Food, Energy, & Society: Options & Solutions

by David Pimentel and Marcia Pimentel

Tough questions about conservation of natural resources, development of alternative energy resources, desired standards of living, types of diet, and optimum population size must be answered. All require decisive action.

The foremost question is how humans will be able to provide a nutritionally adequate diet for a world population expected to be more than 6.1 billion by 2000 and 12 billion by about 2040.

Food security for all is dependent on and interrelated with many factors within the vast human social and ecological system. Fundamentally, it depends upon human population numbers and the standard of living those humans desire. Environmental resources such as arable land, water, climate, and fossil energy for fertilizers and irrigation influence the outcome. The food supply is also affected by crop losses to pests, availability of labor, environmental pollution, and the health and lifestyle of the people. Distribution systems and the social organization of families and countries play a role in the solution.

Future Food Needs

For about a million years, the human population growth rate was slow, averaging only about 0.001 percent per year. During that long period of time, the world population numbered less than 10 million (Keyfitz, 1976). Growth in human population numbers began to escalate about 10,000 years ago, when agriculture was first initiated. Rapid population growth, however, only started after the year 1700, when it accelerated to today's rate of 1.7 percent per year, about 1700 times the historical rate of 0.001 percent (NAS, 1975; Keyfitz, 1976; PRB, 1993). World population now stands at 6 billion and is expanding at a quarter million persons per day. Unless unforeseen factors intervene, it will reach more than 6.1 billion by 2000 (PRB, 1995) and about 12 billion by 2040 or so. Growth is not expected to end until after the year 2100.

The rapid growth in the world population has already resulted in an increased need for food. Estimates are that today from 1 to 2 billion people, or approximately 25 percent of the world population, are seriously malnourished.

Population Health

Rapid growth in the world population coincided with the exponential growth in the use of fossil fuels (Figure 21.1). Some of this energy has been used to promote public health, control disease, and increase food production for the ever-growing world population. The control of typhoid disease, for example, was achieved by improving water purification, which required large energy expenditures (Audy, 1964). The program for eradicating malaria-carrying mosquitoes required the application of DDT and other insecticides. Producing these insecticides used substantial quantities of energy (Audy, 1964).

Reduction in death rates through effective disease control has been followed by substantial increases in population growth rates. For example, in Sri Lanka (Ceylon), after spraying mosquitoes with DDT, the death rate fell from 20 per 1000 in 1946 to only 14 per 1000 in 1947 (PEB, 1955), and population growth

---

***David Pimentel and Marcia Pimentel.** Chapter 21, "Summing Up: Options and Solutions," from David Pimentel and Marcia Pimentel, editors,* Food, Energy, and Society, *revised edition. Niwot, CO: University Press of Colorado, 1996. Reprinted from* FOCUS, *Vol. 7, No. 3, 1997 BY PERMISSION OF Carrying Capacity Network, 2000 "P" Street, Suite 310, Washington, DC 20036, (202) 296-4548.*

rates concurrently increased. A similar dramatic reduction in death rates occurred after DDT was used in the island of Mauritius, where death rates fell from 27 to 15 per 1000 in one year, and population growth rates increased from about 5 to 35 per 1000 (Figure 21.2),

Historical evidence documents many similar occurrences in nations where public health technology improved sanitary practices and medical supplies have significantly reduced death rates (Cors and Oakley, 1971). The effective control of human diseases, coupled with increased food production, has contributed significantly to rapid population growth (NAS, 1971). Unfortunately, the immediate increase in family size and explosive population increase in cities, town, and villages all too often overwhelms existing food, education, health, and social systems (NAS, 1971).

The presence of some chronic disease also increases the need for food. For example, when a person is ill with diarrhea or malaria or is infested with a parasite such as hookworms, anywhere from 5 to 20 percent of the individual's energy intake is expended to offset the illness. With malaria, hookworms, and amoebic dysentery, the parasite removes blood and nutrients and reduces the individual's ability to make effective use of his food.

Food Losses

Significant quantities of our food supply are lost to insects, plant pathogens, weeds, birds, rodents, and other pests. World crop losses due to pest infestation are estimated to be about 40 percent (Pimentel, 1991). These losses include destruction by insects (15 percent), plant pathogens (12 percent), weeds (12 percent), and mammals and birds (1 percent). Although mammal and bird losses are more severe in the tropics and subtropics than in the temperate regions, they are still low compared to those attributed to insects, pathogens, and weeds.

