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Food Systems: Perspectives on Demographics and Affluence, Food Supply and Consumption

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Global population may double by 2020 but the Malthusian specter of rapid population growth outracing slower increases in production will continue to be a false alarm. A vast array of agricultural technologies have the capacity to increase output 10-fold, perhaps as much as 100-fold. Discovery of a sweetener 54,000 times sweeter than sucrose (cane or beet sugar) indicates the magnitude of prodigious increases portended by new technologies. Productive agriculture, however, has become capital intense, limiting its availability in poorer nations. Increased production is the key to low prices and affordable supplies. In a world continuing to face starvation, there is no place for government policies purposely limiting supplies and artificially propping prices at high levels that place life-sustaining food beyond means of the poor. Affluence provides financial wherewithal to secure an adequate diet. Unfortunately, an estimated 25% of the world's population go hungry and face starvation. The specter of starvation may afflict as many as 600 million, and malnutrition, another 150 million by the year 2020. Improving self-sufficiency in these nations will remain a top humanitarian concern.

Agribusiness Ranks As America's Largest Single Economic Sector

Agribusiness in all its many activities, although seldom thought of in this way, constitutes America's largest industry. Agriculture usually is merely perceived as a minor industry. Nothing could be farther from the truth.

The entire agribusiness complex—food, fisheries, fiber, and forestry, as well as downstream suppliers and upstream secondary activities—comprises America's largest industry. Combined components accounted for an astounding 30 to 35% of the total U.S. 1984 gross national product, as tabulated by Public Policy Forecasting, Inc. Former Secretary of Agriculture Block aptly and correctly characterized the U.S. agribusiness system as the "world's largest commercial industry."

Agribusiness also may be appropriately characterized as the most technologically advanced of all economic sectors. Centuries of technological improvement and productivity advances have made this possible. High-tech. may get all the recognition. Agribusiness, however, deserves proper recognition of its true role in national economic affairs.

Also, agribusiness is no "flash-in-the-pan." Perhaps most important of all, agribusiness is one of the very few economic sectors based on renewable resources. Limitations of finite resources are not a looming problem. Undertakings can be sustained indefinitely. In short, agribusiness is the linchpin of the domestic economy.

Demographic Influences on Food Production and Consumption

Population Increase and Stabilization, Domestic and Global

Global population growth continues relatively unabated. The world's population, totaling 5 billion persons in 1986, may increase to 8.7 billion by 2033 and to 10 to 11 billion by 2100. In practical terms this means that enough food somehow must be provided to feed the equivalent of another entire planet earth; seemingly, this is an impossible task. In reality it is one easily within grasp, merely by bringing existing technologies to bear.

Slowed population growth in the U.S. as well as other advanced-affluent countries exerts lesser pressures. Americans, numbering 239 million in 1986, are projected to reach 256 million (low projection) to 282 million (high projection) by 2025. Thereafter, domestic population is expected to reach 208 million (low) to 261 million (high) by 2100. By the year 2100 some speculate the world population also will peak at 10 to 11 billion, then decline and stabilize.

Pressures on food supplies will remain strong in less-developed countries (LDCs). In developing nations where high birth rates linger on, food supplies will

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remain a vexing problem for decades to come.

Global population patterns are a very important consideration for domestic agriculture. Primarily, most large cash crops are not principally grown for domestic consumption. As much as 87% of some crops produced in this nation have been exported in recent years: cotton, 87.2% (1983); wheat, 67.2% (1978); soybeans, 46.7% (1981); corn for grain, 45.5% (1983); and tobacco, 45.4% (1979).

Legal and Illegal Immigrants Currently Account for a Major Proportion of the U.S. Population Increases

Illegal (over 1 million) and legal immigrants (570,000 in 1985) recently have accounted for as much as 50% of the U.S. population growth. America took in more aliens during 1981 than all other countries combined. More than one million illegal immigrants have entered the U.S. each year since the late 1970s. In 1986 alone, the Immigration Service apprehended 1.7 million illegal aliens at the Mexican border.

Census estimates 6 million illegal aliens were in the U.S. during 1983. Other estimates place the number of illegal aliens in the U.S. as high as 12 million.

Contraception, Abortion, and Lifestyles Reduce Population Growth

The blunting of population growth in the U.S. has been brought about by a host of factors including the introduction of effective contraception and lifestyle changes. The liberalization of abortion laws also has played an important role in holding down population increases. Legal abortions have more than doubled in recent years, rising from 744,000 in 1973 to 1,588,600 in 1985.

Life Expectancy Increases Add to Overall Population Growth

Adding to population growth is the fact that humans are living longer. Male life expectancy worldwide for 1980 to 1981 averaged 56 years of age—68 years of age in developed nations and 54 years of age in developing nations. Life expectancy worldwide is projected at 61.1 years of age during the 1985 to 1990 period and 67.2 years of age by 2000.

Life expectancy among Americans lags behind other advanced nations. American males born during 1983 had a projected life expectancy averaging 71.1 years. For females, lifespans were higher, averaging 78.3 years. In the U.S., life expectancies, by 1990, are projected at 71.9 years for males and 80 years for females.

Icelandic and Japanese women enjoy longer life expectancies than counterparts living elsewhere. Icelandic and Japanese females averaged 79.7 years of age in 1983. Among males with lifespans typically 5 to 10 years less than females, Japanese men topped the list worldwide. Japanese males born in 1983 could look forward to a life expectancy averaging 74.2 years.

The record authenticated lifespan is ascribed to Shigechizo Izumi of Japan who died February 21, 1981, just 128 days short of his 121st birthday. Lifespans have been forecast up to a theoretical maximum of 160 years. One medical authority anticipates Americans could live to 130 to 140 years by a life-long adherence to an optimal diet. Whatever the precise numbers may be, the prospects are for more people living even longer.

Aging of U.S. Population

In 1870, persons 65 years of age and older, numbering 1.2 million, constituted a mere 3% of the domestic populace. By 1980 the proportion of elderly nearly quadrupled to 11.3% of the population, which was 25.7 million persons. By the year 2000, the proportion is expected to reach 14%, the equivalent of 28.7 million persons (low projection) or 36.2 million persons (high projection). As the population continues to age, the proportion is projected to reach 21.5% of the total population by 2030 (Fig. 1).

Energy (caloric) requirements of the elderly are much lower, so they consume less food. The recommended average consumption for persons 51 years and older is 1800 calories for females and 2,400 calories for males. These lower energy requirements contrast sharply with needs recommended for 19 to 22 year olds: 3,000 calories for males and 2,100 calories for females.

A steadily advancing aging of the U.S. population is expected. Median age in America rose from 20.2 years in 1950 to 31.5 years in 1985. The shift is projected to continue upward, increasing to 33.6 years by 2000 and 38.4 years by 2010.

Ethnicity Growth and Diversity

Ethnic minorities, growing faster than whites and already constituting a substantial proportion of the total population, will become larger still. Minorities accounted for 20% of the total U.S. population in 1980. The minorities are broken down as follows: blacks, 26.7 mil-

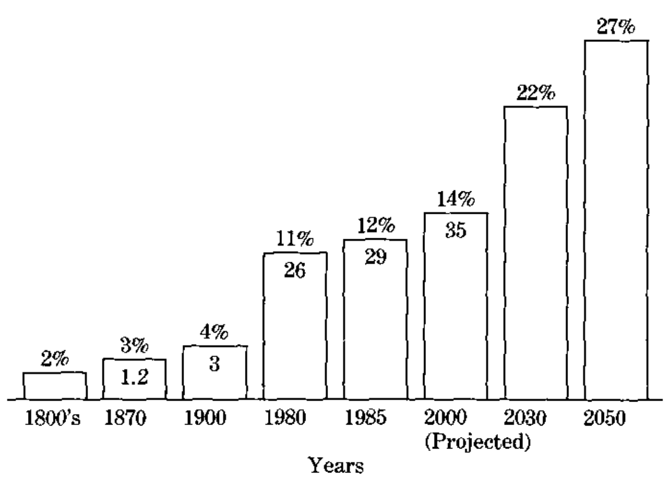


FIGURE 1. U.S. population 65 years of age and older (numbers in millions and percent).

lion; Hispanics, 14.6 million; Asians, 3.5 million; and Indians, 1.4 million. Blacks and Hispanics alone may account for 25% of the total U.S. population by 2000 and 30% by 2033. Blacks, Hispanics, and other minorities under age 30 already make up 30% of the U.S. population in that age cohort.

Though it may be difficult to believe, America already ranks as the seventh most populous Spanish-speaking nation in the entire world! Spanish-speaking populations worldwide in the early 1980s numbered 119 million in Brazil; 67 million in Mexico; 38 million in Spain; 28 million in Argentina; 21 million in Columbia; 17 million in Peru; and 15 million in the U.S. Accurate enumeration of illegal Spanish-speaking immigrants probably would reposition America fifth in this rank-ordering.

Culturally ingrained dietary habits of ethnics and their growing numbers assure a sustained demand for ethnic foods. Coupled with increasing consumer interest in experimenting with new and novel foods, the diversity of available foodstuffs should proliferate.

Increased consumption of Mexican and Oriental dishes, often featuring meat or seafood as garnishes rather than as the main meal entre, may have a considerable impact on food production and consumption. Ethnic dishes of this type are perceived as highly nutritious and healthful. Reducing meat consumption is consistent with recommendations of macronutrition goals and statements advanced by a wide range of health and nutrition authorities. Ethnic foods also are considered fun to prepare. Stir-fry preparation, for example, provides just that sort of self-satisfaction.

Sooner or later U.S. consumers will become conscious of the fact that protein consumption, already nearly double the recommended dietary allowance (RDA), is excessive and unnecessary. Only about 2 oz of complete protein are needed per day by the average American adult. The RDA for protein, incidentally, has a hefty safety factor built into it. This means that protein intake falling substantially below the RDA is unlikely to cause serious nutrition deficiency.

Cutting back on the consumption of meat and seafood, the most costly components in the typical domestic diet, reduces food expenditures and provides relief to the pocketbook. Low-cost foods always have been popular and they always will be.

One more factor worthy of mention is the ease of preparation. Food processors increasingly cater to consumer interests by providing prepackaged, ready-to-use fresh fruits and vegetables. All the scullery work has been performed at mass-scale food processing plants. These developments provide a new option for meal preparation in which all the fixings have been preprepared and require minimal effort and time to heat and serve.

Consumers have their eyes fixed steadily these days on their pocketbooks and opportunities for cutting back spending as well as their waistlines, weight, and overall health. Therefore, the influence of ethnic food preferences on American food consumption should not be underestimated.

The sparing consumption of meat (and other proteins) is likely to be a hallmark of the next several decades. This represents a major departure from traditional American dietary habits.

Smaller Family Size and Households

The average size of the household has been shrinking. During colonial times the number of persons per household averaged 5 to 7 (1750) and plummeted to 2.7 in 1986. Fertility rates are down and the family size has dwindled. Singles, mingles, childless couples, divorcees, "empty-nesters" and widows or widowers account for much of the increase in smaller household units. Persons living alone as a percent of the total population increased from 10.9% in 1950 to 23% in 1981. Divorces (including annulments), per thousand women 15 years of age and older rose from 9.2 in 1960 to 21.3 in 1983. The proportion of children living with one parent rose from 12% in 1970 to 20% in 1980.

Many couples are electing to have only a single child. Raising a child born in 1985 through age 17 is estimated to cost an average of $198,000. Four years of college could add another $50,000 to $100,000 for attendance and expenses beyond the year 2000. Clearly, it is not inexpensive to raise children these days. Children, more and more, are being considered an extravagant option.

Affluence: Impacts on Food Production and Consumption

Male Wage-Earner/Female Housewife/ Two-Child Family Is Passé

As recently as 1955, 60% of American households were headed by a working father and included a housewife-mother and two children. Families fitting this typical so-called "ideal" family image shrunk to 11% by 1980 and to a mere 7% by 1985.

Working Women and Working Mothers on the Upswing

More women will hold jobs out of financial necessity, social pressures (achievement, assertion of equal rights), and reduced obligations of smaller families. The percent of females 15 to 64 years of age in the workforce jumped from 34% in 1950 to 53% in 1985, and the proportion may reach 75% by the year 2000. In Sweden in 1985 this proportion already reached 80%.

Women 16 years of age and older joining the U.S. labor force between 1970 to 1985 increased by 20 million. Male increases over the same period totaled 13 million. Female participation rates have slowed. While the percentage joining the workforce will decline somewhat, the number of new female entrants projected for both the 1985 to 1990 and 1990 to 1995 periods stands at 4.4 million (8.8 million total).

