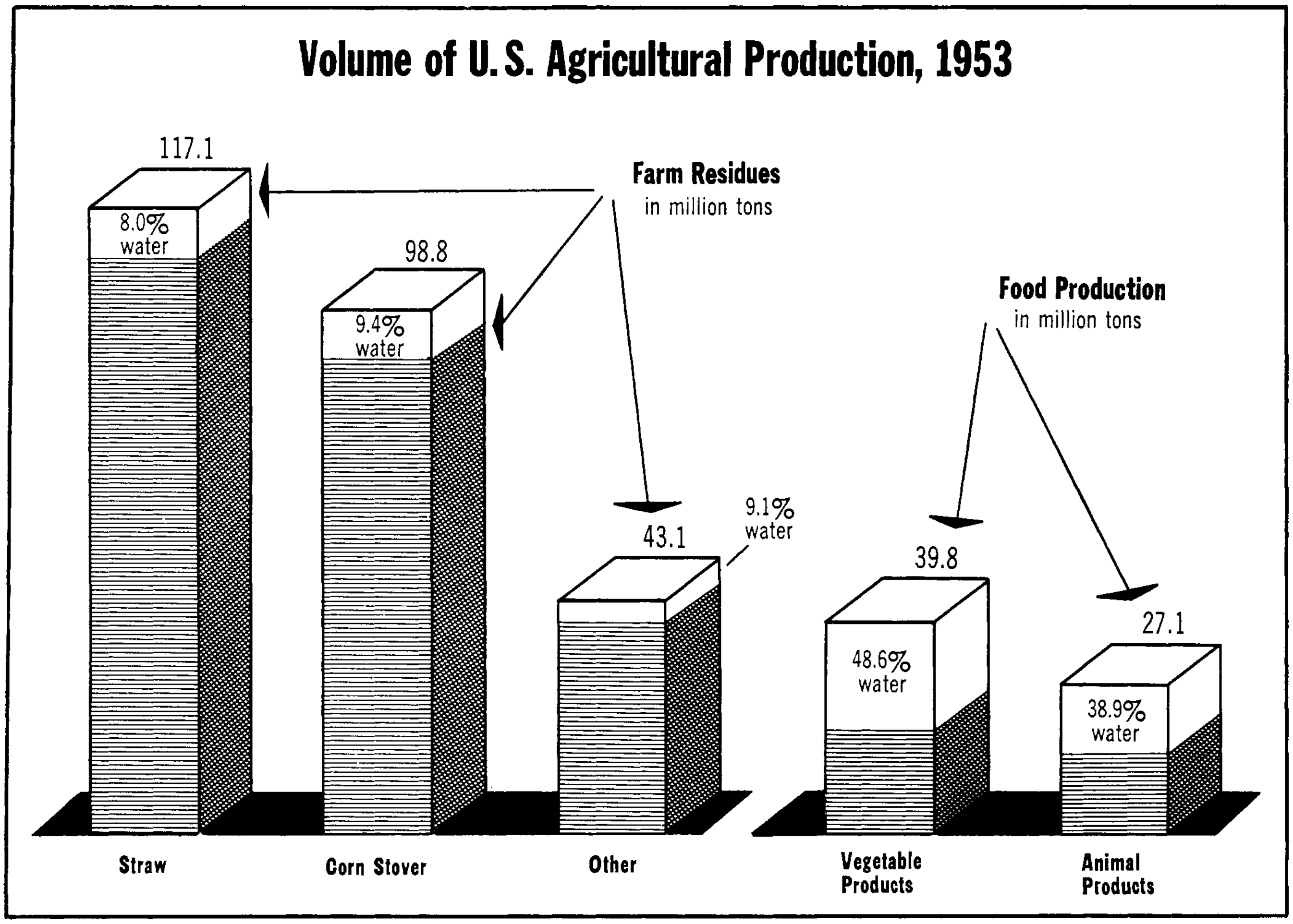


# FOOD FOR TOMORROW

**FRANCIS JOSEPH WEISS,** *Consultant, Washington, D. C.*

Much pessimistic thought on feeding the world has been two-dimensional—like estimating the productive capacity of a plant on the basis of floor space. The third dimension, human ingenuity and resourcefulness, has not been taken into consideration. The author examines some possibilities, not all of which are assuredly practical in the U. S. economy today, for making fuller use of the products of photosynthesis

It has been estimated that about 400 billion tons of sugar is produced each year by the plants of land and sea as primary products of photosynthesis (*38*). Of this enormous amount 90% is synthesized by marine and fresh water algae and the rest by land plants. Of the latter, forests produce the bulk, about 67.5%, while cultivated areas yield 24.5% (*32*). However, the primary products of photosynthesis are rapidly converted into other plant products or used as energy sources by the producing plant, while only a small part of primary photosynthetic products remain as such or are transformed into substances animals can digest. Thus, it is not surprising that all the animals on earth, large and small, have been estimated to consume only 2% of the products of photosynthesis of land plants, which is still a large amount. The entire human race uses for food, clothing, fuel, and structural material, only 0.2% of all the plant matter produced annually (*27*).