In addition, available evidence tends to suggest that some Green Revolution technologies have intensified losses to pests (Pradhan, 1971; I.N. Oka, Bogor Food Research Institute, Indonesia, personal communication, 1991). Some of the new high-yielding crop varieties exhibit greater susceptibility to some pests than do traditional varieties. In the past, farmers saved seeds from those individual plants that survived and yielded best under local cultural conditions and planted them in subsequent years. These genotypes were naturally resistant to pest insects and plant pathogens and competitive with weeds. In this way, farmers developed genotypes that grew best in their localities.

"The major pests that destroy harvested foods are microbes, insects, and rodents. When post-harvest losses are added to pre-harvest losses, total food losses due to pests rise to an estimated 50 percent."

The newly developed grain varieties have more genetic uniformity, and this can become a distinct disadvantage when the variety is planted over large areas in a new environment. Such plantings provide an ideal ecological environment in which the plant pathogens can evolve highly destructive genotypes (Frankel, 1971; I.N. Oka, Bogor Food Research Institute, Indonesia, personal communi-cation, 1991). Concurrently, programs have been developed for multiple cropping in an effort to increase food supplies from limited land resources. This type of continuous crop culture has resulted in increased pest outbreaks (Pathak, 1975). Higher crop losses to pest damage mean lower yields and less food.

Not all losses occur during the growing season; substantial post-harvest losses occur. These are estimated to range from 10 percent in the United States to a high of 25 percent in many developing countries. The major pests that destroy harvested foods are microbes, insects, and rodents. When post-harvest losses are added to preharvest losses, total food losses due to pests rise to an estimated 50 percent. Thus, pests destroy about half of the potential world food supply. We cannot afford a loss of such magnitude when faced with an increasing need for food to feed the growing world population.

Strategies for Meeting Food Needs

Two-thirds of the world's people consume primarily a vegetarian-type diet. These individuals eat about 200kg of grain products yearly. They consume this grain directly and eat little food of animal origin. In contrast, the remaining one-third of the world's people, including those living in industrial countries such as the United States, consumes about 360kg of animal food products yearly (Putnam and Allshouse, 1991). To produce this amount of animal food in the United States, about 655kg of grain per person are raised and then fed to animals (Putnam and Allshouse, 1991).

About 141 million tons of plant and animal protein are produced annually worldwide for human consumption. If evenly divided, this would provide about 64kg of protein per person per day. Of this total amount, animal protein (meat, milk, eggs, etc.) accounts for 34 percent, or about 44 million tons. Livestock, including poultry, in the United States alone number 6 billion and outweigh the human population by more than four times (Pimentel, 1990). Worldwide there are an estimated 20 billion livestock. These animals graze on 3.1 billion ha, or about 24 percent of the world land area (World Resources Institute, 1992).

To increase the production of animal protein, the process must be made more efficient than it has been in the past. This is especially relevant to livestock production. Overgrazing should be prevented and more productive pasture plant species developed and cultured. Applications of limited amounts of livestock manure and perhaps fertilizers would increase forage yields. The annual supply of animal protein could be increased from the present 44 million tons to about 50 million tons by the year 2000. The increase, however, would not be sufficient to maintain the present protein intake of 64g per person per day for the world population, which in the meantime will also have increased substantially.

Some estimates report that the fishery harvest is about 95 million tons. This is probably the maximum yield, considering the serious overfishing problems that already exist. In addition, fish production is energy-intensive; this energy has been and will continue to be a constraint on its expansion.

One way to increase food supplies is for humans to become more vegetarian in their eating habits. Annually, an estimated 40 million tons of grain protein suitable for human consumption are fed to the world's livestock. This represents 34 percent more protein that would be available as food for the world population if it were not cycled through livestock.

