The Green Revolution

Its demographic and environmental consequences

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Humans, like other animals, appear to have an innate drive to convert a maximum amount of their resources, including food, into themselves and their progeny. As a result, the rapidly growing human population is increasing pressure on agriculture and its vital supporting resources (land, water, energy, and biota) (Pimentel, 1987). Although all of these resources have finite limitations, all, except fossil energy, are renewable if they are managed properly.

Despite new agricultural technologies, including the Green Revolution, and the fact that most arable land in the world is already in agriculture, a scarcity of food and essential nutrients exists for some people in all nations. The situation is especially acute in the developing countries. Estimates are that of the more than 5 billion humans that now exist in the world, from 1 to 1.5 billion are malnourished (Latham, 1984; Sivard, 1987; Pimentel, 1989). In addition to food shortages, the quality of life for this 10 to 30 percent of the world population is diminished or threatened by insufficient, clean water, shelter, health care, and satisfying employment.

Productive agricultural programs and ample nutritious food supplies are fundamental to the social structure and economy of all nations. Some have hypothesized that development, including agricultural development, is essential to reducing population growth (Simon and Kahn, 1984). In this paper the role of agriculture as a solution to the population and environmental problem is examined.

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World Population Growth

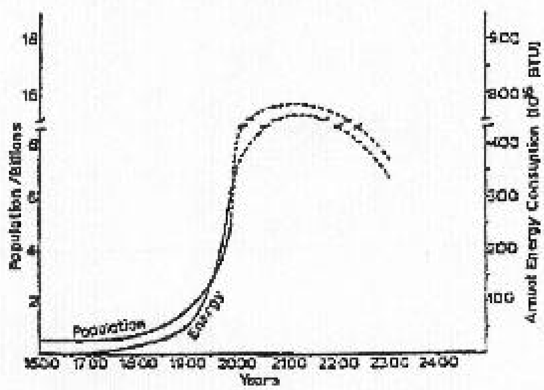
For 99.9 percent of the more than 1 million years that humans have inhabited the earth, the maximum world population was less than 6 million – fewer than the present population of New York City. Population growth during this long period was only about 0.001 percent per year. During most of this time span, humans were hunter-gatherers and depended on their nearby environment to supply food and other basic needs. Without conventional economic development, they managed to stabilize their numbers at a level that was balanced by the availability of their resources (Douglas, 1966; Harris, 1977).

When people began to cultivate food crops about 10,000 years ago, some of the limitations and uncertainties formerly imposed by nature were reduced. The larger, more stable food supply resulting from the newly developed agricultural techniques (Brown et al, 1985) contributed to and supported a slow, steady growth of the world population (Deevy, 1960; Coale, 1974; Paddock, 1983) (Figure 1).

At the dawn of the industrial revolution in 1700, the world population stood at less than 1 billion. By 1900 the numbers had increased to about 1.6 billion. Over that entire 200-year period the average annual rate of population growth never exceeded 0.5 percent per year.

The major increase in the population growth rate that occurred during the last 200 years coincided with the discovery and use of stored fossil energy resources such as coal, oil and gas.

Figure 2. Rapid human population growth associated with fossil energy use. Estimated world population ( ) from 1600 to 1987 and projected numbers (-----) to the year 2300. Estimated fossil energy consumption ( ) from 1650 to 1987 and projected (-----) to the year 2300.



Since then, the increased rate of population growth has closely paralleled the increased use of fossil fuel (Figure 2). Fortunately, the worldwide production of food has been growing at a rate equal to the growth in world population (Hudson, 1989). The fossil energy resources have enabled humans to make fertilizers and pesticides as well as substitute mechanical energy for human energy. These advances have facilitated the increases in food production that the human population requires. Also contributing to the rapid population growth was the use of energy to control human diseases by helping humans to secure safe drinking water, controlling malaria and schistosomiasis, and treating various microbial diseases with various drugs (Pimentel, 1987).

The current world population stands at greater than 5 billion (PRB, 1987). Never in history have humans, by their sheer numbers, so dominated the earth and its resources. Demographers project that the world population will reach 6.1 billion by the year 2000, approach 8.2 billion by 2025 (UN, 1982), and probably reach 12 billion by the year 2100. Present, there seems to be no generally accepted way to limit this growth (NAS, 1971, 1975).

More alarming than sheer numbers is the status of the annual population growth rate. Around the beginning of the twentieth century the rate of population growth increased sharply, first to 1 percent, and then to 1.5 percent, and eventually to 2 percent per year. The rate of increase peaked in the 1970s and at present has begun to decline very slowly. However, in 1988 the growth rate is still about 1.7 percent or about 1,700 times greater than it was during the first million years of human existence.