Dual-Income Households Growing

Dual-income households continue to increase. Levels of affluence, correspondingly, reach new highs. Purchasing power of consumers never has been greater than today. Increased affluence, made possible by the trend to dual wage-earner households, means less time will be available for kitchen and household chores. In turn, this indicates a surge in demand for convenience foods.

Upscale and Gourmet Food Demand Increasing

Affluent, dual-income households are demanding more luxury, more expensive foods, and upscale choices. Higher expectations pace the entire process. Heat-and-serve, no-fuss meals of gourmet quality, proper nutritional balance, and low calorie content are the order of the day for today's upbeat consumer. Consumers not only are trading up to the high-cost, value-added end of the spectrum, but they also are searching out best buys (generic foods, warehouse, and box-store purchases). The food industry has strongly responded to upscale choice. Supermarkets devoted entirely to gourmet foods are sprouting up everywhere.

Consumer Ability to Pay for Foods with Value-added Features

Consumers spend ever more money on food. Total food expenditures rose from $71 billion in 1960 to $501 billion in 1985. Fewer persons per household to feed and more money per dwelling unit affords new opportunities for lavishing more cash per person on groceries. Consumers are ready, willing, and able to spend more for higher quality foods. Willingness is virtually assured of consumers to pay for value-added features in food consumed, such as nutritionally superior food and food components.

Steadily rising incomes result in a declining proportion of disposable income being spent for food. Americans spend the smallest percent of disposable income for food of any nation in the world. In colonial times, the proportion of income spent for food took a domineering 70% of income (1776). For 1985, food spending amounted to only 15% of disposable income. Advancing technologies and automation will contribute to further decreased food costs. Consequently, income spent for food should drop to 14% by the end of the 1980s.

Convenience Food Demand Growing

Time-saving, easy-to-prepare, convenience foods are becoming more popular. Microwavable foods, retortable pouched foods, thaw-and-serve, and heat-and-serve foods enjoy a very strong acceptance among affluent consumers.

Homemakers today have been virtually emancipated from the dreary drudgery of kitchen chores. Work has been transferred out of individual kitchens. Centralized kitchens of food processors capable of production-line efficiencies and economies increasingly are taking on the job. These modern food plants bypass time-consuming, small-batch preparation.

In colonial times homemakers spent most of the day working in and about the kitchen. Not so many years ago, some 4 hr were devoted each day to kitchen duties. Today, convenience foods and modern kitchen appliances such as microwave ovens can reduce the total time devoted to kitchen chores to less than 1 hr daily.

Food processors spare consumers from tasks that range from shopping and picking out the numerous ingredients required and from assembling them in proper sequence for scratch preparation. Mass producers perform the scullery work such as cleaning, peeling, slicing, sorting, mixing, coring, pitting, husking, dicing, and trimming. Master chef services are provided including gourmet sauces and artful flourishes in presentation of preplated meals. Meal planning expertise is provided by staff nutritionists and keen quality control is included in sanitary preparation. Preplated and preproportioned servings in table-presentable containers that go directly from oven to table also provide butler and maid services. Even kitchen clean-up chores are eliminated with frozen prepared meals that require no kitchen utensils for measuring or mixing. Additionally no pots or pans are used since food is both cooked and served in containers provided. Oven clean-up is minimized in microwave ovens because foods are not baked onto the inner surfaces of these cold ovens. From an environmental standpoint, centralizing certain food preparation functions may reduce overall energy requirements and also encourage the discovery of environmentally benign ways to dispose of food and organic waste streams.

Food away from Home: The Ultimate Convenience Food

During the 1990s over 50% percent of every food dollar may be spent for food away from home. Such spending has steadily increased over the years, rising from 25% in 1960; 35% in 1979; 37% in 1981; and 50% in the 1990s. Expenditures for meals and snacks away from home have grown rapidly, rising from $19.5 billion in 1959 to $152 billion in 1983 and $168 billion in 1985.

Eating out has radically shifted from being a treat limited to special occasions or sometime convenience. Fast-paced lifestyles increasingly make eating out a must for dual-wage earners who have little time to prepare meals. Sharply increasing institutional feeding situations also propel this trend, including escalating congregate meal setting for the elderly.

Situations in which meals away from home are necessary will continue to steadily increase into the 1990s, and will include meals and snacks on the job and at school; congregate meals for the elderly; meals at hospitals and other institutions; meals at hotels and motels; foods on airline flights and ocean cruise ships; food for members of the military, merchant marine, and persons at remote outposts; meals that are provided restaurant workers and others; food at the factory cafeteria and the executive dining room; food at recreation and leisure sites, ballparks, museums, and open-houses; drinks and snacks at local bars; vended foods and snacks; and fast foods served at convenience stores and gasoline stations. All of this, and more, assure steady increase in the food services' share of food spending.

Food supplies can be perceived as progressing through five stages during which a specific mode of supply and/or dominated distribution is used: *a*) home grown (self-sufficiency), *b*) market exchange, barter (relying upon comparative advantage and mutual dependencies), *c*) preserved foods using natural processes (sun-dried, smoke-cured, milled, salt-preserved, etc.), *d*) technologically processed preserved (canned, frozen, dehydrated, irradiated, etc.), and *e*) food service channels (restaurants, institutional channels, other away-from-home outlets).

Secondary Proteins: Trading Up the Grain Ladder

Affluence can be considered a two-edged sword. Increasing incomes provide the economic capabilities to acquire more adequate diets. Increased financial ability affords new opportunities for increasing proportions of mankind to eliminate, or at least to alleviate, hunger. At the opposite end of the income pyramid, further increases in personal incomes historically have entailed dietary upgrading. As incomes increase, so does the consumption of meats, dairy products, and eggs.

Increasing consumption of animal foods places considerable additional demands on agriculture to supply necessary animal feedstuffs. Secondary proteins (milk, eggs, animal flesh) require substantial amounts of feed, often in the form of cereals that otherwise could be made available for direct human consumption. The amount of grain required to obtain 1 lb of select animal foods (so-called grain-conversion ratios) suggests the expansive dimensions of these demands (Fig. 2).

In advanced, affluent nations huge amounts of grain are consumed, nearly all of it indirectly in the form of secondary animal proteins. Direct and indirect grain consumption in pounds per capita yearly for the period 1973 to 1975 ranged from 1755 lb in the USSR to a scant 282 lb in African nations. In the year 2000 projections are much higher (Fig. 3).

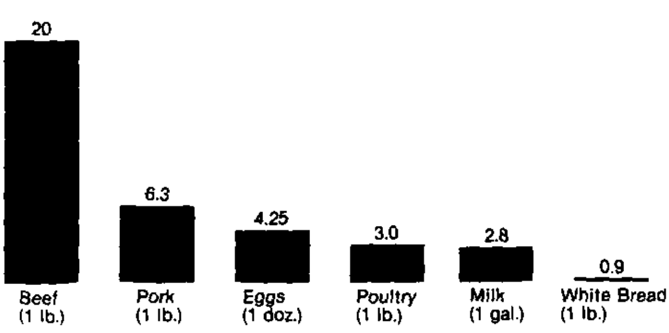
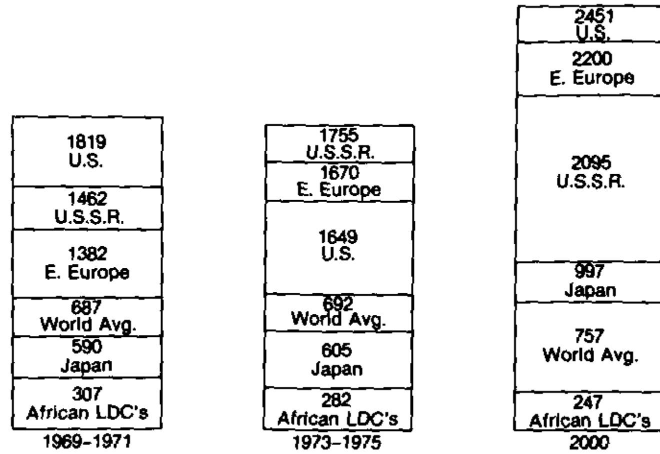


FIGURE 2. Grain conversion ratios—pounds of grain required to produce some foods.



[a]LCD = less developed country.

FIGURE 3. Grain consumption, direct and indirect—annual pounds per capita LDC, less developed country.

Religious convictions and well-entrenched cultural traditions discourage the consumption of meat and eggs in countries such as India where grain consumption amounted to only 348 lb per capita in the 1980s. Of this amount, 65 lb was consumed indirectly and 283 lb, eaten directly by humans. By contrast, Americans during the early 1980s consumed 1641 lb of grain per capita, of which 1441 lb were eaten directly in the form of animal products, with only 200 lb eaten directly as grain by-products.

Vegetarianism has been put forward as a means for alleviating pressures on available food supplies. Animal rations account for an ever-increasing demand on feed and forage supplies. Animal feed accounted for one-third of world cereal use in 1972 and one-half of total cereals in 1982, according to F. M. Lappe. World Watch researchers estimate over one-half of U.S. croplands are devoted to raising livestock feed and that livestock require over one-half of all water consumed in the U.S. These are enormous demands, and the nation may not be able to sustain them indefinitely.

Vegetarianism is likely to increase somewhat over the next several decades, but large-scale changeover is most unlikely. However, the more sparing consumption of meats, use of meats as garnishes, and smaller-portioned servings may become a dietary preference in advanced-affluent nations where protein levels exceed RDA levels severalfold.

Sedentary Lifestyles in Leisure-dominated Postindustrial Societies Prompts Reduced Caloric Intake

Less Arduous Work

Throughout history the most basic problem of survival has been simply to get enough food. Now the reverse is the case. Postindustrial nations confront challenges posed by too many calories. In particular, they must cope with too many calories from the wrong kinds of foods and food groups that may increase the risk of premature death and disease.

Industrialized nations have moved away from heavy manual labor associated with agricultural and industrial enterprise. More sedentary jobs in the services and the knowledge-education-information economy greatly reduce physical energy requirements. Less energy (caloric consumption) and food is required to sustain health and well-being in today's sedentary, leisure-dominated society (Fig. 4).

Increased Leisure Time

Adding further to sedentary lifestyles are long-term historic trends increasing leisure time. During colonial times in America people worked longer and harder, lived shorter lives, and devoted only 23% of life-long activity to leisure. Today people in advanced nations work less, live much longer, and spend an impressive 41% of life-long activity in pursuing leisure.

Work weeks grow shorter. In 1859 the U.S. work week (nonagricultural establishments) averaged 69.8 hr, dropped to 34.9 hr in 1985, and could fall to 32 to 34 hr by 2000. In some nations, beginning with certain hazardous or particularly arduous or strenuous occupations (Russia), and with working mothers (Sweden), the work week already has been set at 30 hr weekly. Political discussion in Europe over the past decade advocates further shortening the work week to a mere 20 hr.

Vacation time also has grown substantially. As recently as the 1930s only a very limited privileged few were accorded any time off from work for vacations. Vacations, a recent social invention, not widespread until after the 1930s, grow longer. In Sweden, the mandatory minimum is 25 working days, and seniority is added to the basic allotment. No wonder that Swedes rank foremost per capita as world tourists.

Holidays have become more numerous. As many as 18 official holidays are recognized in some countries (Italy, Spain). Paid holidays among U.S. employees in private industry averaged 10.1 days in 1980. Florida celebrates 13 legal holidays, while Nevada and Maine recognize only 8 legal holidays. History, as a guide to the future, suggests the number of paid holidays will increase.

Less and less time actually is spent working on the job. Time off is allowed for rest breaks, liberalized sick leave, parental leaves, leaves of absence for all manner of activities (jury duty, military duty, funeral attendance, etc.), sabbaticals, time off for education and training, earlier retirement—the list could go on and on. Work not only has grown more sedentary, but there also is less of it (Fig. 5).

Sedentary Nature of "Couch Potato" Pursuits

Less time on the job means more time for persons to pursue their own interests and more time for leisure pursuits. The overwhelming majority of persons use time off from work to take it easy. Less calorie-demanding lounging-about has turned many into so-called "couch potatoes." Television watching has become the most popular and time-consuming activity in America. Television watching in the average American household increased from 4 hr and 35 min in 1950, to 7 hr and 2 min in 1983. Sedentary activities such as television watching, reading, writing, office work, and the like require minimal energy expenditures amounting to only 80 to 100 calories per hour. No wonder waistlines are bulging.