How can it be explained that man, though often in dire need, uses so little of the potential wealth that vegetation provides in such extravagant and wasteful manner? What is the reason that regions with the most prolific plant growth, such as the tropical rain forests, have the poorest levels of human nourishment? In these regions the annual production of vegetable matter has been estimated as high as 80 tons per acre (*42*) as compared with 2.5 tons yearly accretion in the forests of the temperate zone (*10*) and 5 to 6 tons per acre of whole plants of high yielding hybrid corn (*40*). Yet, deficiency diseases are widespread, especially a malignant protein deficiency, kwashiorkor, which exacts a heavy toll among the children (*5*).

A major factor in these situations is found in the conversion of photosynthetic matter into indigestible structural tissue of no nutrient value for the higher animals and man. The extreme example is wood containing an average of 60% cellulose, 30% lignin, and 10% hemicelluloses (*37*) and a nitrogen content as low as 0.1 to 0.3% (*48*) indicating the almost complete absence of protein. Another part of the answer is seen in the exorbitant rate of decay of plant material and the rapid conversion of plant debris into mineral and gaseous products through the action of heterotrophic organisms, especially bacteria and fungi, whose life processes are greatly stimulated by heat and moisture (*26*).

### Feed for Ruminants

Science has found effective remedies against the tropic diseases of animals and humans and has bred efficient meat and milk producers that could withstand tropical climates and serve as the basis of a better balanced nutrition. So should it be possible, according to the present status of applied microbiology, to convert the uncontrolled breakdown of organic matter by bacteria and fungi into a controlled degradation to such products as can be assimilated by ruminants and with the help of added nitrogenous compounds converted into animal protein, fat, carbohydrates, and vitamins such as are contained in meat and milk products.

Structural plant tissues consist mainly of cellulose and hemicelluloses and lignin. Since there are no cellulose-splitting and -degrading enzymes in the intestinal tract of mammals, provision is made to have these cellulose-digesting microorganisms act on the ingested cellulosic material under conditions most suitable to their growth and metabolic action. This is done in the rumen, which in large cattle reaches a volume of 60 gallons. It constitutes a kind of fermentation vat in which bacteria build their own body substance from herbaceous matter and obtain the necessary energy by degrading carbohydrates to lower fatty acids such as acetic, propionic, and butyric, which in turn, are energy sources for the animal (*9*). In addition to proteins, carbohydrates, and fats, the rumen microorganisms are capable of synthesizing all vitamins with the exception of vitamins A and D. Consequently, the rumen flora constitute a highly nutritious and well-balanced food supplement for the host animal. Rumen microorganism play a twofold role in the nutrition of ruminants. First, they catabolize otherwise indigestible structural parts of plants to make them available for intestinal assimilation. Thereafter, their own body substance supplements the herbaceous matter and constitutes an essential part of the animals diet. It is usually considered that the killed bacteria are attacked by enzymes in the intestinal digestive juices. Protozoa may play a part in the latter process.

Even the most efficient cellulose-digesting ruminants can use structural plant matter only to the extent that it contains digestible protein, without which the rumen bacteria cannot build the enzymatic system necessary for cellulose breakdown. Since these animals digest only about six times as much herbaceous matter as protein, a lower protein availability may mean a wastage of food. Consequently, the most serious limitation to an increased use of structural plant substance is the extremely low protein content of those substances. If no green pastures are available, the shortage of digestible protein in dry roughages can be remedied by adding grain to the fodder. This is no problem in our country, but in densely populated areas it brings the animal into direct competition with man for food supply.

Biochemists and microbiologists as early as 1891 knew that rumen microorganisms live very well in nutrient solutions containing amides instead of protein (*17*). But almost 50 years passed before clear evidence was produced that ammonium salts and urea can actually supply part of the protein requirements for the growing animal (*13*). Soon afterward the utilization of urea by growing sheep (*18*) and in milk production (*35*) was established. These discoveries came just in time to find application in the United States and several other countries in which the shortage of protein concentrates caused by the second world war made the inclusion of urea into ruminant feedstuffs very desirable and brought generally satisfactory results (*34*).