In addition to the actual rate of growth, there is the age-structure that presently exists in the world population. A large proportion of the world population (e.g., 45 percent of Africa, 40 percent of Latin America, and 37 percent of Asia) is now within childbearing age (PRB, 1987). In the long term this young age-structure will sustain the rapid population growth rate. For example, with more than half of the Chinese below the age of 20 years, even limiting births to one child per couple will not stop China's population growth (Coale, 1984). If 70 percent of the couples have only one child, the current population of slightly more than 1 billion (Coale, 1984) will still reach 1.2 billion by the year 2000 (Wren, 1982; Zhao, 1982). As a result, the number of Chinese added during the next 20 years will almost equal the present U.S. population. As mentioned, similar situations exist throughout the developing world, and the inevitable result would be continued growth for 60 years or more in the world population even if zero population growth were adopted immediately.

Increased economic development is frequently cited as a possible solution for high birthrates (Floud, 1985). However, except for Japan, Korea, Taiwan, and Singapore, where the economy depends on industry and trade, most overpopulated countries have insufficient natural resources to support economic development similar to that in Europe and North America (Keyfitz, 1984; Hardin, 1986). In fact, most of the 183 nations in the world now must import some food (FAO, 1985). Furthermore, and equally important, the "biological carrying capacity" of the ecosystem in many parts of the world already has been severely stressed and in some regions it has been exceeded (NAS, 1975; Brown et al, 1985; Pimentel, 1987). For instance, the productivity of many arable lands is being degraded, water resources mined, forests destroyed, and biological diversity reduced.

Economic growth, including the Green Revolution, and prosperity cannot be relied on to control population growth. Clearly, an urgent need exists for all societies to consider methods to slow the growth of their human population (Reining and Tinker, 1975; Smuckler et al, 1988).

Population Growth and Food

Humans depend on adequate food supplies to provide them with the specific nutrients that they must have to sustain metabolism, growth, reproductive, and other vital life processes. The major nutrient needs are: carbohydrates; fats, amino acids, which are the building blocks of proteins; plus vitamins and minerals. These nutrients are needed in varying amounts depending on the age, size of individual, activity, physiological state (e.g., pregnancy), and disease burden. Therefore, the human food supply not only must be adequate in quantity, but adequate in the quality of its nutrient content.

Various guides have been compiled by nutritionists to serve as standards for evaluating how well food intakes or food supplies meet nutritional needs of individuals in population groups. The guide established by the Food and Agriculture Organization (FAO) recommends a daily energy intake of 3,000 kcal for a 65 kg moderately active male and 2.200 kcal for a 55 kg moderately active female. The recommended protein intake, consisting of animal and plant materials, is 41 g/day per person (FAO), 1973.)

If an individual does not meet the suggested intake, it does not necessarily follow that the person is malnourished. This is because the nutrient levels are set with sufficient margins to meet a wide variety of individual differences and needs. The allowances for nutrients are set above the minimum requirements that would prevent the development of specific nutritional deficiencies, like scurvy and pellagra.

For example, the pregnant female needs to increase her energy, protein, vitamin, and mineral intakes to insure her continued health and that of her offspring. Taking these nutrient needs into consideration, the nutrient level for protein increases from about 41 g to 76 g per day for pregnant women, while Vitamin C increases from 60 to 80 mg. and calcium increases from 800 to 1,200 mg per day (FAO), 1974.

The activity of a male or female also influences the nutrient needs of the individual. An adult male, for example, engaged in heavy work, such as tilling the soil by hand, may burn from 400 to 600 kcal/hr above his energy requirement for basic metabolism, and therefore will require increased food energy and additional vitamins per day to maintain his productivity during periods of strenuous labor (NAS, 1960).

Illness often increases the nutritional needs of the person (Anderson, 1979; Carmichael, 1985). For example, the nutrient needs of an individual who is infected with common parasites like ascarids or other parasitic worms will increase. In such cases the increase in nutrients offsets the food needs of the parasite population and the losses that occur if the parasite interferes with normal digestion and absorption processes. Sometimes more nutritious food is needed to counteract the blood and other body fluid losses associated with parasitic infections (Carmichael, 1985). All too often these types of problems occur in population groups that are already being stressed by malnutrition.

Malnutrition, diseases, and heavy farm work may combine to limit reproduction and population growth. In Africa, for example, male and female desire for many children to work on the farm may be constrained by low fertility and high infant mortality. In some segments of the African society, sterility rates are high owing to venereal disease, malaria, and other diseases (Valderrama and Moscardi, 1977; Boserup, 1981). Furthermore, rates of involuntary abortion in African women appear to be high in part because of disease and also because of the heavy agricultural work they do

Change in Agriculture and Population Growth History

The development of a structured agriculture over 10,000 years ago undoubtedly contributed to the growth in the world population (Figure 1) by providing an adequate and more stable food supply for the population than had existed when humans lived more precariously as hunter-gatherers (Deevey, 1960). However, Boserup (1965) has suggested that the growth in population numbers caused the change from hunter-gatherer to farmer; thus, agriculture was the result of population growth and not the cause. Both explanations have some validity and there probably was a positive feedback between population growth and agricultural technology. That is, the new, more stable food supply provided by early agriculture contributed to population growth. At the same time as the population grew, new agricultural techniques had to be developed and used to provide the required food supplies.