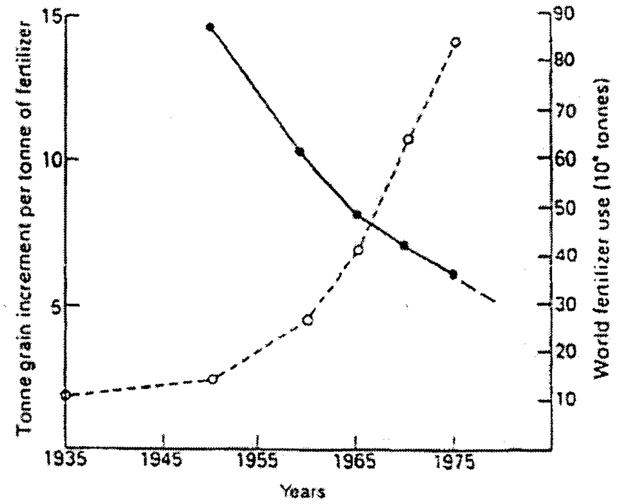
If the protein currently fed to livestock were instead fed directly to humans, then more food grains would be available for the world population. Assuming that improved management of livestock pasture and rangeland yielded an additional 25 million tons of livestock protein, then the increases needed in the following crops over a 20-year period would be: cereals, 41 percent; legumes, 20 percent; and other plant proteins, 50 percent. It is doubtful that these increases can be achieved. However, increased yields in plant crop production are more easily achieved than increases in animal production. Nevertheless. Just as livestock production is vital to humans today, it will be important to humans in the future. Cattle, sheep, and goats will continue to be of value because they convert grasses and shrubs on pastures and rangeland into food suitable for humans. Without livestock, humans cannot make use of this type of vegetation on marginal lands.

Energy Needs in Food Production

In past decades humans did not have to concern themselves about fossil fuel supplies, because relatively inexpensive and ample supplies were available. Such will not be the case in the twenty-first century. An estimated 17 percent of the fossil energy consumed in the United States is used in the food production system. This 17 percent may seem neither large nor important when considered as a portion of the total U.S. energy expenditure, but compared to that of other nations (especially developing countries) it is extremely large. It amounts to more than twice the per capita fossil fuel use in Asia and about four times that in Africa.

The following analysis may help clarify the relationships of fossil fuel supplies to production of food supplies. The total energy used annually in the United States for food production, processing, distribution, and preparation is about 1600 liters of oil per capita per year. Using U.S. agricultural technology to feed the present world population of 6 billion, a high protein/calorie diet for one year would require the equivalent of 9000 x 10^9 liters of fuel annually.

Another way to understand the dependency of food production on fossil energy is to calculate how long it would take to deplete the known world reserve of petroleum if a high protein/calorie diet, produced using U.S. agricultural technologies, were fed to the entire world population. The known world oil reserves have been estimated to be 87 a 10^{12} liters (Matare, 1989), so if we assume that 75 percent of raw oil can be converted to fuel (Jiler, 1972), this would provide a useable reserve of 66 x 10^2 liters of oil. Assuming that oil were the only source of energy for food production and that all known oil reserves were used solely for food production, the reserves would last a mere 7.3 years from today. This estimate is based on a hypothetical stabilized population of 5.5 billion. The reality is that each day an additional quarter



21.3 Declining grain yield increment per fertilizer input (——) (Brown, 1978) and world fertilizer use (– – –) in metric tonnes.

million new mouths must be fed.

How then can food supply and energy expenditures be balanced against a growing world population? Even tripling the food supply in the next 40 years would just about meet the basic food needs of the 11 billion people who will inhabit the earth at that time. Doing so would require about a ten-fold increase in the total quantity of energy expended in food production. The large energy input per increment increase in food is needed to overcome the incremental decline in crop yields caused by erosion and pest damage. (Figure 21.3)

One practical way to increase food supplies with minimal increase in fossil energy inputs is for the world population as a whole to consume more plant foods. This diet modification would reduce energy expenditures and increase food supplies, because less food suitable for human consumption would be fed to livestock. With livestock, roughly 20 calories of increased energy are needed to obtain one calorie of food.

Land Constraints

Feeding a population of more than 6 billion a high protein/calorie diet using U.S. agricultural technology would require large areas of arable land. This will be the case even if only plant production is to be increased. Thus, it is important to know how much arable land now is available for use in agricultural production.