### Corncobs and Urea

Considering the theoretical significance and practical importance of using urea as a protein substitute, it is not surprising that in a relatively short time a vast literature developed on urea utilization in ruminant nutrition (*7*) and that many progressive farmers put urea feeding into practice with success. Roswell Garst of Coon Rapids, Iowa, for example, in three years fed 2200 steers in feed lots with corn cobs and urea. A typical daily ration was 2.5 pounds of alfalfa, 2.5 pounds of soybean meal, 2.5 pounds of molasses, 0.25 pounds of urea and 19 pounds of ground corn cobs. On this food the steers gained 1.75 pounds per day for a 120-day feeding period, and their meat graded equal to that of corn fed steers (*15*).

The addition of molasses, while not an absolute necessity, makes the food more palatable and provides minerals and ready energy which tend to bring the microbial action to a vigorous start. Also small amounts of starch will show he same beneficial effect. While it has been shown that urea can replace up to 40% protein without any detrimental effects, it is considered safe practice not to use more than a third of the protein from nonproteinous nitrogen sources. The impact of this newly de-

**Mammoth pile of corncobs illustrates part of the tremendous amount of photosynthesis products wasted every year. Recent research indicates, however, that corn cobs can be utilized in animal fodder, if urea or ammonia and molasses are also mixed with the ration**

### Important Constituents of Various Plants at Successive Stages of Growth and Development[1]

(In percent)

| Days | Protein | | | Cellulose | | | Lignin | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Barley* | *Oat* | *Timothy* | *Barley* | *Oat* | *Timothy* | *Barley* | *Oat* | *Timothy* |
| 7 | 43.4 | 32.0 | 10.7 | ... | ... | 24.9 | 1.48 | 1.86 | 5.98 |
| 14 | 36.8 | 34.6 | 9.5 | ... | ... | 23.9 | 1.71 | 2.14 | 5.81 |
| 21 | 37.7 | 35.0 | 7.4 | 19.0 | 21.2 | 26.6 | 2.31 | 1.90 | 6.20 |
| 29 | 31.6 | 37.8 | 7.6 | 20.1 | 21.2 | 28.5 | 2.50 | 2.42 | 6.66 |
| 35 | 24.4 | 35.1 | 7.2 | 21.9 | 22.4 | 29.2 | 2.88 | 2.24 | 7.35 |
| 42 | 19.3 | 26.2 | 5.6 | 25.6 | 25.4 | 31.4 | 3.49 | 2.43 | 8.52 |
| 49 | 12.2 | 16.6 | 5.4 | 28.6 | 26.6 | 30.4 | 5.10 | 3.78 | 8.47 |
| 56 | 11.0 | 13.3 | 6.7 | 27.8 | 29.5 | 32.9 | 5.93 | 5.30 | 8.95 |

[1] From Phillips, Max, and M. J. Goss, Composition of the Leaves and Stalks of Barley at Successive States of Growth, *Journal of Agricultural Research*, Washington, August 15, 1935, pp. 301–319. Phillips, Max, M. J. Goss, B. L. Davis, and H. Stevens, Composition of the Various Parts of the Oat Plant at Successive Stages of Growth, *Journal of Agricultural Research*, Washington, September 1, 1939, pp. 319–366. Phillips, Max, B. L. Davis, and H. D. Weihe, Composition of the Tops and Roots of the Timothy Plant at Successive Stages of Growth, *Journal of Agricultural Research*, Washington, May 1, 1942, pp. 533–546.

veloped food upon our own food supply and agricultural economy could be significant, but for the tropical countries it may well prove to be revolutionary. There exists an abundance of herbaceous matter and, in cane growing areas, also an abundance of molasses. However, protein from either vegetable or animal sources is very short and the food intake restricted to such energy yielding crops as cassava, yams, rice, and sweet potatoes. What is needed to supplement these empty calories, with all the essential protective nutrients, is nitrogen in such a form as can be used by ruminants in combination with readily available herbaceous matter to grow and get fat or produce milk.

## *Wartime Practices*

While the United States and Germany were trying to meet the growing shortage in protein feeds caused by the second world war by using farm residues in combination with urea, the Scandinavian countries used their large wood pulp resources in combination with ammonia to overcome a very acute food shortage. The animals did very well on this fodder and in 1942 alone about 1 million tons of it were fed (*33*). This feeding practice, however, became uneconomical when, after the war, concentrates became again available and the demand for pulp and paper was very great.