Early agriculture was a form of slash/burn agriculture (Ruthenberg, 1971). In this, an area near the campsite was burned over and seeds of some grain or other crops were planted. Several months later the early farmers returned to harvest the crop that remained after weeds, insects, plant pathogens, mammals, and birds had taken their share of the harvest. Usually the amount of food that was harvested was still greater than that obtained by searching the countryside for food. Over time the processes were refined and improved to enhance yields. Population groups became more settled, enabling them to devote more time and energy to control weeds and other pests. Estimates are that from 300 to 400 hours of humanpower per hectare were expended in a slash and burn operation for crops like corn. From 500 to 700 hours were devoted to weed control, especially in the second and third years of planting. Crop harvesting required up to 200 hours of labor per hectare (Pimentel and Pimentel, 1979). The total human labor input per hectare of corn production was about 1,200 hours (Lewis, 1951; Freeman, 1955). This is in sharp contrast to the present-day mechanized farming in the United States where only 10 hours of labor are expended per hectare for the total farming operation (USDA), 1985.)

Draft Animal Power

Because a human adult can produce from only 0.05 to 0.1 hph, the eventual use of draft animal power significantly reduced the human labor input. For example, the input of 200 hours of ox power reduced the human labor input about 800 hours per hectare (Pimentel and Pimentel, 1979). A horse, which is faster and more efficient than an ox, has a greater capacity to reduce the labor input in agriculture than does an ox.

Currently in China, where horses still are used in agricultural production, the human labor input remains high. For example, the labor input for corn and rice production in northeastern China ranges from 1,300 to 3,000 hours plus a horse input ranging from 330 to 440 hours per hectare (Wen and Pimentel 1984). The use of draft animal power increases the efficiency of farming by helping the farmer prepare farmland in a timely fashion for planting. This facilitates a more effective use of seasonal rainfall and/or favorable temperature conditions.

Family Size Related to Farm Size

One anticipated benefit from the substitution of animal power for human power could be the reduction in family size. Unfortunately, no assessment has been made of the number of children in families who farmed by hand versus those that farmed with draft animal power.

Generally, farmers who used some draft animal power were able to increase the land tilled and planted and thus have larger farms. The only available data on the relationship of farm size and family size are those of by Kabir and Chowdhury (1982), who reported that in Bangladesh farmers with large acreages also had large families. Perhaps the larger families were needed to cultivate crops on the larger farms.

In general, farmers in both developed and developing countries have larger families than city dwellers (NAS, 1971, 1975; Easterlin, 1976; Knodel, 1977; Coale, 1984; Coale and Watkins, 1986). If, as in the United States, farmers make up only 2 to 3 percent of the population, then the larger farm families will minimally alter the demography of the nation. However, in many developing nations, where from 70 to 80 percent of the population earns a living from agriculture, large families will contribute significantly to rapid population growth of the nation.

Although all members of farm families generally assist with crop and livestock culture, distinct differences exist in the social structure of farm families located in various regions of the world. In Africa, for instance, nearly all the agricultural work is carried out by women and children (Boserup, 1981; Fortmann, 1989). Children, even the very young, are used to keep pest birds and other animals from the crops. They also pull weeds and care for small numbers of livestock. Thus, it is clear that self-employed farmers have a wide range of opportunities to exploit their children on the farm (Schultz, 1971).

Also, young African males help clear land for long-fallow cultivation. Thus, the male head of family, who has an adequate number of sons, does not need to hire additional labor and does not have to fear for lack of support in his old age (Boserup, 1981). For this reason, large families are considered the ideal in the rural areas of Africa.

In contrast to Africa, men dominate the farming systems in Asia and South America. The men usually do the heavy work like plowing, while women and children are relied on for the lighter work of weeding crops and tending animals.

Earlier it was mentioned that families managing large farms usually have large families. In addition, the incomes earned by farmers who own large farms are likely to be nearly double those of farmers who own small farms (Coale and Hoover, 1958). Generally, the landless earn less money than the landowner of a small farm. It is logical to assume, however, that the very poor farmer will have less adequate food and health care than the more affluent farmer. Thus, infant and child mortality is likely to be higher in poor farm families compared with the affluent farm families (NAAS, 1971, 1975). For this reason, their ultimate family size may be slightly smaller than that of the affluent farmer.