The United States, with a current population of 260 million people, has about 160 million ha planted to crops (USDA, 1991). This averages out to 0.6 ha per person. However, the cropland needed per American is only about 0.50, because 20 percent of our present crop yield is exported.

Worldwide, about 1.5 billion ha of arable land now exists for crops. Based on the present population of 6 billion, this averages out to be only 0.25 ha per person. Therefore, if at least 0.50 ha per person is needed to produce a U.S.-type diet, there is not sufficient arable land, even with the addition of energy resources and other technology, to feed the rest of the world on a U.S.-type diet.

In some regions it may be possible to bring some poor land into production. Best estimates are that cropland resources might be doubled to 3 billion with great cost, using large amounts of energy for fertilizers and other inputs. This increase in cropland would necessitate cutting down most forests and converting some pasturelands to cropland. Both changes would have negative impacts on biodiversity and production of needed forest products. Also, forest removal increases erosion, flooding, and other environmental damage (Pimentel et al., 1992a).

Worldwide, more than 10 million ha of agricultural land are abandoned annually because of serious soil degradation. During the past 40 years, about 30 percent of total world arable land has been abandoned because it was no longer productive. Loss of arable land is increasing because poor farmers worldwide have to burn crop residues and dung as fuel because firewood supplies are declining and fossil fuels are much too costly. It is expected that 750 million ha of cropland will be abandoned by 2050 because of severe degradation. This is extremely bad news; about half of the current arable land now in cultivation will be unsuitable for food production by the middle of the twenty-first century.

"Iowa, which has some of the best soils in the United States, reportedly has lost half its topsoil after little more than 100 years of farming."

Wind and water erosion seriously reduce the productivity of land. In the United States, the rate of soil erosion is estimated at 13 tons/ha annually. The United States has already abandoned an estimated 100 million has (Pimentel et al., 1995). At least one-third of topsoil has been eroded during more than a century of farming. Iowa, which has some of the best soils in the United States, reportedly has lost half its topsoil after little more than 100 years of farming (Risser, 1981).

So far, the reduced productivity of U.S. cropland due to erosion has been offset by increased use of fertilizers, irrigation, and pesticides. The estimate is about 50 liters of oil equivalents per hectare are expended each year to offset cropland degradation. In developing countries, the rate of soil loss is more than twice that of the U.S., an estimated 30 to 40 tons/ha/yr (Pimentel, 1993). Therefore, based on what we presently know, both the amount of arable land available for crop production and the amounts of extra energy needed to put poor land into production are serious constraints on expansion of crop production.

Water Constraints

Water is the major limiting factor in crop production worldwide because all plants require enormous amounts of water for their growth. For example, a corn crop will transpire about 4.5 million liters of water during the growing season (Leyton, 1983). If this water has to be added by irrigation, approximately 8 million liters of irrigation water must be applied. Another way of assessing water needs is to point out that 1400 liters of water are necessary for the production of 1kg of corn.

Indeed, agriculture is the major consumer of available water. In the United States, irrigated agriculture consumes (nonrecoverable) about 85 percent of the fresh water that is pumped, and the public and industry consume the remaining 15 percent (NAS, 1989a). Worldwide, agriculture uses about 87 percent of the fresh water pumped (Postel, 1989).

Only about 16 percent of the world's cultivated land is now irrigated (WRI, 1992). In the arid lands, various sectors of the economy have conflicting demands for available water. Agriculture must compete with industry and public use of water, because the economic yields from agriculture per quantity of water used are far less than economic yields from industry. The public always needs water to drink and for other personal uses.

"The changes wrought by irregularities of climate patterns call attention to interdependency of nations and the importance of cooperative planning."

Expansion of irrigation is further limited because it requires large amounts of energy. About 20 million kcal of energy is needed to pump 8 million liters of water from a depth of 30 m and irrigate by sprinkler system (Smerdon, 1974). This is more than 3 times the fossil energy input of 6 million kcal usually expended to produce 1 ha of corn (Pimentel, 1980). In addition, 13 percent more energy is required to maintain the irrigation equipment. These figures do not include the environmental costs of soil salinization or waterlogging often associated with irrigation.