Stimulated by the success of the Swedes and the experience obtained in using ureas as a nitrogen source in this country, Americans tried to overcome the protein feed shortage also by ammoniating various carbohydrate-containing agricultural and industrial wastes. Air-dried sugar beet pulp was converted into a palatable and nutritious ruminant food by treating it with anhydrous ammonia. Ammoniated beet pulp is palatable, well digested, and has a protein equivalent of 25% (*25*).

Another protein supplement was developed by treating dehydrated citrus pulp, from grapefruit, orange, and lemon processing, with fertilizer grade anhydrous ammonia. By a simple batch process several tons of nitrogen-containing fodder could be obtained and the product has a protein equivalent of 40% as compared with 6% in untreated citrus pulp. Calves fed with this material gained 1 pound per 7.49 pounds consumed, while control animals showed the same gain when fed an equal amount of a grain-cottonseed mixture (*23*).

Success in feeding ammoniated woodpulp, sugar beet pulp, and citrus pulp suggests that ammoniated molasses obtained as a by-product of sugar manufacture or grain distillation would be equally valuable as a protein supplement. In fact, several attempts have been made to feed beef and dairy cattle ammoniated blackstrap molasses (*19*) or condensed distillers' molasses solubles (*39*) and at several places good results were observed by replacing two thirds of the nitrogen content of soybean meal or cottonseed meal with ammonia nitrogen (*22*). However, recent reports not only showed ammoniated molasses to have poor protein replacement value, but feeding cattle more than 12 pounds of ammoniated molasses per day with 15% protein equivalent caused the animals to act strangely in such a manner as to run wildly into fences, buildings, or other objects (*2*). Similar stimulations were not observed in feeding either urea or ammoniated pulps. The difficulties with ammoniated molasses now are under study. One approach being tried is to make ammonia less rapidly available. Another possibility which might bring results would be to apply techniques such as those in use in modern industrial microbiology to obtain a rumen flora better adapted to available feedstuffs.

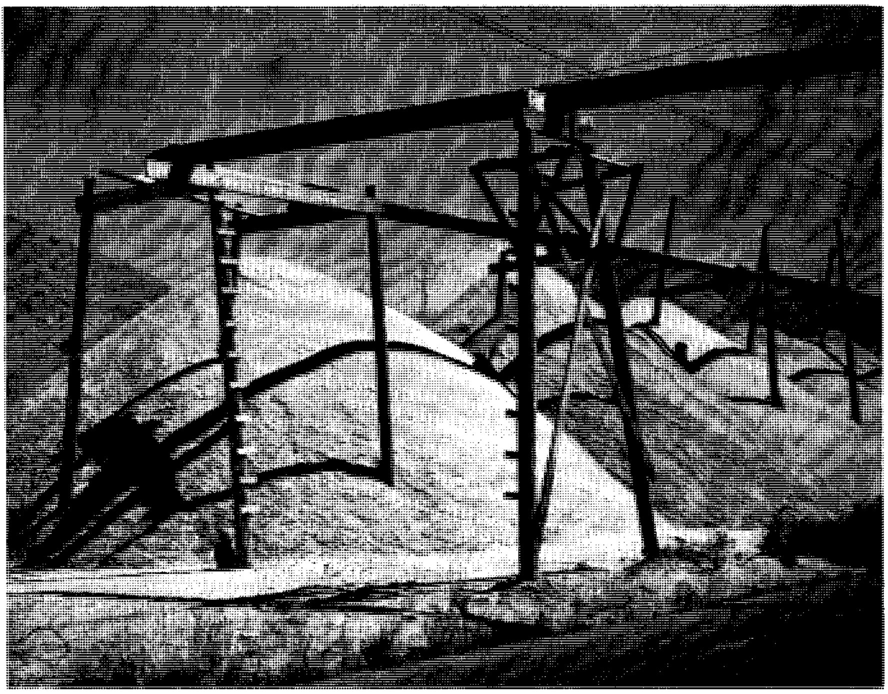
## *Use of Carbohydrate Wastes*

Next to the dearth of nitrogen, the high degree of lignification constitutes the most solid obstacle to the use of structural plant material as food for cellulose digesting ruminants. In an early stage in the development of higher plants the cell walls become hardened by the deposition of lignin, which makes the plant resistant to bacterial and enzymatic attack (*30*). If lignin is present in a free state as is the case in some plants, its affinity to protein and amino acids exerts a strong bacteriostatic action upon the rumen flora. The food value of plant material decreases rapidly with increasing lignin content as lignin not only protects the cellulose against bacterial or enzymatic attack but also reduces digestibility.