Growing Proportion of Elderly

Demographic shifts involving increasing proportions of older persons reinforces food consumption declines. The older persons become, the more sedentary their

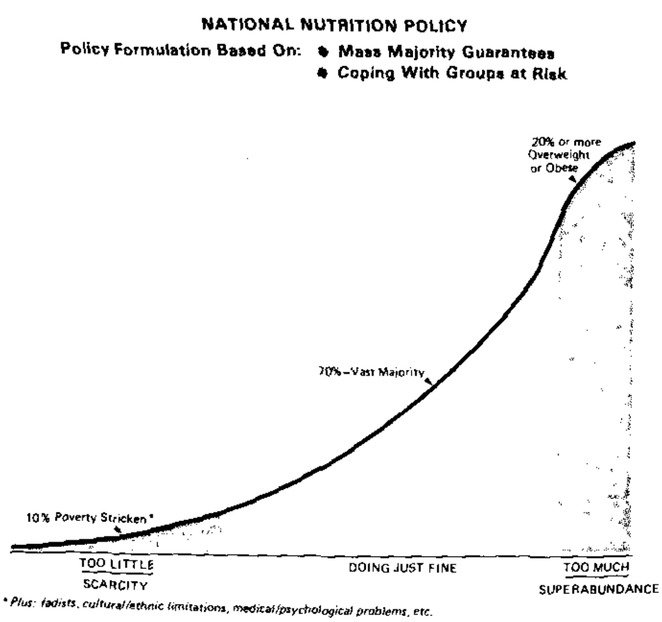


FIGURE 4. National nutrition policy—policy formulation based on mass majority guarantees and coping with groups at risk.

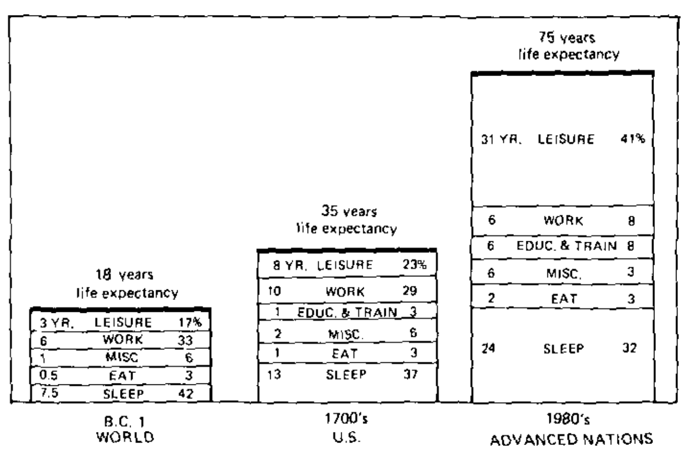


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FIGURE 5. More leisure time.

lifestyles become. Older persons generally consume far less of almost everything including food.

Self-Esteem and Self-Image

Although a rotund appearance may have been fashionable—at least among elites in the sixteenth and seventeenth centuries, as evidenced in paintings of the Flemish masters such as Peter Paul Rubens—thinness is in style these days. It is high style and just good common sense to maintain a well-proportioned healthy appearance. It is uncomfortable as well as unhealthy to be fat.

Survey after survey indicates that consumers, first and foremost, are occupied with consciously controlling and lowering caloric intake. Women are a bit more dedicated than men in fighting the war against calories. A 1984 survey showed that during any 2-week period, 38% of adult females dieted, compared to 27% of adult males.

Helping women deal with increasing girth is the little-known fact that waistlines for a size 10 skirt have grown from 25 in. in 1970, to 28 in. in 1987! As if that were not bad enough, a size 12 has been ballooned from a 26-in. waist to 29½ in. Talk about the need for truth in advertising and truth in labeling!

Extent of Obesity, Overweight, Dieting, and Exercising

Obesity

Controlling weight and food consumption excesses has become a major national health problem. As much as 20 to 30% of all Americans and others living in advanced-affluent nations may be described as clinically obese. Currently, 70 million Americans diet, and 30 million people are obese. Regarding food consumption and nutrition trends, The National Health and Nutrition Examination Survey covering the 1970 to 1980 period indicates little or no downward trend in obesity.

Overweight

Some 50 to 60% of all U.S. consumers may be described as overweight. Overweight averages an excess 14.3 lb for Americans over 18 years of age. According to the National Center for Health Statistics, overweight plagues 20% of females aged 25 to 34. Up to 70 to 75% of persons interviewed in survey after survey consider themselves overweight, even if they are not. Americans are heavier than at any other time in the past.

Dieting

More than 50% of the overweight people are making efforts to lose weight according to FDA's 1985 National Health Interview Survey. Among average weight schoolgirls surveyed in Michigan and Indiana, 60% of those with average weights were found to be making efforts to lose weight. Among overweight girls, the percent trying to control weight was even higher, amounting to 80% of those surveyed.

Health concerns were motivating factors for 61% of the persons making diet changes within a period of the previous 2 years according to data from FDA's National Health Interview Survey. Proper nutrition was discussed with medical doctors by 22% of males and 29% of females interviewed by FDA in their 1986 National Health Interview Survey. Obviously the concern is great. The question is whether or not there is sufficient understanding and willpower to alter the situation.

Physical Exercise

An alternative way to cope with lesser energy requirements of postindustrial/leisure-dominated lifestyles is to engage in vigorous physical exercise to offset caloric excesses. Daily exercising is on the increase. The percent of Americans exercising daily rose from an estimated 24% in 1964 to 59% in 1984. The extent to which Americans engage in physical exercise varies enormously, depending on what is counted as exercise and how many persons are telling the truth. In 1979 the Department of Health and Human Services (DHHS) set a goal for motivating 60% of Americans 18 to 64 years of age to regularly pursue vigorous physical exercise. Recognized as overly ambitious, the goal was scaled back to 30% in 1985, and the time frame for accomplishing this goal was set for 1990. DHHS estimates that only 10 to 20% of the people exercise enough to improve their cardiovascular systems. They further estimate that some 60% of all Americans do not exercise regularly.

Macronutrition Goals Interposed to Readjust Dietary Intake

Recent Restatement of Macronutrition Goals over Previous Several Decades

Sedentary work, increased leisure time, aging, and health-conscious concerns have prompted a growing number of countries to establish national nutrition goals. Guidelines suggest optimal amounts of calories and the proportions derived from protein, fat, and carbohydrates (and sometimes from sugars, alcohols, and other specific components).

Sweden formally adopted a macronutrient/exercise/health program in 1971. The U.S. trailed 6 years later, putting forward its own version of the goals during 1977. Recommendations followed a similar pattern: reduced caloric intake overall; selective reduction in the proportion of calories derived from fats, sugars, and alcohol; and increased consumption of complex carbohydrates and dietary fiber.

First Statements of Macronutrition Goals Date Back Nearly 100 Years

Macronutrition goals are not new. Recommendations nearly identical to those being pursued over the last several decades date back to the beginnings of biochemistry before the scientific discipline called nutrition emerged. Earliest known macronutrient recommendations concerning fat, protein, carbohydrates, and sugar consumption date back more than a century!

One of the earliest U.S. government biochemists, Dr. Wilbur Olin Atwater, who has been called the father of American nutrition, published the following statement in the *1894 Yearbook of Agriculture*: "Our food is one-sided. It includes a relative excess of the fat of meat, of starch, and of sugar."

Many years earlier, while heading the U.S. Department of Agriculture (USDA) Office of Experimentation Stations, Dr. Atwater put forward the first official guidelines specifying optimal proportions for the macronutrients. Expressed as a percent of total calories in the diet, his recommendations called for: 15% protein; 34% fat; and 50% carbohydrate. These guidelines, even considering the more vigorous physical activity and higher energy levels peculiar to those times, still are fairly close to contemporary recommendations.

In 1918 Dr. L. H. Peters, in her book entitled *Diet and Health*, recommended that "A balanced diet should contain: 10 to 15% protein . . . 25 to 35% fat; 60 to 65% carbohydrates." These recommendations are nearly identical with contemporary guidelines.

Picking up on the same theme a few years later, Dr. Grace McLeod in speaking to the National Canner Association called for dietary improvements accomplished by increasing the intake of mature legumes, nuts, fruits, vegetables, and whole grains; she also called for consuming smaller quantities of meats. Put into practice, today's macronutrition goals realize their objective by changing intake in accordance with these recommendations.

Periodically picking up on restatement of the macronutrient goals, the *1936 Yearbook of Agriculture* put forward a somewhat revised set of recommendations specifying the following proportions of total energy: 10 to 12% from protein; 25 to 35% from fat; and 60% from carbohydrates. Dr. Henry T. Sherman, perhaps America's foremost nutritionist, set forth dietary intake recommendations in his 1950 publication, *Nutritional Improvement of Life*. Recognizing the link between proper foodstuffs and health, he recommended increased consumption of mature legumes, fruits, vegetables, and milk and milk products. He also proposed lower levels of intake for sugar, eggs, meat, and fat.

Untold numbers of health professionals and nutritionists played a vital role in building up evidence establishing the importance of optimal intake of macronutrients and certain foods. A major turning point occurred during the 1950s and 1960s. The outstanding national and international studies developed by Ancel Keys provided convincing evidence of dietary risk factors associated with heart disease and its complications. It was this work, in large measure, that provided the foundation that eventually prompted more formal recommendations from leading heart organizations and other experts. In his 1959 book, *Eat Well and Stay Well*, Dr. Keys urged steps to prevent coronary heart disease. Mainly stressing reductions in fats (particularly animal fats) and recognizing contributory factors such as tobacco and alcohol use, he also identified obesity as a major risk factor.

Soon after the publication of Keys's findings, heart associations around the world, alarmed by rising incidence of heart and circulatory diseases, began publishing recommended dietary modification as preventive health measures. The American Heart Association began in earnest to address these matters in 1965. Over time the scope of dietary recommendations grew broader and more detailed.

Today's macronutrient recommendations are but a reiteration of the same principles that have been put forward for over a century. Contemporary goals suggest the following proportions of dietary energy: 10 to 15% from protein, 25 to 35% from fat (reductions in saturated fats and cholesterol also called for), and 50 to 65% from carbohydrates (reductions in alcohol and in sugar to 8 to 12%, and increases in dietary fiber are also called for) (Fig. 6).

Proposed Goals of Calorie Reduction and Increased Physical Exercise Are Mostly Being Ignored

Contending with the excessive intake of calories and other food components, has been attempted or accomplished mainly by traditional means, which are reducing energy intake (cutting calories) or increasing energy output (exercising more). So far, neither of these approaches has been terribly successful.

Human caloric intake has been edging up while caloric energy requirements associated with increasingly sedentary lifestyles are declining. To maintain proper body weight and good health, calories should be cut, physical activity levels should be increased, or a balance should be struck between the two.

Since the macronutrition goals were set, consumption

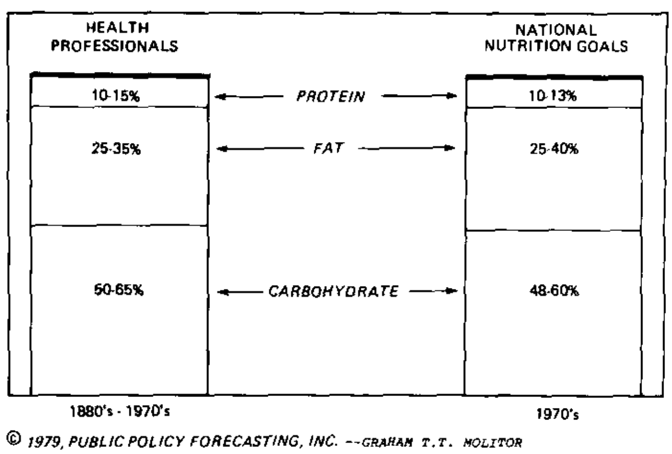


FIGURE 6. Macronutrient standards.

patterns (as reflected by USDA disappearance data) have ignored the advice. In 1976, the year before the first U.S. macronutrition goals were published, caloric consumption averaged 3,380 calories. For 1984, national average intake amounted to 3,450 calories.

Recommended daily dietary allowances (RDAs) established for caloric intake have declined steadily over the years to keep pace with changing lifestyles. Caloric intake for males, 23 to 50 years of age and weighing 70 kg, dropped from a high of 3,200 over the 1953 to 1967 period down to 2,700 calories for the period 1974 to the present. Average national per capita consumption of calories, hovering in the 3,300 to 3,400 calorie range, indicates that adult males who have the highest energy needs of any group in society continually have exceeded the RDAs by a wide margin (Fig. 7).

It is not that the U.S. population does not know what to do. Macronutrition guidelines also have been set to steer intake toward a better balance between fats, proteins, and carbohydrates, calories overall, and other food components. Government officials responsible for nutrition policy have been setting the right goals. Based on the best scientific evidence, the goals are correct statements of proper food intake requirements. It is only the lack of human willpower that makes realization of these goals elusive.