High rainfall and/or the presence of too much water, or rapid water runoff, also cause serious environmental problems. The removal of forests and other vegetation, in particular on slopes, encourages water runoff and often results in serious flood damage to crops and pasture. In fact, environmental damages caused by floodwater, soil sediments, and related watershed damage are estimate to be about $6 billion per year (Clark, 1985).

Climate

Climate has always determined the suitability of land for cultivation of crops. For this reason, changes in temperature and/or rainfall can be expected to influence food production and supplies (Pimentel et al, 1922b). These two considerations must be evaluated on different time scales. Within any given decade, there are likely to occur irregularities in temperature and rainfall patterns that may either improve crop yields or inflict enormous damage to agricultural yields (for example, the drought that occurred in the United States in 1988) (USDA, 1989). However, long-term changes may have far more serious consequences. In particular, many scientists are concerned about global warming because of the greenhouse effect, which may affect agricultural production (Pimentel et al, 1922b). The sensitivity of crops to temperature change is illustrated with corn. For example, a mere 0.6°C increase in temperature would lengthen the growing season by about two weeks and increase crop yields. However, global warming would also reduce the amount of water available for crop production. On balance, global warming would have a negative impact on agriculture.

The changes wrought by irregularities of climate patterns call attention to interdependency of nations and the importance of cooperative planning. The effects of such irregularities also emphasize the need for the establishment of an international food reserve to offset years in which crop yields in the food-producing regions of the world are unexpectedly low.

Environmental Pollution

Numerous wastes produced by agricultural production are considered pollutants. These include fertilizers, pesticides, livestock manure, exhaust gases from machinery, soil sediments, odors, dust, wastewater, and crop wastes. Pesticide use in the world totals 2.5 million tons, yet insects, plant pathogens, and weeds will destroy about 40 percent of all potential food in the world. However, pesticides are important, for without them food losses would rise to about 55 percent.

Pesticides, however, also cause serious public health and environmental problems. Worldwide, about 3 million human people a year suffer from pesticide poisoning, with about 220,000 fatalities. In the United States there are about 67,000 human pesticide poisonings per year with about 27 fatalities (Litovitz et al, 1990). In addition, there are as many as 10,000 cases of cancer associated with pesticide use (Pimentel et al, 1992c). In addition, fish, honeybees, birds and natural enemies are killed. The total environmental and health costs of using pesticides are estimated to be more than $8 billion per year (Pimentel et al, 1992d).

On the world scene, pesticide use in agriculture has contaminated water with pesticides and exposed mosquito populations to insecticides. The result has been the development of high levels of resistance to insecticides worldwide and an explosion in the incidence of malaria, which is now difficult to control (NAS, 1991). The various environmental problems associated with pesticides appear to be increasing worldwide (Pimentel et al, 1992c).

The Future

There is no single cause of the growing shortages of food, land, water, and energy or pollution of the environment, nor are there simple solutions. When all the world's resources and assets must be divided among an increasing number of people, each one has a smaller share, until there are insufficient amounts to go around.

At this point it is relevant to reconsider the biological law Malthus proposed: "First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary and will remain nearly in its present state … Assuming then my postula are granted, I say that the power of population is definitely greater than the power of the earth to produce sustenance for man." Malthus may not have been thinking about this aspect, but it is true that food production increases linearly, whereas the human population increases geometrically. Therefore, there is no biophysical way for food production to increase and stay with the growth of the human population. Even if population increase were not geometric, there are limits to the earth's carrying capacity.

Perhaps Bertrand Russell (1961) best expressed the biological law related to population growth when he wrote: "Every living thing is a sort of imperialist seeking to transform as much as possible of its environment into itself and its seed." This law suggests that the human population will increase until food or some other basic need limits its survival and growth.

Although science and technology will help alleviate some of the future shortages, they cannot solve all the problems the world faces today. Science has been unable to solve many of the world's problems during the past 50 years, and with fewer resources that must be shared with more people we have no reason to expect that biophysical limits can be overcome. For example, more, larger and faster fishing vessels have not increased fish production; on the contrary, it is declining. Likewise, water flowing in the Colorado River now ceases to reach the Sea of Cortes. There is no technology that can double the flow of the Colorado and/or increase rainfall.

We remain optimists, for we see some signs that people are beginning to understand that resources are not unlimited and that a balance must be achieved between the basic needs of the human population and environmental resources, many of which are finite. This is the time to take action.

