enormous part that algae have had is shown in the estimate that algae have synthesized 90 percent of the world's organic carbon.

Many algae can grow in sea water. As only 30 percent of the world's surface is covered by land, it stands to reason that 70 percent of the solar energy that reaches the earth falls on the sea. As solar energy is necessary for photosynthesis, one could reason that the seas potentially offer greater opportunities for food production than the land.

Algae in general utilize solar energy more efficiently than higher plants do. The single-celled algae are particularly efficient. Few higher plants capture as much as 2 percent of the sun's radiation; indeed, it has been estimated that only 0.2 percent of the solar energy that falls on a cornfield is utilized.

Because single-celled algae are distributed much more uniformly throughout the medium in which they grow, they miss less sunlight. Every cell is a chlorophyll-bearing, productive unit, whereas in higher plants many cells have been differentiated into conductive and storage tissues and are no longer productive. The photosynthetic efficiency of some of the green algae such as Chlorella, at low light intensities, approaches use of 25 percent of light energy.

We are interested primarily in the few algae that have a particular food potential, the large marine algae and single-celled algae adaptable to mass culture.

Marine algae, or seaweeds, are not new in the human diet. Orientals, even during the era of Confucius, regarded seaweeds as a delicacy. Chinese, Japanese, Filipinos, and Hawaiians were particularly fond of them. Until 1800, peoples of the Western World did not use them, but since that time certain types have come into food use, partic-

712-224°—64——5

ularly in Scandinavia, Scotland, and the West Indies.

Several species of brown and red algae with large forms are cultivated for food in Japan. They have large holdfast structures that superficially resemble roots. Bundles of bamboo, to which the seaweeds attach themselves, are "planted" in the mud bottom of shallow marine waters. In other countries, natural stands of more than a score of species are harvested.

In general, all marine algae used as human food have large forms and are low in protein, fats, and digestible carbohydrates. The aversion of western people to extensive eating of seaweeds is due mostly to their poor digestibility and palatability. Odd as it may seem, digestibility of seaweed seems to increase with regular eating over a period of time. It is theorized that certain microflora, which aid in the digestion, are acquired and built up in the human digestive tract.

The amount of protein composition of seaweeds approximates that of the more highly developed plants. Also, like the protein in leaf tissue, it has poor digestibility unless it is processed. It rarely exceeds 15 percent in brown algae and often drops to 5 percent in late summer. Seaweeds of the red algal group may contain 25 percent of crude protein. Marine algae differ from fresh water algae and land plants in that they contain considerable nonprotein nitrogen. Ruminant animals therefore find them more nutritious than nonruminants and people do.

Except for the abundant minerals in them, seaweeds must be regarded, because of poor digestibility, as having low food value for human beings and can be only a minor supplement to the normal diet. As animal feed, particularly for ruminants, they have moderate value.

Culture of algae under controlled conditions has the potentiality of producing large quantities of proteins in a relatively small space. Algae may be cultured in large vats in the open, in large tubes on the roofs of buildings, or, when the temperature needs to be controlled, in large jars or vats in a greenhouse. This means of food production merits particular attention in operations such as space travel.

For mass culture, single-celled species are considered more efficient than the complex forms. The most widely used genus in experiments is Chlorella.

For most efficient production, the water medium in which the algae are grown must be fertilized with plant nutrients, aerated with carbon dioxide, and agitated to prevent settling and to assure uniform lighting of all cells. Temperature control and supplementary light may be required.

Experiments with Chlorella on a pilot-plant scale were conducted for a few summer months in the United States and for several years in Japan.

In the United States experiment, conducted in one large polyethylene tube on the roof of a building at Cambridge, Mass., the cost of Chlorella production was estimated as 25 to 30 cents a pound and the yield was calculated as 8 tons of protein per acre per year. With the large production systems, potential yields up to 20 tons of protein per acre have been estimated.

In Japan, Chlorella was produced in culture ponds covering about 1 acre. Sunlight furnished the only source of energy, and production was continued the year around. Over a 2-year period, about 2,200 pounds of protein a year were produced on 1 acre. The product sold for nearly 2 dollars a pound.

The protein content of the single-celled algae suitable for mass culture varies among species and with environmental conditions. Japanese-produced Chlorella averaged 40 percent crude protein. Other experiments have shown as high as 55 percent for this species. The quality of protein also varies. Most tests show low values for the amino acids methionine, histidine, and tryptophane.

Feeding trials with rats and rabbits showed higher gains than obtained when proteins were supplied with soybean meal, particularly when the algae were supplemented with amino acids that are deficient. No digestive difficulties were encountered in humans conditioned to the diet, except when more than 100 grams a day were consumed.

Certain conclusions can be drawn. Production of algal protein in mass culture as a common food is not economically feasible at present. Digestibility of algae is difficult for people, and additional processing studies are needed. The bitter, strong, spinach-like flavor is objectionable to most westerners, and further research on palatability is required.

A number of micro-organisms besides unicellular algae have been investigated as sources of proteins. Most of them do not contain chlorophyll and therefore cannot synthesize sugars. Waste sugars, however, occur in many products, such as citrus-waste press juice, molasses from sugarbeet and sugarcane, and wood sugars. In the presence of inorganic nitrogen, many micro-organisms can synthesize proteins from such wastes.