As numerous feeding tests have shown, wood molasses, prepared in the pilot plant of the U. S. Forest Products Laboratory, proved satisfactory in feeding cattle, sheep, hogs, and poultry when mixed with other feeds, the sugar from wood being equivalent to that from other sources (*49*). In addition wood molasses has been suggested as a raw material for making yeast for human and animal consumption, by which way inorganic nitrogen compounds could be converted into a high protein food (*6*). This method is also applicable to the large amounts of sugar that could be obtained from agricultural and industrial waste products, especially from the sulfite liquor of the pulp and paper industry (*31*). At present the plants of Lake States Yeast Corp. and Charmin Paper Mills are producing feed yeast from waste sulfite liquor.

But while chemists and microbiologists are busy breaking down wood and other structural plant products, then building up fungal tissues rich in essential nutrients by biological action, there are great numbers of microorganisms in field and forest doing just that. Wood-destroying fungi belong to two distinct classes: the destructive fungi which act rapidly upon cellulose causing brown discoloration and leaving finally a carbon-like friable substance high in lignin; and the corrosive fungi which act more slowly but eventually destroy the hardest heart wood. The latter cause white discoloration and leave a substance consisting of almost pure cellulose (*12*). Both groups of fungi, which are well known in this country as "brown rot" and "white rot," have one enzyme in common which assists them in dissolving the bond that holds cellulose and and lignin together. But the rest of their enzymatic systems are different inasmuch as brown rot fungi possess cellulase which hydrolyzes cellulose, while white rot fungi contain lignase which acts exclusively upon lignin (*7*).

From the viewpoint of eventual utilization of wood-rotting fungi, the lignin degrading white-rot fungi deserve attention. They not only break down indigestible substance into digestible matter by removing its lignin component, but also accumulate the nitrogeneous constituents of wood in their hyphal system in form of protein. Considering the experience in feeding animals with wood yeast it appears likely that wood decayed by white rot fungi containing also the fungal substance might serve as a feedstuff supplement for ruminants. In this way a destructive pest would be converted into a valuable tool of food production for animals and ultimately for man.



**Some 60% of the sawdust and other wood wastes produced every year piles up outside sawmills and goes unused: If a way could be found to change even 10% of this waste into fodder, some 4.25 million tons of carbohydrate could be added to our annual supply of animal feed**

### *Impressive Array of Fungi*

There exists already an impressive array of wood-rotting fungi whose enzymatic action has been studied. Brauns gives a comprehensive list (*4*). In addition to these wood-destroying fungi we have to consider a host of soil microorganisms that are able to decompose lignin as enormous amounts of lignified plant debris is continually converted by soil-inhabiting fungi, especially under aerobic conditions. Waksman showed that lignin is very efficiently utilized by these microorganisms. Very little carbon dioxide is liberated and most of the organic matter is transformed into microbial cell substance (*45*). Phillips demonstrated that under proper conditions the capacity of soil microorganism of selective decomposition of the constituents of corncobs, cornstalks, oat hulls, and wheat straw can be directed toward preferential degradation of lignin which capacity is greatly enhanced by adequate aeration and the addition of urea as a source of nitrogen (*28*). Pelczar, Gottlieb, and coworkers studied 35 cultures of white rot fungi for their ability to utilize spruce lignin and found that cultures of *Polyporus abietinus* and *Poria subacida* could be adapted to lignin utilization as the only source of organic carbon by growing them on a lignin glucose medium and gradually decreasing the glucose substrate to zero (*28*).

In addition to the chemical and biological decomposition of lignocellulose material there has very recently been shown a physical method to make wood available to the rumen bacteria. Working at the General Electric Research Laboratory in Schenectady, N. Y., and the Department of Bacteriology of Washington State College in Pullman, Lawton and Hungate showed that wood exposed to 100 million Roentgen is readily fermented by rumen microorganisms to low fatty acids in yields 79% of that possible with pure cellulose. They claim that on a large scale this treatment of wood could be economical and the irradiated product, when mixed with other feedstuffs, especially those containing nitrogen, could serve as a cattle fodder (*20*).