Quantitative food intake amounted to 1,600 pounds annually per capita during 1909 to 1932, which was the peak of the physically demanding industrial era. Food consumption subsequently declined to 1,500 pounds yearly per person during 1934 to 1950. With the advent of the information era and a majority of the workforce using their brains and not their brawn, consumption declined to 1,400 lb yearly during the 1965 to 1980 period. Translated into more understandable terms, per capita consumption during these three time periods declined from 4.38 to 4.11 to 3.84 lb daily per capita. Beyond the year 2000, Public Policy Forecasting, Inc. projects that consumption will drop to 1,335 lb annually or 3.66 lb daily per capita (Figs. 8, 9).

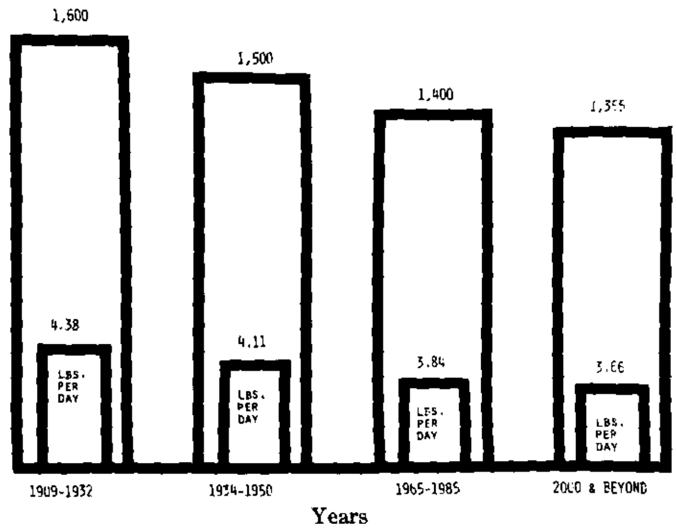


FIGURE 8. Quantity of food consumed declining (pounds per capita).

Declining quantitative food consumption, although subject to erratic ups-and-downs, has been paralleled by similar declines in terms of caloric intake. From an historic perspective, caloric intake dropped from 3,500 calories daily in the early 1900s, to 3,300 to 3,400 calories daily from the 1950s to current times. Public Policy Forecasting, Inc. projects a continuing decline to 3,000 to 3,100 calories consumed daily per person by the year 2000 and beyond.

Apparently, consumers have a mind of their own. Overindulgence, however, may be only a short-lived response. Long-term, I foresee dietary adjustments in accord with those specified by nutrition experts. During the interim—from short-term behests to long-term response—consumers will be buffeted with barrages of ideas, new diets, and gimmicks to postpone the day of reckoning. Very likely, such changes will be accom-

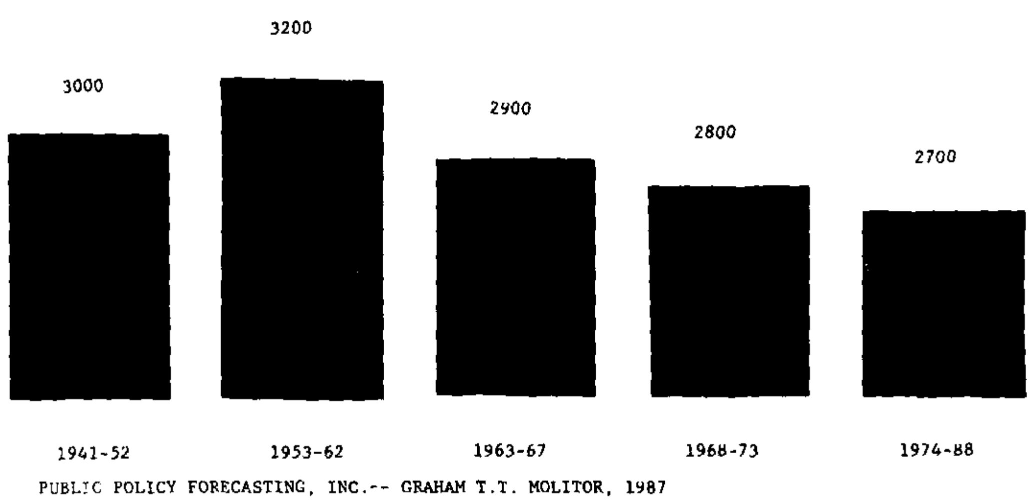


FIGURE 7. Recommended daily dietary allowances, calories: males, 23 to 50 years of age, 70 kg.

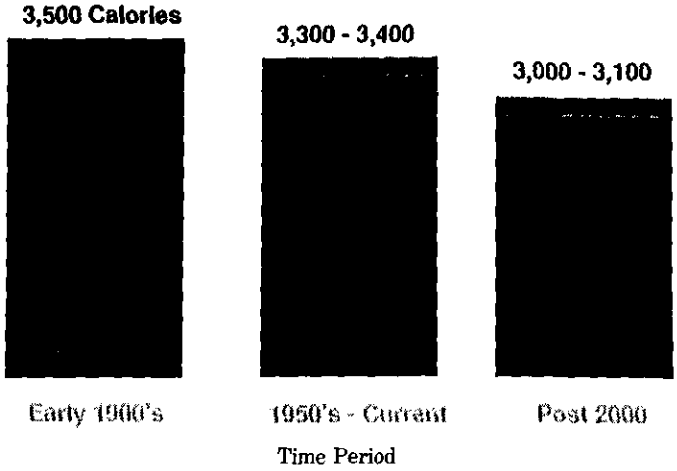


FIGURE 9. Caloric daily intake per capita, U.S.

plished over the course of several generations. Children may have to grow up with sound nutrition practices before passing them along to their own.

Cultural Cuisine Is Deeply Ingrained, Very Slow to Change

Long-established and cherished eating patterns have a very powerful inertia. Deeply embedded and ingrained patterns of cultural cuisine do not change quickly or easily. Eating habits appropriate to arduous life-styles persist. A cultural lag of this sort may entail a generation or so before dietary patterns are altered. The movement, even though at glacial speed, is slowly going toward caloric intake levels that are more consistent with sedentary lifestyles that are primarily devoted to nonexertive leisure-time pursuits. Dietary habits are difficult and usually slow to change, but change they must.

Self-Correction of Dietary Excesses through Technology

Initially I had believed that technology would self-adjust dietary excesses. My assumption was that low-calorie foods, along with foods reduced in fats, salt, and sugars, would effectively resolve the problems associated with dietary excesses. I remain convinced of that eventuality in the long-term.

Concerning sweeteners, I assumed that the increasing use of low calorie sweeteners would displace caloric sweeteners to a significant degree, thereby largely resolving any problems thought to be associated with excessive sugar consumption. However, my preliminary review of consumption trends in a number of countries that adopted macronutrition goals indicates—much to my surprise—that human behavior has ignored the recommendations and continues to run counter to suggested macronutrition goals. In the countries surveyed, caloric intake continues to climb along with the consumption of sweeteners! This is an amazing state of affairs. This matter certainly warrants careful appraisal, particularly since the overconsumption of calories and people concerned with obesity represents the number one opportunity to reduce premature death and to improve the quality of life.

Calorie-controlled sweeteners may supplement more than they supplant other sweeteners—at least temporarily during this era of self-indulgence, self-gratification, and hedonistic excess. Suggestions that calorie-controlled sweeteners may not supplant so much as they may supplement consumption of other caloric sweeteners has some profound implications. A major appeal of noncaloric and low-caloric sweeteners is the general belief that they are useful in weight reduction and weight maintenance—the number one nutrition concern among U.S. consumers. Furthermore, reducing caloric consumption is thought to be helpful in reducing risks associated with several leading causes of death among Americans. Reports in the literature cast doubts on the value of, or at least the effectiveness of calorie-controlled sweetener use in weight loss dietary regimes. Clinical-type weight-reduction studies, including trials in which calorie-controlled sweeteners were introduced into their diets, failed to show weight reduction of the kind, magnitude, or duration anticipated. These subjects were not aware of the calorie-controlled sweeteners being added. Such surveys suggest that weight loss claims (construed as an extension of labeling claims, and regulated as such) may require much more definitive study. Without such proofs, weight control promotional claims could run afoul of misbranding and adulteration provisions and penalties of existing laws.

The assumption that increased availability and the use of calorie-controlled sweeteners would supplant, not supplement, caloric sweetener intake had some foundation in the experiences with their use during World War I and II. During periods of worldwide warfare, shipping difficulties and the urgent priorities of wartime needs substantially changed sweetener use. U.S. sweetener consumption dropped from 125.7 pounds per capita in 1930 to 93.2 lb in 1945, then rebounded to 123.3 lb in 1965—a drop of approximately 30 lb representing a 25% decline during WW II.

During both World Wars when cane and beet sugar imports were all but cut off, saccharin took up the slack. Faced in the past by wartime caloric sweetener shortages, saccharin disappearance for food use sharply increased. During WW I saccharin use doubled in the U.S., rising from 26,000 tons in 1910 to 60,000 tons in 1918, then dropping to 32,000 tons in 1930. During WW II, statistics for saccharin use once again soared, rising from 81,000 tons in 1940 to 335,000 tons in 1946, then declining to 171,000 tons in 1960.

Similar wartime use patterns involving the increased use of alternative sweeteners such as saccharin can be portrayed for most industrialized nations. In Germany, during WW I and the ensuing economic readjustment period, centrifugal sugar production plummeted to as little as one-third the prewar level. Saccharin production in Germany, which stood at 30,000 kg in 1894, increased tenfold to 300,000 kg in 1922, then dropped to 96,000 kg in 1934. Production levels in Germany spiked again during the WW II period, reaching 500,000 kg in 1944, then dropping to 27,000 kg in 1965. Whereas, beet sugar had been Napoleon's answer to short sweetener supplies, saccharin did the same for Hitler. Wartime substitutions, such as those recounted, suggested to me that alternative sweeteners fundamentally supplanted or replaced traditional caloric sweeteners. The question to ponder is whether or not alternative sweeteners do in fact supplant other sweetener use, or whether they supplement the use of other sweeteners. Very important considerations hinge on this point.

Drastic Consumption Declines in Cane and Beet Sugar Ahead

Cane and beet sugar consumption per capita declined in the U.S. from a highpoint of 101.8 pounds in 1970 to 62.1 pounds in 1987; it may decline to 60.9 pounds by 1990. A near-total substitution of sucrose may be a future outcome. Cane and beet sugar are likely to become premium-priced mere specialty items. The unique functional properties of sucrose chemistry will slow this substitution. Eventually, however, virtually all functional properties of sucrose will be replicated, and sucrose will steadily be displaced from the end-use categories it previously dominated.

Great numbers of new high-intensity, low-calorie, and noncaloric sweeteners, many of them already discovered, will be coming onto the market. By satisfying the taste for things sweet and bereft of unneeded calories, calorie-controlled sweeteners will account for over 50% of all sweeteners beyond the turn of the century. Consumers, the majority of whom already are obese or overweight, will hasten the disfavor and decline of caloric sweeteners (Fig. 10).

Health concerns bolster the change-over from caloric to good-tasting, lower-costing, calorie-controlled alternative sweeteners. Noncarcinogenic and even anticarcinogenic properties of alternative sweeteners add to the appeal. Far more important however is the possibility of avoiding excess calories that aggravate the risks of developing a host of diseases and maladies. People want to live longer and healthier lives.

Health care costs have been the fastest growing sector in the economy for quite some time. Health care, as a percent of the gross national product, rose from 4.5% in 1950 to 10.7% in 1985; it is projected to exceed 15% by the year 2000. At the turn of the next century health care costs may become the largest single item of consumer spending. Increasingly costly health care burdens will become a matter of great concern to consumers.

Incentives for preventive health care, accomplished through dietary modification, will have strong appeal. Increasingly sedentary lifestyles will accentuate consumer interest in calorie-controlled dietary substitutes.

Cane and beet sugar mass consumption will be diverted more and more to lesser developed nations where just getting enough calories into the diet is a major challenge. Sugarcane is a most bountiful crop; in terms of caloric yield per acre of production, sugar cane still leads all other major crops.