One class of organisms, yeasts and yeastlike micro-organisms, has shown particular promise. Production of a species of food or nutritional yeast, known as *Torulopsis utilis*, which is unlike baking or brewing yeasts, is an established industry in some places.

Thousands of tons of food yeast were propagated and eaten by Germans during the Second World War, and food yeast is now being produced in the United States, British West Indies, Sweden, and Germany. The product is known as torula. Yields of proteins vary with the waste sugar material on which the yeast is grown. The range of crude protein generally is 40 to 60 percent. The protein is of good quality except for a deficiency in the sulfur-containing amino acids, particularly methionine.

A number of other yeast and yeast-like organisms are being investigated experimentally and commercially for the production of food yeast.

A technique was developed to convert whey, a waste product from the cheese industry, into food yeast. The yeast micro-organism used in the process belongs to the genus *Saccharomyces*. It grows well on whey sugar, and within 3 to 5 hours produces one-half pound of yeast for each pound of whey sugar.

Of the myriad species of fungi in the world, a goodly number can grow in a medium containing sugar and inorganic nitrogen salts. A near-theoretical conversion of inorganic to organic nitrogen is accomplished by some species within 4 days. The protein productions of 10 genera of *Fungi Imperfecti* have been reported.

Crude proteins of the products of the different genera varied from 6 to 35 percent. From the better fungi, a conversion of 1 pound of protein was obtained from 6 pounds of hexose sugar. The product was white to very light buff and usually odorless and tasteless. Mouse-feeding trials indicated that the substances were not toxic. From performance of the better fungi, it was calculated that the sugar produced by an acre of sugarcane with added nitrogen could be converted by fungi to more than 2.5 tons of protein. The economic feasibility of such conversion is questionable.

As in the case of yeasts, potential commercial production probably must be reserved for sugars occurring as industrial waste products.

STILL ANOTHER class of micro-organisms, the bacteria, is worth scrutiny.

Like the yeasts and fungi, many species of bacteria can synthesize their own proteins from sugars and inorganic nitrogen. Certain bacteria also can utilize free nitrogen from the air. One group with this capacity is the Rhizobia, which enter into a symbiotic relationship with legume plants. Another group, the Azotobacter, is free living in soil. Because of its ability to grow with only the air as a source of nitrogen, a species known as *Azotobacter venelardii* has been investigated as a protein-producing organism.

In its natural habitat, the soil, the organism grows on decaying plant materials and available minerals.

When soil nitrogen is limited, it uses nitrogen of the air to build up protein within its body. Upon death of the bacteria, this nitrogen becomes available for the nutrition of plants. Scientists in the Soviet Union have reported appreciable increases in plant yields after inoculation of new lands with Azotobacter, but studies in the United States failed to support this claim.

When grown in an aerated, liquid medium containing sugar and a few simple salts, Azotobacter multiplies rapidly. If it is harvested, killed, and dried at the time of maximum growth, the nitrogen remains locked in the bacterial proteins and becomes available for the nutrition of people or animals ingesting the bacteria.

Feeding trials with mice indicated no toxic substances. Human taste panels did not distinguish biscuits in which the flour contained 2 percent Azotobacter powder. Protein content approached 75 percent, which is extremely high for vegetable products. The amino acid balance of the protein compared favorably with that from yeast and other micro-organisms.

LET us summarize the sources of proteins for nutrition.

At the outset, we must realize that man and animals are completely dependent on plants to synthesize proteins; that is, to combine inorganic nitrogen with sugars. Plants, as used in this statement, include the highly developed plants, algae, yeasts and other fungi, and the lowly bacteria. Whether the synthesis occurs in the sunny fields, the ocean, the paunch of a cow, or in the vat of a commercial establishment, the process is similar and equally vital.

Many proteins are incorporated into plant parts that are indigestible to humans. Animals can convert a large part of these proteins to digestible proteins. Regardless of population densities, animals will continue to serve as effective converters of proteins indigestible to humans and as machines to harvest plant materials in inaccessible terrain. When animals are fed proteins that are digestible by man, the conversion efficiency is low, as only one-fourth to one-twelfth of the protein will be available to man.

High-protein plant sources must be exploited to supply the protein needs of the ever-increasing numbers of people. Among the higher plants, particular attention must be given the pulses and oilseed crops.

Direct extraction of protein from green leaves and mass culture of single-celled algae have great potential for maximum protein yield per unit area. Until digestibility and palatability of these sources of protein can be improved, they cannot be considered ideal sources of nutrition for direct human consumption.

The mass culture of yeasts and other fungi and bacteria has great potentiality in producing high yields of protein with acceptable amino acid balance.

MARTIN G. WEISS *began his research career with the Department of Agriculture in 1936 in Iowa as a breeder of new soybean varieties. Improved varieties resulting from this program, notably Hawkeye, Adams, and Blackhawk, were grown on more than half of the United States acreage at the peak of their production. Soybeans have become a major source of protein in the United States and were grown on more than 29 million acres in 1964. Dr. Weiss became leader of soybean production investigations for the Department of Agriculture at Beltsville in 1950, Chief of the Field Crops Research Branch in 1953, and Associate Director of the Crops Research Division in 1957.*

RUTH M. LEVERTON, *a nutritionist, has spent all her professional career in research and graduate teaching in agricultural experiment stations and land-grant universities before joining the Department of Agriculture in 1957. In 1961 she became Assistant Administrator, Agricultural Research Service.*