### *Wood Residues*

According to a study by Winters and coworkers of the U. S. Forest Service the total wood waste in logging and primary manufacturing operations of the United States in 1944 was estimated as 108.9 million tons or about 43% of the wood cut (*47*). Although 40% of this waste is used as a fuel in a very inefficient way, 60% is not used at all. Large amounts of sawdust, slabs, and shavings in excess of what can possibly be used as fuel or for other purposes are piling up near sawmills and other processing plants and it is here rather than in the woods where conversion of waste material into animal fodder appears to be more economical. If an effective strain of white rot fungi were found, finely divided wood, such as sawdust, would offer a more favorable substratum for fungal action than standing timber, especially with adequate nutrients containing inorganic nitrogen and traces of minerals supplied. These nutrients would become integrated into the final product of fungal metabolism, making the delignified fodder even more nutritious. Assuming that only 10% of the wood waste not used as fuel becomes available for conversion and assuming further a sugar equivalent of 65% we obtain

**Francis Joseph Weiss,** a native of Vienna, Austria, obtained his Ph.D. in chemistry in 1922 at Vienna University and subsequently an Sc.D. in economics and statistics in 1928 from the same university. Combining his background in natural and social sciences, Dr. Weiss devoted most of his research work to the exploration of natural resources for the benefit of mankind. He worked for the National Planning Association, the Bureau of Agricultural Economics, the Office of Technical Information, and the Fish and Wildlife Service of the U. S. Department of the Interior, as well as for the Sugar Research Foundation. He is now a scientific consultant on food and nutrition. Dr. Weiss was the author of "Food from the Sea," *Ag and Food*, Sept. 16, 1953.

4.25 million tons of carbohydrate fodder from wood waste.

### Agricultural Residues

Agricultural Research Administrator B. T. Shaw, has estimated that we produce about 250 million tons of agricultural residues yearly, but are using, in terms of industrial and other products, only 1% of that. Most of these residues consists of lignified herbaceous matter such as:

| | |
|---|---|
| Wheat straw | 68.1 million tons |
| Other straw | 49.0 million tons |
| Corn stover | 98.8 million tons |
| Corn cobs | 14.0 million tons |
| Cotton and soybean stems | 24.1 million tons |
| Bagasse and hulls | 5.0 million tons |
| Total | 259.0 million tons |

Most of this material is not a "waste product" in the narrow sense of the term, but when left on the field, fulfills an essential function in soil building and providing subsequent crops with organic matter and mineral nutrients. It would be a bad practice to take all the residues off the land, even if this were economically feasible. However, there are numerous instances where crop residues accumulate in such amounts that they constitute an embarrassment rather than an advantage to the farmer and there are the large processing plants of farm products where the accumulating herbaceous matter does not fulfill any useful function. Taking 5% of the total farm residues economically available for conversion into animal feedstuffs and assuming in contrast to wood a content of 80% carbohydrate and protein as a very rough average, we obtain 10.36 million tons of farm residues potentially convertible into fodder for ruminants.

Thus, in using 5 to 10% of our annual farm and forest waste we obtain a total of 14.6 million tons of herbaceous matter to which may be added as a source of nonproteinous nitrogen, 2% urea (N = 42%) or 292 million tons to provide for one third of the protein requirement of ruminants. We obtain as total additional feedstuff from waste products, 14.9 million tons as compared with 18.8 million tons of commercial feeds disappearing in 1951 (*41*).

### Synthetic Carbohydrates and Fats

However great may be the theoretical value of producing sugars synthetically, they are of no significance from a practical point of view. Nature produces them in so great abundance and with such efficiency from the most inexpensive raw materials on earth, namely air and water, that no chemical or biochemical operation may possibly be able to compete with autotrophic plants.

Next to carbohydrates the most important energy foods are fats. But while plants produce the former in greatest abundance and subsequently convert most of them into indigestible structural tissues, fats are made in a much smaller scale mostly as a reserve food for germinating young plants. Thus we obtain an ample supply from seeds, nuts, and beans of the flowering plants; and since marine and terrestrial animals have the capacity to convert ingested carbohydrates into fats which they too deposit as reserve energy supply in their bodies, the aggregate visible fat supply from all these sources surpasses the demand for industrial and food purposes.

**Bagasse, plant structural material from sugar cane not utilizable as it is by humans or higher animals, represents another opportunity for making more efficient use of photosynthesis**

Although the synthetic fat obtained from coal hydrocarbon residues in Germany and distributed under the name "Kunstbutter" had, according to objective observers, an excellent taste and showed no harmful effect in continued use by many people (*44*), we still cannot accept this judgment as final since not enough experience has been gathered to exclude possible long range deleterious consequences.

It is unlikely that synthetic fats are going to make any significant contribution to human nutrition, unless nations living on a low calorie level and with large coal but little oil resources, such as the Chinese, enter on a big scale into the manufacture of liquid fuel according to the Fischer-Tropsch or a similar method. Then probably the fatty acids obtained would be used for soap making and other industrial uses rather than for human nutrition, thus indirectly allowing more fat to be used for human consumption.