Viewed from a historic vantage, I envision the human quest for sating sweetness passing through four stages (Fig. 11); these are as follows:

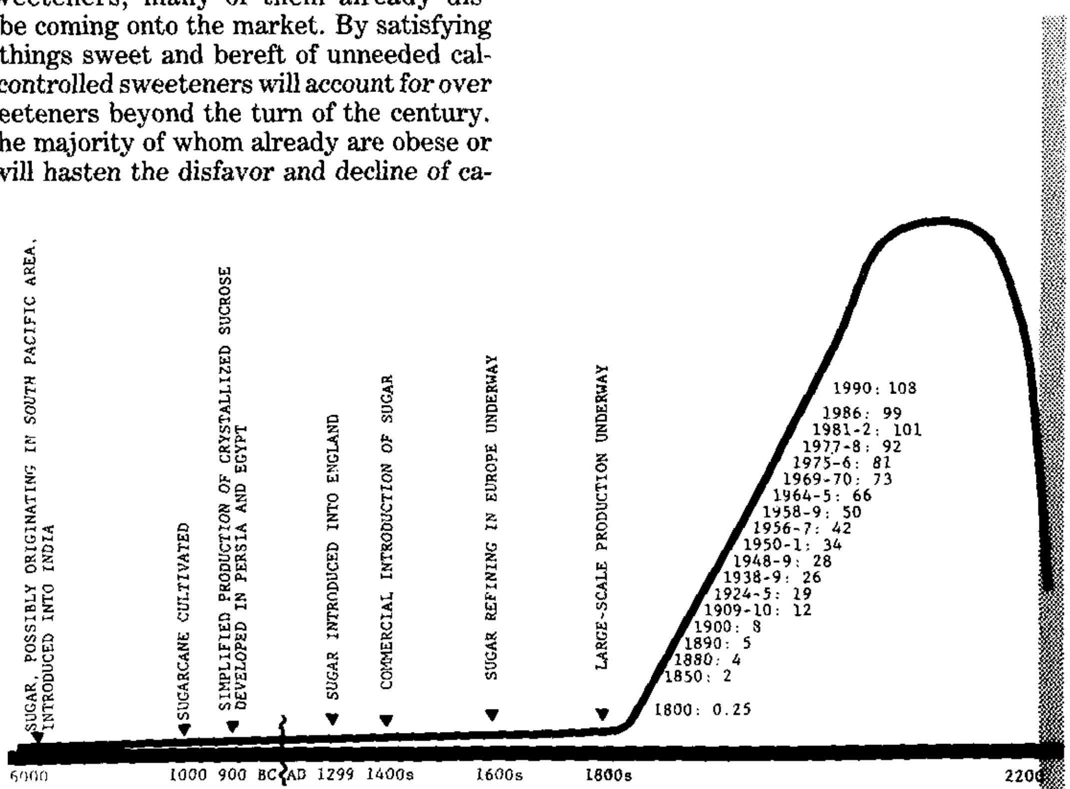
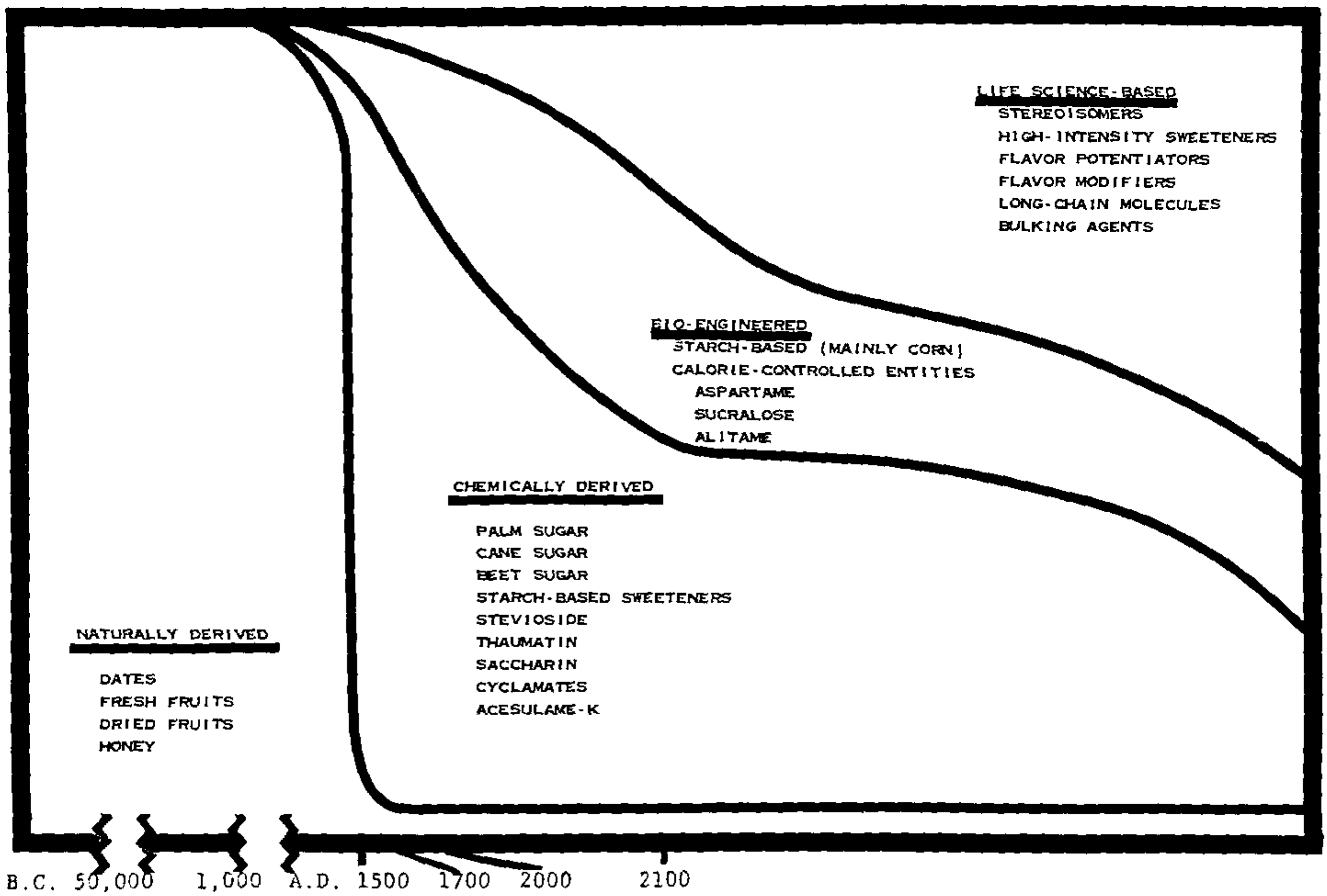


FIGURE 10. Sucrose production—historic perspective (million metric tons, raw value).

SWEETENER SUCCESSION

EVOLVING STAGES OF DEPENDENCY



Naturally Derived Sources. Sweeteners gathered initially from the land in the form of fresh and (later) dried fruits, and still later by honey.

Chemically Derived Sources. Extraction of sweeteners from plant sources by chemical techniques — sugar cane, sugar beets, and starch-based sweeteners at a later time, as well as laboratory-synthesized alternative sweeteners (beginning with saccharin).

Bioengineered/Mediated Sources. Sweeteners extracted from plants and also those derived from biotechnological processes (i.e., aspartame) relying on fermentation technologies and unique strains of bacterium, many of which have been biomanipulated by modern bioengineering techniques.

Life Science-based Compounds. Emerging stage during which emphasis is on manipulating the senses to achieve desired taste phenomena including the psychophysiological perception of sweetness sensations (reliant on all previous three stages of development for raw materials).

Controlling Dietary Excesses with Sham Food Components

Devious though they may be, new technologies are unleashing a number of food components and foodstuffs into the food supply; these satisfy the senses but provide little nutritional value. Some substances are configured in such a manner that their food value is metabolically unavailable, and others achieve their sense-satisfying effects with the merest of scintillas or unique sense-tricking phenomena. Some may reverse undesirable flavors like sour flavor notes into heavenly sweet ones. Others may synergistically boost effects perceived by the senses, thereby allowing costly principal functional component quantities to be reduced. One might term foods or food components purposely selected or designed so as not be biologically available as sham foods or nonfood.

Sham food products fool human organisms. They provide oral and gut satisfaction but few, if any, calories. A number of unanswered questions remain as to whether or not such substances merely temporarily sate the appetite. Apparently, other physiological drives may be overriding, with the result that the drive to consume more gets satisfied in other ways. Answers to such questions will have instrumental effects on the fate of such products.

Perhaps one of the most contrived of these approaches and certainly one of the more technologically sophisticated involves locking metabolically undesirable entities onto long-chain molecules. These substances are lashed onto polymers so that resulting molecules are too large to be assimilated by metabolic pathways and they pass through the human digestive system without being absorbed. So far, food colorants using this system have been developed. To date, these results and the Food and Drug Administration (FDA) attitudes have not been favorable.

Flavor modifiers that can transform taste sensations have been known for centuries. Literature accounts dating back to 1852 make reference to so-called miracle fruit. Botanically known as *Sysnsepalum dulcificum*, miracle fruit has the unique capacity to cause sour foods to taste delightfully sweet. The active ingredient, glycoprotein—a flavor modifer—was not isolated and characterized until 1969. This flavor-changing entity has a sweetness equivalency 150 times more potent than sucrose, the standard that the sweetness of other compounds is measured against.

Flavor potentiators, such as ones marketed by Ottens Flavors, are promoted for their ability to reduce the costly aspartame content in foods by nearly one-third with no discernable changes in the flavor.

Bulking agents are designed to fill in functional properties of food components such as high-intensity sweeteners that are lacking in body. They also are to be counted among food components that sate the senses but provide very little, if any, caloric value to humans.

Noncaloric sweeteners provide the classic example of sating inborn craving for sweetness but without the calories carried by traditional sweeteners such as cane and beet sugar or sweeteners derived from starch chemistry. Consumers use them only for effects, not for nutritive value.

High-intensity sweeteners, even though caloric, are consumed in minute quantities. Functional effects are achieved with such small quantities that, for all practical purposes, they make no contribution to caloric intake.

Dietary fiber constitutes another food component category that might be considered sham so far as nutrient delivery is concerned. Fiber is promoted primarily for providing bulk to facilitate and speed up the transport of waste products through human digestive systems without adding any additional calories. Dietary fiber might be viewed as a sort of Roto-rooter service for human plumbing. The fullness of feeling provided by dietary fiber also may help to curb the appetite, thereby helping to suppress intake and maintain appropriate body weight. Therefore, in this limited sense, fiber tricks the human organism. In truth, all foods are not consumed strictly for the nutritional value that they contribute toward growth and maintenance of basic body functions.

Physiochemical receptors that trigger sweetness are on the threshold of being better understood. With this new understanding comes the capacity to manipulate effects. Food technology stands on the threshold of enormous new capacities to coax maximal pleasure and to minimize possible harms from dietary habits. Efforts to maximize pleasurable sensations add to the enjoyment of living. If, in the process, excess calories can be moderated and transmit time through the lower colon can be improved—without otherwise doing harm to human biologic processes—important new strides forward in fitting cuisine to human needs will have been accomplished. On the darker side, stroking the senses, or manipulating the senses may be viewed for nefarious purposes. Deceiving the senses may represent only the most recent sophistication in the economic adulteration of foods.

Important metaphysical questions also are posed by this new panoply of food technologies. The ethics of selling foods that have no intrinsic nutritive value and that have the sole purpose to simply sate the senses pose interesting issues. Such products are a boon for the affluent who over indulge. For economically disadvantaged consumers, they may be a bane by putting in "harm's way" nonnutritive foodstuffs when such persons desperately may need maximum calories and nutritive food value at the least cost.

Stereoisomers, the Ultimate Sham or Nonfood

Stereoisomers, or left-handed sugars, which are biologically unavailable to humans, emerged from science fiction beginnings. Serendipitously discovered by Gilbert Levin during the course of his work on NASA's 1976 Viking Mars mission, a biotechnology firm, Biospherics, was created to exploit the concept. At least 10 use patents, along with various process patents (both chemical and enzymatic), have been staked out including L-fructose, L-glucose, and L-gulose. Engaged in developing tests for detecting Martian life forms, Levin considered the possibility that Martian life might have adopted mirror images of earth chemicals. Contrary to reports in the literature, he noted that such sugars were not bitter, but sweet, and went on to patent them and form the Biospherics company to develop them.

Mirror images of traditionally right-handed molecules were first confirmed by Louis Pasteur in 1848. Stereoisomers of certain compounds have long been known to possess unique advantages over right-handed molecular configurations of the same entity. Some examples include: the left-handed form of morphine, which is the only one effective as a pain reliever, and right-handed amphetamines, which are some 10 times more effective in treating Parkinson's disease.