Above all else humans must control their numbers. This task is probably the most difficult one facing all of us today. If birth rates are to decline on a massive scale, parents must understand that having fewer children is in their own and their children's interest. This understanding can be achieved only if the direct costs of having children are increased and if socially acceptable substitutes for large families are developed. Within each country and each ecological system, difficult social changes must be encouraged in conjunction with policies that augment food supplies and improve health, education, and lifestyle.

What humans choose to do in the coming two decades will determine the kind of world the next generations will live in. Ultimately, it is up to each individual to reduce his or her reproductive rate. Clearly, if humans do not control their numbers, nature will do so through poverty, disease, and starvation. ■

[*References available at the offices of The Social Contract.*]

Bad News on Fertility

by Lindsey Grant

The National Vital Statistics Report in July 2001 conveys a great deal of bad news about U.S. fertility in one dense little paragraph.

> *The total fertility rate (TFR) indicates the number of births that a hypothetical group of 1,000 women would have if they experienced, throughout their childbearing years, the age-specific birth rates observed in a given year. The TFR for 2000 was 2,133.5, a 3-percent increase over 1999 (2,075.0) and the highest TFR since 1971. TFRs increased between 1999 and 2000 for all racial and ethnic groups--from 1,850.0 to 1,887.0 for non-Hispanic white. from 2,146.5 to 2,183.5 for black, from 2,056.5 to 2,098.5 for American Indian, from 1,927.0 to 2,072.0 for Asian or Pacific Islander, and from 2,985.0 to 3,107.5 for Hispanic women...*

(These figures are per 1,000 women. The more usual and more easily understood formula is "per woman." Thus 3,107.5 translates to 3.1075 children per woman.)

What this means is that, at current fertility levels, the U.S. population would never stop growing, even if there were no immigration. And immigration has risen to over 1.2 million per year.

It also shows what "shifting shares" can do. The more fertile population groups become a larger proportion of the population (barring much higher mortality rates), and that in turn drives the total population up faster. By far the highest fertility, and the largest share of immigration, is Hispanic. In fact, Hispanic fertility in the United States is well above the average fertility of 2.92 in the "less developed countries" (UN medium variant) and – unlike fertility in the LDCs – it is rising. It is much higher than in Mexico, where it is about 2.5.

Fertility tends to be higher for the poor and less educated. That explains much of the difference between, say, Blacks and non-Hispanic whites. It is not sufficient to explain the high Hispanic fertility, which presumably has cultural roots.

These things can change, sometimes very suddenly. In Quebec, for instance, fertility plummeted dramatically – too far, perhaps – in a few years, despite complaints from political leaders and the church. Perhaps more Hispanic women will come to agree with most women in industrial countries that there is more to life than childbearing. Perhaps they will sense the increased crowding around them and the competition for jobs and wonder how many children they should be bringing into a changing world.

It is difficult for a non-Hispanic to say this to them. The charge of "racism" is immediately raised. They need leaders who will warn them that the growth they are generating hurts them, as Cuban-born George Borjas has warned with respect to immigration and as Richard Estrada did before his untimely death.

The Census Bureau expected U.S. fertility to rise, but not so fast. The new fertility rates are higher even than its "highest" fertility projections. Two years do not predict what will happen in 100 years, but that "highest series" leads to a population of 553 million in 2050 and 1.18 billion in 2100. That, I think, would be an unmitigated disaster. I will watch for the 2001 and 2002 figures with nervous interest.

Some Mexican-Americans take pleasure in what they describe as the "reconquest" of the land Mexico lost in 1848, but nobody gains from the growth that we face. Ethnic rivalry is a poor basis for fertility policy. I will propose a better ideal, and one that discriminates against nobody: the ideal of the two-child family – stopping at two – for everybody, of every group and religious persuasion. It would particularly benefit the poor, since by encouraging them to have fewer children it offers them, and society, the hope of

---

***Lindsey Grant** is a former U.S. Deputy Assistant Secretary of State for Environment and Population and author of several books including* Elephants in the Volkswagon, Juggernaut: Growth On a Finite Planet, *and* Too Many People: The Case for Reversing Growth, *which is available from The Social Contract Press.*