### Synthetic Amino Acids

The main problem in the world's nutrition is a question of adequate protein supply. If we could provide an expanding world population with foodstuffs containing sufficient amounts of protein of adequate quality, we could expect to achieve any necessary expansion in production of carbohydrates and fats with relatively little difficulty. In the field of proteins the sources from which sufficient amounts of protein-containing food can be obtained are limited, and in many instances the protein food does not meet adequately the body's requirements. In these cases, the chemist might be called upon to improve the quality and nutritional value of natural proteins by adding one or two lacking factors. It is in this field where the chemical industry, based upon the work of biochemists, nutritionists, and food technologists, may make an important contribution to the health and well-being of future generations.

Even if the chemist were able to duplicate the proteins needed by the body by effecting the correct combinations from among the astronomical number possible with known proteins, it would be short of the needed answer. The proteolytic enzymes of the digestive tract would rapidly dismember the synthetic protein into its simplest components, the amino acids, so that the body can build its own very specific proteins according to its needs. Thus the problem of increasing or improving the protein supply can be stated in simplified form as provision of the necessary amino acids. We can leave it to the anabolic forces of the organism to use them according to its requirements. A few essential amino acids constitute the limiting factors in protein utilization. A great step toward solving the world's dietary deficiencies, where available natural proteins are inadequate in quality or quantity, might be achieved by supplementing the natural protein food with those amino acids that are lacking.

### Amino Acid Supplementation

Individual food proteins lack only a few amino acids which the body cannot form. These deficiencies tend to compensate one another in a diversified protein diet and become perceptible only if the diet is reduced to one single protein food of inadequate composition or to several foods of similar inadequacy which consequently have no compensatory value for one another. In such instances restoration of protein balance by incorporation of synthetic amino acids in amounts required to make up for existing deficiencies may well be considered. Synthetic amino acids will have their proper place in the first line in animal nutrition, if for economic or other reasons no well balanced protein diet can be provided. They are most likely to enhance the food value of inadequate feedstuffs and thus lead to increased efficiency of animal production and better supply of man with animal proteins. Where, for economic, religious, or hygienic reasons, insufficient animal protein is consumed for good nutrition, the diet of man lends itself most favorably to reinforcement with synthetic amino acids.

When amino acids are not obtained from natural sources, but synthesized in the chemical laboratory or factory from inactive raw material, the product thus obtained is racemic, that is it contains an equal amount of the L- or D-configurations of the optical isomers possible with amino acids. Since the naturally occurring amino acids are all of L-configuration, the introduction of racemic mixtures of the natural and the unnatural isomer brought up a double problem, namely whether the unnatural amino acids have any nutritional value and, if they cannot be assimilated, have any harmful effect. Numerous studies have shown that the physiological requirements for lysine, leucine, isoleucine, threonine, and valine are very specific inasmuch as only the natural or L- form can be utilized. However, in the case of tryptophane, histidine, phenylalanine, methionine, and arginine, the D- form can be assimilated in amounts varying with species. In some case the D- form is assimilated as well as is the L- form (*46*). The ingestion of the racemic mixture has no harmful effect as the unnatural moiety is excreted (*43*). In spite of the lack of toxicity of the D-forms, it appears preferable in cases where resolution of the racemate and and conversion of the unnatural into the natural isomer can be accomplished, to use the natural amino acids only. This is desirable particularly for economic reasons, as the D- forms constitute a waste.

### Methionine Used

The first amino acid which attained commercial importance in this country was the sulfur-containing essential nutrient, methionine. It rapidly gained a place in poultry feeding, where some of the most common feeds are poor sources of both methionine and cystine (these two amino acids can supplement one another as sulfur-providing amino acids).

If we consider the law of the limit according to which proteins are utilized in the measure of the least available essential amino acid, the use of nutritionally unbalanced food means a great waste in otherwise assimilable nutrients. Thus it is not surprising that the addition of so small an amount of methionine as one pound per ton to broiler or turkey feed increases the feed efficiency by 10% (*8*). The price for this synthetic amino acid is $3.00 per pound which in turn is equivalent to about $10 extra profit per ton of feed. A similar product, methionine hydroxy analog, a DL-2-hydroxy-4-methylthiobutyric acid, sells for about the same price, and is equally effective in increasing the feed efficiency (*16*). Ruminants too, may benefit from small additions of methionine, especially when urea is used as a protein substitute. Loosli and Harris have presented evidence that such additions increased significantly the weight gain and nitrogen retention of lambs (*21*).