A little closer to matters of interest to alternative sweetener manufacturers, is the fact that aspartame sweetness is derived from the L-L dipeptide ester; whereas, the D-L-, the L-D-, and D-D- dipeptides are, reportedly, not sweet. Pfizer's newly developed dipeptide sweetener which uses the D-optical isomer of phenylalanine as a raw material of production provides another case in point.

L-sugars are highly coveted because metabolic enzymes of the body accept only right-handed sugars such as those abundantly occurring in nature. Because they cannot be metabolized they are noncaloric. In most other respects they behave like regular right-handed sugars. L-sugars are noncarcinogenic because they do not add to available fermentable carbohydrates that can be used by buccal bacteria. By using these sugars consumers avoid plaque build-up and dental decay. In addition, these sugars are heat stable and stable in aqueous solution, not subject to spoilage, and leave no aftertaste. Most important, perhaps, is that such compounds apparently pose no health or safety hazard akin to those plaguing other sweeteners based on toxic metals or halogens. Precisely, the effects (if any) that high-volume usage of L-sugars might have on human organisms and how fast organisms might change themselves in order to metabolize L-sugars remains to be seen.

Malthusian Pessimism Versus Technological Optimism

Malthus was not the first to alarm the world about geometric rates of population growth outstripping global food supplies growing at linear mathematic rates. Hung Liang-Chi published essays on the disproportion between increase in the means of subsistence and faster-growing population in 1793, five years before publication of Malthus's *First Essay on Population*. Malthus, incidentally, was the food industry's most famous forecaster. His major benefactor was the East India Trading Company, which was seeking ways to exploit Commonwealth resources from the New World. Going back still further in time, rapid population growth overtaking food shortages had been a theme of Euripedes, Polybius, Plato, and Tertullian, among others.

Malthusian-style prophets of gloom and doom always have been with us. Offsetting them are the Cornucopians, the prophets of plenty. This paper deals with the vast array of technologies that have the capacity to increase food output by multiples measured by 10s, 100s, even 1000s!

How severe is the hunger problem? Mass starvation and death has been relegated to times past. Chronic malnutrition is widespread and commands compassionate response. Short-term (1- to 3-year) solutions are humanitarian ones involving aid and assistance while causes remain unresolved. Intermediate (10- to 90-year) answers are technology-based, and capital intensive ones aimed at increasing output, lowering prices and raising income levels. Long-range resolution (100-plus year) involves establishing a global population equilibrium.

Lord Boyd Orr, first Food and Agricultural Organization (FAO) Director General, highlighted dimensions of the hunger problem early-on: "A lifetime of malnutrition and actual hunger is the lot of at least two-thirds of mankind." President Carter's Commission on World Hunger reported in 1980, "One out of every eight (12.5%) people on earth is hungry most of the time." World Bank estimates place the proportion of malnourished at 25% of humanity. By the year 2000, the World Bank estimates that in developing nations 150 million still will be severely malnourished plus another 600 million living in extreme poverty will regularly experience hunger/malnourishment. Chronic malnutrition stunts physical growth; dulls mental ability; shortens life; and, left unchecked, causes death, no matter how one measures them, these are tragic conditions. What is to be done?

The terrible tragedy, the moral and ethical blackmark of these times, is that food surpluses exist right along with, and in the face of, malnutrition and starvation. Agricultural policy makers in many nations strive mightily to cut back production and remove surpluses from glutted markets. While striving to bestow dubious benefits upon a few farmers, they woefully neglect and ignore the millions who suffer, starve, and perish in the morbid wake of the contrived short supply and high-price policies that place life-sustaining food supplies beyond financial reach.

Huge Range of Resources for Human Sustenance Are Available

Global food supplies are based on the merest handful of commercially cultivated crops. A vast potential of alternative sources are available to feed the world; these are listed in Table 1.

Some Basic Indications of the Ability to Increase Agricultural Output

World Record Output for Key Crops

World records provide positive proof of potentials, already realized, not merely theorized. Granted, one-time records may entail extraordinary nurturing with little practical carryover to commercial production. They do, however, set a goal, a target toward which field production can aim. Some world records are included in Table 2.

Available Edible Portion of Crops

The edible proportions of crops directly available as food vary greatly. Shifting to crops with greater portions available as human food suggests the tonnage of foodstuffs could be increased at least 3-fold. The percentages of the edible proportion of the plant in relationship to dry weight of whole plant includes the following crops: sugarbeet (root) = 78%, potato (tuber) = 75%, corn (grain) = 36%, rice (grain) = 34%, oats (grain) = 32% and wheat (grain) = 28%.

Caloric Yield Per Acre of Production

The caloric value of the output per acre of cropland varies enormously depending upon the crop. Shifting to crops that yield more calories per unit of production suggests another theoretical potential for increasing caloric output by at least 113-fold. Acres required for production of one million calories are as follows: 0.15 acre for sugar; 0.44 acre for potatoes; 90 acre for corn (corn meal); 1.2 acre for wheat (refined flour); 2.00 acres for hogs (pork and lard); 2.80 acres for whole milk; 7.80 acres for eggs; 9.30 acres for chickens; 17.00 acres for steers. Measured another way, comparison between crops with

Table 1. Current and potential food resources for commercial use.

Food source	Comments on source and its usage
Current sources	
Fish	22,000 species; 1,000 species used for food and 200 for commercial use; 20 to 30 species account for most food use. Waters cover 3/4 of the global surface, yet provide only 1 to 3% of human food; 4/5 of world catch is consumed by well-fed nations; 1/2 is diverted to animal feed.
Fungi	40,000 to 100,000 species; estimated 80,000 additional species yet not found; may be the most underdeveloped resource; yields of 3 lbs/ft^2 are typical; morels recently sold for as much as $40/lb; shiitake mushrooms sold for $12/lb.
Plants	350,000 species; 80,000 are edible species; 3,000 are used for food and 150 are commercially cultivated; 30 provide 95% of mankind's calories and protein; wheat, rice, and corn together provide 50% of all calories and protein consumed by humans.
Insects	900,000 species; 7,000 to 10,000 new species discovered annually; 5 to 30 million species thought to exist; may be underused, particularly for industrial purposes
Animals	2 million species; 50 in commercial use
Potential tropical sources	
Cereals	
Echinochloa turnerana	Requires only one deep watering
Grain amaranths	High protein including lysine
Quina	One of best protein sources among all plants
Zoster marina	Grows in seawater
Roots and tubers	
Arracacha	1/2 the production cost of potatoes
Cocoyams	More nutritious than cassava
Taro	High yield; grows in waterlogged soils
Vegetables	
Chaya	Spinachlike
Hearts of palm	Delicacy in great demand
Wax gourd	Melonlike; three crops yearly; keeps 12 months without refrigeration
Winged beans	Tropical counterpart of soybeans
Fruits	
Durian	Huge fruits up to 20 Kg each
Mangosteen	A best-tasting fruit
Naranjilla	Dessert fruit with refreshing juice
Pejibaye	Chestnutlike fruit, extraordinarily well-balanced nutritionally
Pummelo	Shelf-life up to four months
Soursop	Good source of pulp and juice; keeps well
Uvilla	Grapelike; can be fermented as a wine
Oilseeds	
Babassu palm	Similar to coconut oil
Buffalo gourd	Arid survivor; seed is 30 to 35% protein and 34% oil
Caryocar species	Prolific oily seeds; resembles Brazil nuts
Jessenia polycarpa	Oilseeds similar to olive oil
Jojoba	Yields liquid that is similar to sperm whale oil
Forage	
Acacia albida	Suited to dry areas; verdant foliage plus fruit
Brosium alicastrum	Drought resistant; edible leaves, fruits, seeds
Cassia startii	Year-round foliage
Saltbushes	Suited to arid conditions, saline soils
Tamarugo	Thrives in saline conditions

Table 2. World record for crop specimens.

Food	Weight: Pounds	Weight: Ounces
Fruits		
Apple	3	1.00
Lemon	6	4.00
Melon	200	—
Cantaloupe	41	2.00
Orange	3	11.00
Pear	3	1.44
Pineapple	17	—
Strawberry	2	0.13
Vegetables		
Artichoke	8	—
Broccoli	28	14.75
Cabbage	123	—
Carrot	11	—
Cauliflower	53	11.50
Celery	35	—
Cucumber	13	—
Lettuce	25	—
Onion	6	3.00
Parsnip	5	15.50
Potato	18	4.00
Squash	513	—
Sweet potato	22	8.00
Tomato	6	8.00
Turnip	73	—
Zucchini	19	2.24

high and low caloric content reveals a 10-fold difference for vegetables; avocados (edible portion) have a high caloric value amounting to 741 calories per pound, whereas cucumbers have a low caloric content of only 73 calories per pound.

Highest Production Countries for Select Crops

Crop output per unit of production varies considerably between nations. Countries enjoying the largest commercial output per acre warrant careful attention to determine reasons for efficiencies that might be emulated to increase yields elsewhere. Countries with the highest yields must be doing something right even though they may not be the lowest cost producers (Table 3).

Annual Productivity Gains

Crop yields over time in a given country or region highlight potentials for rates of productivity advancement. Careful study can pinpoint factors that have actually enhanced yields, the very ones that are worthy of emulation elsewhere to boost output. Table 4 shows increased productivity per acre yearly for select crops in the U.S.

Table 3. Countries with highest and lowest production for select foodstuffs or crops.

Foodstuff/crop (volume produced)	Country: Highest production		Country: Lowest production	
Milk (kg/cow, 1982)	Japan	= 6238	Greece	= 2017
	Norway	= 5239	Australia	= 2952
	Denmark	= 5215		
	The Netherlands	= 5212		
Rice, (metric tons/ha[a], 1982–1983)	Republic of Korea	= 6.05	Zambia	= 0.40
	Egypt	= 5.71	Mozambique	= 0.60
	Uruguay	= 5.71	Upper Volta	= 0.70
	Japan	= 5.69	Zaire	= 0.73
	Italy	= 5.51	Guinea	= 0.75
Corn (metric tons/ha, 1982–1983)	Austria	= 7.83	Botswana	= 0.15
	Belgium	= 7.83	Mozambique	= 0.46
	Luxembourg	= 7.83	Algeria	= 0.50
	Switzerland	= 7.39	Lesotho	= 0.50
	U.S.	= 7.21	Swaziland	= 0.53
Wheat (metric tons/ha, 1982–1983)	The Netherlands	= 7.38	Venezuela	= 0.50
	Ireland	= 6.79	Algeria	= 0.53
	Denmark	= 6.71	Zaire	= 0.60
			Mozambique	0.60
Sugarbeets (metric tons/ha, 1982–1983)	Hawaii	= 222.9	Haiti	= 13.0
	Peru	= 140.0	Bangladesh	= 24.1
	Columbia	= 126.0	Malaysia	= 28.3
Potatoes (metric tons/ha, 1981–1982)	Switzerland	= 48.5	Bolivia	= 5.5
	The Netherlands	= 39.3	Portugal	= 7.2
	Belgium	= 33.2	Peru	= 8.0
	Luxembourg	= 33.2	Yugoslavia	= 8.3
	United Kingdom	= 32.4		
	Germany (FRG)	= 31.0		

[a]ha = hectare

Table 4. Annual increased U.S. productivity per acre for select crops and milk.

Food source/unit weight	Period	Volume produced/unit
Corn (bushels)	1800–1825	25.0
World record: 354 bushels	1900	25.9
Theoretical maximum: 500–600 to 1066 bushels	1940–1941	28.9
	1950–1954	39.4
	1976–1980	96.1
	1984	106.6
Potatoes (hundredweight)	1930	66.0
World record: 1429 hundredweight	1950–1954	151.0
	1976–1980	264.0
	1984	278.0
Wheat (bushels)	1800	15.0
World record: 216 bushels	1900	13.9
	1940–1941	15.3
	1950–1954	17.3
	1976–1980	32.0
	1984	38.8
Milk (hundredweight)	Earliest domesticated cows	6.0
World record: 500 hundredweight	1950–1954	54.0
	1976–1980	113.0
	1979–1983	121.0
Chicken eggs (number)	Earliest domesticated chickens	6–12
World record: 365 eggs	1950–1954	181
	1976–1980	238
	1979–1983	243

Potential Productivity Gains

Table 5 indicates estimates of productivity for developing technologies in the future.