The amino acid most likely to be deficient in the diet of a major part of the world population is lysine. It occurs in deficient amounts in all vegetable proteins with the exception of that of leguminous plants. Since cereal grains and food products made therefrom constitute the only protein source of a major part of the world population and also a large part of our own diet, it is possible that lysine deficiency is more widespread than is generally recognized. Americans do not live from bread alone, but usually compensate lysine deficiency of cereal food with ample lysine from animal products. But hundreds of millions in other countries are dependent almost completely on grains and other vegetable foods which not only have a very low protein content, but offer it in such unbalanced form that it is only incompletely available.

Considering the importance of lysine we can understand that several attempts have been made to devise synthetic methods suitable for commercial application. But most efforts that have been made to obtain this diamino acid failed because of low yield or the unsuitability of the intermediary products (*36*). However, recently Rogers and coworkers developed in the laboratories of Du Pont Co. a method by which DL-lysine is obtained from the easily available dihydropyran and hydroxybutylhydantoin and which appears to be well suited for production on an industrial scale (*34*). There still remained the difficulty that the product so obtained is a racemic mixture of L- and D-forms, as lysine belongs to those amino acids which can be assimilated only in their L-form. This difficulty can be overcome by first resolving the racemic mixture by the usual method of combining it with an optically active substance, for instance D-camphoric acid, and then racemizing the unnatural isomer by a new method, namely heating with a cation-exchange material. Repetition of this process leads to almost pure L-lysine (*11*). In spite of the rather involved procedure leading to the natural amino acid, methods have been worked out to manufacture this product at a plant of Du Pont Co. at Niagara Falls, N. Y., so economically that it is eventually expected to sell for less than $10 per pound. Pure L-lysine, preferably in form of its hydrochloride which looks like salt and tastes like salt, might be used with advantage for the enrichment of flour and bread. It is, as Flodin says, "the key that can open the latent store of protein in bread and flour for the body's use" (*14*).

### Synthetic Vitamins

In the area of vitamins the chemist has been particularly effective in lending a helping hand to nature. An important industry has sprung up in this country, stimulated especially by War Food Order No. 1 which, beginning January 1943, made the enrichment of bread and flour with thiamine, riboflavin, and niacin mandatory. Today large quantities of pure chemicals are consumed directly or added to foods. As a great deal has been published about manufacture and use of synthetic vitamins it will not be discussed at length here.

The first vitamin manufactured commercially was vitamin C, ascorbic acid. That manufactured in largest quantity today is choline. Of the 2,248,000 pounds made in the U. S. in 1952, 2,210,000 pounds went into animal feeds, while 38,000 pounds was used for human consumption.

Other vitamins manufactured synthetically in considerable quantities are Vitamin A, vitamin $B_1$ (thiamine), and vitamin $B_2$ (riboflavin).

### Vitamin Production and Sales in U.S.A. in 1953[a]

| | PRODUCTION (1000 lb.) | SALES | |
|---|---|---|---|
| | | Quantity (1000 lb.) | Value ($1000) |
| Ascorbic acid | 1,672 | 1,770 | 15,865 |
| Choline chloride | 3,161[b] | 2,341[b] | 1,200[b] |
| Niacin | 1,893 | 1,660 | 6,037 |
| All other | 1,093 | 775 | 55,848 |
| Total | 7,819 | 6,546 | 78,950 |

[a] United States Tariff Commission, Synthetic Organic Chemicals, United States Production and Sales, 1953, Report No. **194,** Second Series, Washington, 1954, p. 35–6.

[b] For poultry feed: production 3,108,000 lb., sales 2,301,000 lb., valued at $1,138,000. Medicinal grade: production 53,000 lb., sales 40,000, lb. valued at $62 000.

## Conclusion

Malthus' error was that he saw agriculture only in a two-dimensional way and put too great emphasis on acreage available per capita. It is as though we would estimate the productive capacity of a factory only on the basis of its floor space. He did not consider the third dimension of agriculture that is human ingenuity and resourcefulness which brought about first the mechanical and later the even more decisive chemical revolution in agricultural production. Now that we stand on the threshold of this new era of human civilization, we should realize that every new invention leading to increased productivity, every new use found for hitherto wasted material, every new chemical that either promotes plant growth or protects plants and animals against disease, sets a new level for the operation of the law of diminishing returns within the framework of specific technological conditions.

As to the future world population many predictions have been made on the basis of past trends of population growth. The most reasonable one was made by the United Nations which assumes a maximum increase of 50% and a minimum increase of 25% for each generation and consequently would lead to a world population of 2972 million at the minimum and 3636 at the maximum in 1980. It was the purpose of this paper to show that with the knowledge we already possess and the technical facilities at our command, an even larger world population could be fed a better diet than the present one which in many lands is nutritionally inadequate.

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