Table 5. Estimated productivity increases forecasted for *developing technologies in food production.*

Technology	1980 percent yield increase compared to the year 2030
Plant breeding	35
Irrigation and crop combinations to conserve water	33
Genetic engineering	25
Growth regulators	24
Nitrogen-fixation	18
Multiple cropping	15–18
Photosynthesis enhancement	16–17
Temperature acclimation	13
Forage nutritional quality	12
Crop maturity	11–12
Transpiration suppressants	10–12
Intercropping	8–11
Seed coating	10
Carbon dioxide climate modification	10–20
Grain nutritional quality	7
Protected (greenhouse) cultivation	5

Fuller and More Efficient Use of Agricultural Inputs Can Increase Production

Land Use. Land area constitutes only 27% of the global surface. Of that portion, 10 to 11% is devoted to crops and 17 to 19% is used for grazing livestock. Another 30% is in forestlands; and 40.5% is used for other purposes. Only 41% of the earth surfaces suitable for cultivation were devoted to agricultural purposes in the early 1980s.

Just nine nations account for 50.4% of land area worldwide: the U.S.S.R., 14.9% Canada, 6.7%; the U.S., 6.4%; Brazil, 5.7%; Australia, 5.1%; India, 2.0%; Argentina, 1.9%; Sudan, 1.7%.

Land devoted to agriculture amounted to 3.768 million acres in 1979. Medard Gabel in *Ho-ling: Food for Everyone* (1979) estimated alternative production modes would result in smaller percentages of the land base to sustain the same level of output: 70 to 90% by reducing post-harvest losses; 49% by eliminating animals; 43% using intensive Chinese techniques; 11% using North American techniques and converting to vegetarianism; 3.9% using North American practices and producing three crops yearly in greenhouses; 0.4% by converting to hydroponics (15 million acres needed); 0.35% by resorting to algae as the food source (13.5 million acres required).

Water Availability. Water is becoming increasingly scarce. Global rainfall amounts to 126,000 cubic miles annually (99,000 of which falls into the oceans; 27,000 fall onto land and 64% of it evaporates); 10,000 go into groundwater and surface runoff; rivers and reservoirs store 3,000 cubic miles of which 1,000 cubic miles is situated in sparsely populated areas).

In America 83% of water use is accounted for by agriculture. Only 5% of U.S. farmlands or 49 million acres were irrigated in recent years. Countries with most irrigated farmland (1976): 85.2 million ha in China; 34.4 million ha in India; 16.6 million ha in the U.S.; and 15.3 million ha in the U.S.S.R.

Conservation measures are required to increase the efficiency of available water supplies. Measures increasing the efficiency of irrigation modes include:

- Drip-trickle systems served by underground pipes to outlets near root systems of each plant (90% efficient).
- Center pivot systems using large pipes and sprayers rotating on wheels in circles up to 0.5 mile in diameter (70% efficient).
- Sprinklers and sprayers using nozzles at or slightly above plant level (60–65% efficient).
- Furrowing and flooding (very inefficient due to rapid runoff and evaporation).
- Design improvements, including energy efficiency and reduced pressure coupled with preventive maintenance to assure optimal performance (50% reduction in operating costs).
- Optimal delivery/application scheduling (predawn, to minimize evaporation; watering correct amounts to correct depth; pacing application to crop cycle requirements; usè of soil/crop sensors to fine-tune application).
- Reduced evaporation from reservoirs; fuller utilization of underground storage.
- Increased control/eradication of unwanted vegetation that otherwise depletes water availability.
- Use of crops requiring lesser quantities of water (pounds of water required to produce one pound of specific crops: 20,000–50,000 for meat; 10,000 for milk; 3,000–5,000 for vegetables; 1,500–2,000 for rice; 600–800 for potatoes; 300–500 for wheat; 200–250 for millet).
- Increased reliance upon advanced weather forecasting to avoid unnecessary irrigation.

Fertilizer Use. Fertilizers can provide an immediate increase in crop output. Global use of inorganic fertilizers (nitrogenous, phosphates, and potassium) have increased almost continously since they were introduced commercially. As much as 50% (and even more in some areas and for some crops) of recent productivity advances may be attributable to fertilizer (Table 6).

Table 6. Use of fertilizer per acre of cropland by certain countries or areas, 1957–1961.

Country	Pounds of fertilizer/acre cropland
U.S.S.R.	10
East Asia	25
Oceania	27
U.S.	30
East Europe	41
West Europe	85

Table 7. Nations accounting for 52.1% of worldwide organic fertilizer use in 1980 and the world's percentage of fertilizer used by each.

Nation	Fertilizer use, %
U.S.	21.3
U.S.S.R.	18.8
China	14.9
France	5.6

Just four nations accounted for 52.1% of worldwide organic fertilizer use that totalled 116 million metric tons in 1980 (Table 7).

Capital investment in fertilizer production may exceed $100 billion over the next 20 years. New plants cost $100 to 150 million and require three to eight years to build. The U.S.S.R. ranks as the world's largest producer of inorganic fertilizers (combined million metric tons, 1980–1981). See Table 8 for a listing of major fertilizer producers.

Fertilizers are not inexpensive. Nitrogen is six times more costly than potassium and sixteen times more expensive than potassium; their use must be optimized. Controlled application rates are essential as rapidly diminishing additional yields are realized at high levels of use. See Table 9 for the 1977 nitrogen fertilizer use (pounds per acre) and increased corn yields (bushels per acre).

Table 8. Nations producing the most fertilizer, 1980–1981.

Type of fertilizer	Producer nation	Volume, million metric tons
Nitrogen	U.S.[a]	11.8
	U.S.S.R.	10.2
	China	10.0
Phosphate	U.S.	9.4
	U.S.S.R.	6.5
	China	2.3
Potassium	U.S.S.R.	8.1
	Canada	7.3
	U.S.	2.1

[a]The U.S. consumes about 25% of total world output, of which about 50% goes for corn alone.

Table 9. Nitrogen fertilizer use in increased corn yields during a 1977 study.

Pounds/acre of nitrogen	Corn yield, bushels per acre
0	35.0
70	65.3
140	94.2
210	108.4
280	113.7

The deep placement of fertilizers may increase efficiency and prevent runoff. Linkage with trickle irrigation applied directly to roots can double fertilizer utilization rates. Foliar (leaf) application as well as root placement of fertilizer during crucial stages such as flowering or fruiting may be decisive in enhancing yields of desired plant parts. Alternatives to costly synthetic nitrogen fertilizer long have been available: crop rotation or intercropping with nitrogen-fixing species; crop selection emphasizing root nodulation; and nitrogen-fixing microorganisms symbiotic with specific root systems.

Energy Use. Energy used in agriculture has shifted successively from humans to animals to natural power (wind and water) to mechanical power (steam, fossil fuels) to manufactured sources of energy (chemical fertilizers, pesticides, herbicides, other agriculture chemicals and off-farm inputs—transportation, processing, packaging, preservation, preparation). Farm inputs in 1910 and 1980 highlight this shift: labor decreased from 93% of all inputs to 18%; machinery increased from 6% to 35%; and chemicals soared from a mere 1% of input to 47%. Table 10 categorizes the energy use distribution for on-farm activities in the U.S. during the early 1980s.

Increased energy inputs reduce labor, increase productivity, reduce crop failure, and help improve quality. Assuming a farmer earned $36.70 for 10 hr of work, it was estimated (1980) that five cents worth of electricity provided an equivalent amount of mechanical work. Under these conditions, farm labor substitution continues at a rapid pace. Tractor horsepower on U.S. farms has risen rapidly: 101 horsepower in 1951; 264 horsepower in 1978; 311 horsepower in 1984. The number of U.S. farmworkers declined from 10 million in 1950 to 3.6 million in 1985.

Less Energy-intensive Crops. Selection of less energy-demanding crops can be resorted to as an option in reducing farm energy inputs. Ratios of kilocalorie output to kilocalorie input vary enormously among U.S. crops (Table 11).

Energy Conservation. The use of energy may be augmented by resorting to energy conservation techniques: biomass conversion of both animal and plant wastes (especially plant parts harvestable in bulk without regard to selectivity); solar capture (heat, photoelectricity); low-temperature drying of crops (energy savings of 20 to 30% over high-temperature methods; however, longer drying time may subject crop to offsetting losses incurred by additional unprotected exposure).

Table 10. U.S. energy use distribution for on-farm activities during the early 1980s.

Procedure/equipment	Percentage of energy use
Fertilizer	31
Irrigation	13
Farm vehicles	13
Preharvest operations	12
Harvesting	10
Grain and feed handling/drying	8
Livestock care	6
Pesticide use	5
Other inputs	2

Table 11. Ratios of kilocalorie output to kilocalorie input among U.S. crops and meats.

Region	Crop/meat	Kilocalorie ratio output to input
Illinois	Soybeans	4.50
U.S.	Corn	3.50
North Dakota	Wheat	2.70
Georgia	Peanuts	1.30
Arkansas	Rice	1.10
Eastern U.S.	Apples	0.90
U.S.	Broiler chickens	0.80
California	Tomatoes	0.60
U.S.	Beef (range)	0.50
California	Lettuce	0.50
	Beef (confined)	0.07

Capital-intensive Agricultural Operations. Farm inputs are costly, however these costs can be managed. Steadily advancing technological fixes hold the key to keeping costs down. In the process, agriculture has become increasingly dependent on capital and credit. Financial management is an imperative for successful agricultural operations.

Capital intensive farming is characterized by application of the latest technologies and intensive use of land, water, energy, and agricultural chemicals. Modern agricultural practices of this sort contrast sharply with labor-intensive, biologically based approaches closer to nature's rhythms and sparing of land, energy, and water resources. Labor-intensive operations frequently enjoy greater output per acre, but they may not be as productive per farm worker or other input. However, both systems will persist. Globally most of commercial production will emanate from capital intensive systems situated in less than ten countries.

A dramatic example of how capital intensive agrisystems can supplant traditional agriculture involves sweeteners. Often thought of in terms of one to two substances, in reality there may be as many as 1,000 different sweet-tasting substances. Sweeteners 54,000 times sweeter than sucrose have been discovered. Carried to the ultimate, this might mean that perhaps two to five manufacturing plants situated on a few acres could supplant millions of acres, and idle thousands of processing facilities now devoted to produce crop-based sweeteners. This may not be as far-fetched as it appears. Throughout history, one sweetener after another has come along to successively supplant one another as the principal sweetener; natural sugars from dates, figs, grapes, and other dried fruits were dominant for perhaps 50,000 years. Honey, next in line, was used as a principal sweetener over the next 40,000 years. Sugarcane dominated world sweeteners for nearly the next 3000 years, and sugarbeets have become a close competitor with sugarcane over the past 200 years. Starch-

Table 12. Approaches and technologies that will potentially increase global food production by at least 14-fold.

Methodology	Potential increase × original yield
Full use of agricultural lands	2.5
Multiple cropping	1.5
Use of high-yield varieties of crops	2.0
Increased volume of fertilizer	1.5
Additional irrigation	1.5
Reduced losses in farm/distribution chain	2.0
Other minor but cumulative activities	2.0

based sweeteners derived from corn (or other starch bases) surpassed cane and beet sugar (sucrose) use in the U.S. during the early 1980s, and currently they are the dominant domestic sweeteners. Synthetic sweeteners, of which there are many hundreds, may eventually become (collectively) the dominant dietary sweetener source.

Agricultural Output Can Be Increased Enormously by Using Available Technologies

Potential Increases in Global Food Production

Currently available technologies, if fully capitalized on worldwide, have an enormous potential for increasing food output (Table 12).

Shorter Growing Cycles

Compressing maturation of farm crops can increase total output as well as reduce costs of production by substantial margins. Selective breeding of broiling chickens already has reduced production cycles. In 1950 broiler chickens required 12 to 14 weeks to reach maturity. By 1982 they were reaching maturity in only 7 to 8 weeks. Feed requirements for broiling chickens declined more than 50% from 1955 to 1982, declining from three pounds to two pounds over the period. Feed costs for raising chickens amount to 70% of production costs. Economic benefits of these changes is considerable.

Enhancing Crop Survivability and Conquering Agricultural Diseases

Survivability of newly born animals and seedling plants adds incrementally to overall productivity and overall output. New techniques, for example, have increased successful egg hatchlings by 30% from the 1940s to 1982. Contending with animal diseases, avoiding incidences of diseases and premature death, as well as enabling growth potentials to be realized without interferences, adds to productivity and increases overall production. Hog cholera has been eradicated. Marek's disease, tuberculosis, and foot-and-mouth disease have been dealt with. Diseases requring further research include bluetongue, scrapie, pseudorabies, respiratory diseases, African swine fever, mastitis, to mention a few.

Planting seedlings in a gel that largely eliminates desiccation enhances survival. To further assure the development of new seedlings, optimal planting depth, planting density, planting dates, and timely harvest contribute to plant yields.

Increased Crop Yields

Making two blades of grass where only one had grown before is made possible by twinning animals and by double, even triple cropping. Selection of plants with short maturation cycles in areas with long growing seasons allows multiple crops to be grown on the same land during the normal growing season.

Enclosed Growing Systems

Closed-cycle controlled agriculture systems, usually coordinating optimization of all key growth parameters by computer control, are capable of producing 17 or more crops of lettuce annually.

Protected cultivation in controlled environments previously has involved expensive greenhouses. Now less expensive structures are available: air-inflated, self-contained, supported bubble houses and less costly plastic-covered tunnel farms. Plastic-covered tunnel farms entail costs 40% higher than required for investment in open-field farming. A 150-foot tunnel covering one-eighth an acre can yield the same amount of tomatoes as one acre planted in open fields. Plastic films cover row crops, seed beds, and soil mulches. The technique extends crops to new areas, expands the season by extending starting and finishing of the growing period, improves yields, and greatly improves the quality of output. An Egyptian experiment at Omar Makram involved starting seedlings under plastic tunnels and growing tomatoes on wire structures instead of allowing them to sag onto the ground. Yield increases advanced 6-fold, increasing from 4 tons in open fields to 27 tons in plastic tunnel farms. Earnings increased an additional $1900 per acre. Other experiments in the same area with mangoes and cucumbers demonstrated yield improvements five times greater than open-field runs.

Natural Substitutes for Agricultural Chemicals

Intercropping using wheat and soybeans (with high nitrogen-fixation properties) has increased productivity up to 30% on lands south of 40 degrees latitude. The use of crop residues and mulches with allelomorphic properties that literally conduct chemical warfare between plants may reduce or eliminate the need for chemical herbicides. Reduced reliance on synthetic herbicides also reduces development of herbicide resistance and ameliorates problems associated with herbicide runoff. Among nature's own herbicides are: barley, corn, oats, rye, sorghum, apples, apricots, mustard, peas, potatoes, and tomatoes.

Insect Control

Insect control is imperative in achieving high yields. Integrated pest management based on field analysis, plant growth models, and insect lifecycle models provides a basis for optimizing the use of minimum amounts of pesticides, thereby entailing savings in both time and money. Controls extend further than just insects, covering pests, parasites, and predators of all kinds. One promising development involves the electrocution of insects on plants. A diesel-powered generator charging a grid plate system is passed over rows of crops. Leaves touching charged plates conduct a charge that kills insects on plants and in the earth around root systems. Treatment cost is estimated at $1.00 per acre or 20% of the cost of chemical alternatives. Insects are unlikely to build up resistance to electricity. Resistance to chemical intervention is becoming a growing problem. Thus far, 430 insects are known to be resistant to chemical pesticides; 100 diseases are resistant to fungicides and bactericides; and 36 weeds are resistant to herbicides. The growing problem of pest resistance has concentrated attention upon biological control methods: natural parasites, pest reproductive control intervention, host plant resistance, and cultural techniques.

Growth-enhancing Mycorrhize

Mycorrhize (fungi) and the soil-root-fungus relationships hold promise for enhancing the productivity of certain plants. At least 80 species of fungi live in and around root surfaces. Root-absorbing surfaces affected by water and nutrient intake may be increased as much as 10-fold by the presence of specific mycorrhize. Mycorrhize may account for only 1% total plant weight, but they can contribute to a 150% increase in growth. Among the biggest productivity increases might be those associated with beneficial rhizo-bacteria that influence plant health by protecting them from harmful bacteria in the soils. Increased plant growth also may be associated with the capacity of root colonizing bacteria to produce iron-binding compounds called siderophores.

Feedstuff Modification and Enhancement

Feedstuff modification holds considerable promise to increase yields and boost the bioavailability of plant nutrients. The plant growth regulator, Mefluidide, sprayed on tall fescue at the rate of 280 g/ha has been shown to improve the digestibility of the regrowth by an average of 6% and to improve cattle productivity by 17 to 18% ha. Research is targeted at regulating plant growth so as to both enlarge and fix (hold) the growth state of feedstuffs that command the highest nutritional value and acceptability to animals. Efficiency of feedstuffs can be materially enhanced by adding limiting amino acids not present in traditional feeds in amounts and proportions to optimize bioavailability. So far, only lysine and methionine (limiting amino acids) are available at prices affording them to be used in animal feeds. Lower cost for threonine, tryptophan, and valine, affording use in swine for feed, could greatly reduce the amount of supplemental protein now being fed.

Weed Control

Weed control is an age-old and obvious detractor from crop productivity. Elimination of weeds that compete for nutrients, water, and solar radiation concentrates resources on principal crops. Farmers now spend about as much for herbicides as for seed. Prior to the advent of herbicides and chemical fertilizers, only 14,000 seeds of corn per acre were sown. Thereafter, 24,000 seeds per acre were sown—nearly double the density. Mechanical cultivation increases yields 50% above acres with no weed control efforts; herbicides show a 67% improvement; and hand cultivation entails a 70% increase over fields given no weed control. The profitability picture (1976 study) was quite another matter. Compared to fields with no weed control, mechanical cultivation return to producer was increased 46%; lands treated with herbicides showed a 60% increase in return; and acreage cultivated by hand to control weeds showed a 50% decline in producer return. No tillage agriculture reduces energy-intensive machinery or labor-intensive human muscle power, involves time savings, and ameliorates soil erosion. However, offsetting environmental impacts resulting from increased use of herbicides, pesticides, fertilizers, and other agricultural chemicals also must be considered.

Adopting Plants to Hostile Environmental Conditions

Identifying or adopting plants to hostile conditions provides yet another way of extending acreage potentials and crop production. Halophytes, which are salt-tolerant plants, hold considerable promise for fuller use of salt-laden soils and saline water for irrigation. As much as 3.8 million square miles of land have soil conditions with too high a degree of salinity to sustain most crops. Crops have been found that thrive under such conditions; whether they are suitable for commercial exploitation requires further research. Genetic selections of barley and tomatoes already have been found that can be grown in seawater, once seeds have been germinated.

Protection from Hostile Weather Conditions

Cold weather protection approaches by genetic modification of plants are years away from commercial realization. Biological inhibitors and natural defensive mechanisms in or on plants already are being experimented with, and they hold some short-term promise for protection against early and nonsevere frosts. Other approaches that add to crop productivity include wind machines, water sprays, heating (costly), and foam.

High-Tech Solutions

High-technology solutions for alleviating world hunger problems include remote satellite sensing and robotics. Machine-harvestable varieties have been specifically developed. In California, 97% of tomatoes commercially grown are machine harvested.

Electric milking machines, under development and available possibly as early as 1990, may entail savings of up to 4 hr daily per cow. Dedicated microcomputers affixed to cows identify the specific animal as it steps into a milking stall. Data involving nutrition requirements, time, and yield of last milking transmits feeding instructions to the feeding system that mixes and releases tailor-mixed feed. Sensors gently move attachments into place and milk the cow, then remove the attachments and clean up the equipment for the next use. The target price for such a "cow-bot" from a Dutch manufacturer (Vicon) is $100,000; anticipated savings are projected to recoup investment cost in the first 4 years of operation.

Multifunction farm machines performing up to 12 tasks simultaneously have been developed. One multicultivator from Italy completes nine functions in one field pass (aerates soil, incorporates crop residues, smooths, levels, creates drainage, plants, fertilizes, and applies herbicides and insecticides). A robotic fruit picker from France picks 30 apples/min, compared to hand-picking rates of only 8 or 9/min. Robotic equipment, furthermore, can work around the clock, day-in and day-out. Japan, with 80% of industrial robots worldwide in 1981, clearly dominates this field. "Agrimation" is coming to the farm, make no mistake about it.

Biotechnologies Poised to Greatly Increase Agricultural Output

Selective plant and animal breeding and hybridization of plants, which has dominated productivity increases for over a century, are about to be largely supplanted by emerging biotechnologies. Approaches featuring natural processes, even though mediated by humans, were haphazard and random. The coming century will be dominated by direct genetic intervention controlling plant processes. Greatly enhanced yields will be accomplished by development of superior breeds and cultivars through cloning, protoplast fusion, recombinant DNA manipulations, and tissue cultures.

Photosynthesis Enhancement and Plant Efficiency Improvements

Significant Biotech-manipulated Contribution. This is anticipated by 1995. The expected contribution to yields is 25%. Plants may use as little as 1% of the sun's radiant energy, but they should be able to capture up to 12% of solar radiation.

BIOENGINEERING TARGETS. Targets include leaf area improving plant architecture, delaying or slowing senescence, propagating plants with superior photosynthetic rates, reduced photo respiration and maintenance respiration, and initial rapid growth to achieve quick ground cover and area dominance.

Plant Growth Regulators. The first significant bioengineering manipulation is anticipated by 1994. The expected contribution to yields is 49%.

BIOENGINEERING TARGETS. The targets are decreasing the loss of developing seed; enhancing the size of the plant part to be harvested (shorter but stockier stalks to minimize knock-down by wind, rain, and weather and also to support larger and heavier head of grain; hybrid dwarf wheats of this type as well as other dwarf varieties developed by traditional technology are already available); increasing water and nutrient uptake and utilization; and adopting plants to hostile environments (thereby opening up new lands to agriculture).

Biological Nitrogen-Fixation. The first significant contributions are anticipated by 1996. The expected contribution to yields is 7%.

BIOENGINEERING TARGETS. Targets include inhancing internal mechanisms that fix nitrogen and increasing root numbers and size of nitrogen-fixing species to enlarge nodulation sites.

Cell or Tissue Cultures. The first significant biotech contribution is anticipated by 1990. The expected contribution to yields is 10%.

BIOENGINEERING TARGETS. Targets are refining replication of crops for which commercial propagation of superior stocks is near at hand: African oil palm, asparagus, banana, Boston fern, broccoli, brussels sprouts, carrots, cauliflower, citrus, garlic, select trees, onion, papaya, pineapple, potato, rootstocks (tree fruits), spinach, strawberry, taro, tomato, Welsh onion, yam.

Bovine Growth Hormone. The first significant contribution has already been developed but regulatory approval process (including long-term animal studies) may take several years. The expected contribution to yields is up to 30%.

Traditionally developed plant growth regulators of many kinds already are commercially available. Brand or generic names for some of the more prominent ones include the following: Cyocel (wheat: shorter plants, thicker stems, better filling of head, less lodging); Terpal (barley: shorter plants, thicker stems, better filling of heads, less lodging); Ethephon (winter rye: reduces lodging); brassinosteroids (vegetables: yield increases of 25–60%); gibberillins (Valencia oranges, grapes, peaches, tomatoes: reduces creasing, enlarges cells); ripeners (sugarcane: increases yield by 10%); ALAR (apples, peaches, cherries: delays harvest, accelerates maturity and color); plant respiration inhibitor (soybeans: increases yields up to 100%; and tricontanol (many crops: boost yields from five to 20%.)

Importance of Nutritional Food Value to Health and Well-Being

Major changes in annual per capita food consumption, although often given short shrift, have been occurring.

Impacts are profound and many materially affect human health and well-being. Dairy products plummeted from 451 to 301 lb (1945–1983), thereby bringing about huge calcium and phosphorous dietary deficiencies and beneficially reducing cholesterol and saturated fatty acid intake. Potatoes plunged from 198 pounds (1910) to 121 lb (1983). Thereby, potatoes were displaced as the primary dietary source for vitamin C, making room for the enormous popularity of frozen orange juice, nonexistent in the early 1900s, but consumed at a rate of 38.4 lb per person in 1983 (amply providing for vitamin C dietary requirements). Wheat flour use dropped from 217 lb (1919) to 116 lb (1983), thereby, dietary sources of vitamin B-complex, other trace minerals and fiber were altered. Soft drink consumption amounting to 40 gal, and total alcoholic beverages amounting to 28.4 gal (1983), became the beverages of choice. Thereby, these displaced fluid milk, the consumption of which amounted to 27.3 gal (1983), and coffee use which stood at 26.2 gal (1983) and massively increased the consumption of caloric sweeteners (soft drinks comprise the single largest category of delivery for sweeteners).

Humans consume 6 to 10 lb of fluids daily, about twice the quantity of food solids (3–4 lb daily), thereby underscoring the vital importance of beverages in the diet. Safe, even nutritionally valuable water may be the most overlooked nutrient component. Trends such as the ones posed here, and their import for enhancement of nutrition will figure prominently in changing dietary patterns.

As the amount of food consumed declines, the nutritional value provided by what is consumed grows correspondingly. A bigger nutritional heft for each mouthful will catch on. Changes in culturally embedded eating habits do not come about overnight. No matter what the pace, substantial changes are coming with important marketing implications.