The benefits and costs of raising children are difficult to assess for any culture, but in rural areas children are usually a greater benefit than their cost (NAS, 1971, 1975; Cavalli-Sforza, 1986; Watts, 1987). Because a male child of 14 can earn an adult wage, he is a major asset to the family on or off the farm (Watts, 1987). This emphasizes another important factor, the special value placed on male children by farm families. The economic advantages of male children have led to female infanticides in some rural areas of the world (Boserup, 1981). Sometimes the female children are just neglected and allowed to die.

Children, especially males, provide substantial help on the farm after they reach 3 years of age. As adults they provide social and economic security for their parents when they are too old to work (Boserup, 1981). Throughout history, children have provided the major support for aged parents.

For the poor in many developing countries, maintaining a child costs less than buying and feeding draft animals. The only cost for a child in rural areas is its care and its food supply (grown on the farm) for the first 3 to 4 years. After this the child can pay for itself by working in the farming operation. In contrast, a draft animal like a water buffalo may cost about $100 to purchase and still have to be fed and cared for; note, a farmer's total annual income may be only $100 (ADAM, 1978; Pimentel unpublished).

Green Revolution and Population Growth

Much has been said about the benefits and costs of the Green Revolution for developing countries (Dahlberg, 1979; Baum, 1987; Swaminathan, 1987). In general, large farmers who owned good quality bottom land benefited from the Green Revolution, while small farmers who were working marginal land in the hills benefited very little or not at all from the new technology (Prahladachar, 1982; Khan, 1984). Farmers on bottomland usually produced high-yielding crops like rice, whereas those on marginal land, which has lower yields and lower economic returns, were producing crops like cassava.

A different set of technologies must be developed for farmers if they are to be productive on the marginal lands (Baum, 1987). This is in part the reason for growing interest in fostering agroforestry on sloping lands and other marginal lands (Pimentel et al, 1989).

An agroforestry technology that combines the culture of crops and trees/shrubs helps protect the land, water, and biological resources while it increases food and fuelwood production on the land (Pimentel et al, 1989). Although more research is needed, it has been demonstrated that by using agroforestry techniques crop yields can be doubled or tripled, and additionally significant amounts of fuelwood can be produced for the family. Fortunately these economic benefits can be achieved while protecting the natural resources and sustaining the environment (Pimentel et al, 1989).

In general, the Green Revolution and the use of agroforestry technologies in agricultural development have required an increase in the size of the farm labor force and also in the total labor input per hectare (Hayami and Ruttan, 1971; Kikuchi and Hayami, 1983; Chadha, 1984; Pimentel et al, 1986, 1989). Unfortunately, during this increase in labor, the percentage of landless laborers also increased sharply (Bhalla, 1984). Concurrently, as labor on farms increased, population growth escalated.

Available data strongly suggest that children are an advantage in farming, and this advantage exists whether the agriculture is hand-powered, draft animal-powered, or tractor-powered mechanized farming. Agricultural development generally contributes to rapid population growth because farmers recognize that large families provide cheap labor. Thus, agricultural development alone does not appear to have provided a solution to the population growth problem.

Green Revolution and the Environment

By most standards everyone would judge the Green Revolution a resounding success (Baum, 1987). However, in terms of the impact it has had on the environment, the Green Revolution has not been successful (Swaminathan, 1987). The Consultative Group on International Agricultural Research (CGIAR) that developed the crop plant improvements paid little or no attention to how this new technology would affect the quality of the environment (Baum, 1987).

Some of the Green Revolution crops that were developed were susceptible to insect pests and required stepped-up insecticide use (Pradhan, 1971; Barr et al, 1975; Oka, 1976). Pesticide use in Green Revolution rice production, for example, was reported to increase seven-fold over levels used in traditional rice production (Subramanian et al, 1973). To date, no evaluation has been made of the precise impact the increased use of insecticides has had either on agroecosystems or the surrounding natural ecosystems. Many insecticides used not only are known to be toxic to humans, but also kill beneficial natural enemies of pests in the treated crops and adjoining crops (Pimentel, 1983) Further insecticide resistance developed in the brown plant hopper associated with rice and this reduced rice yields and increased insecticide use (Oka, 1987). Then, too, insecticides have killed the shrimp and fish in rice paddies that are important sources of food for the poor. The spread of insecticides into the aquatic environment has contributed to the increased resistance observed in mosquito populations and has resulted in the spread of malaria in Asia, Africa, and Latin America (ICAITI, 1977).

In addition to heavy reliance on pesticides, fertilizer requirements of Green Resolution crops increased in some cases 20- to 30-fold (Wen and Pimentel, 1984; Wittwer et al, 1987). While long experience has demonstrated that their heavy use contributes to eutrophication, this aspect of the Green Revolution has not been studied.

Other notable difficulties with the Green Revolution are the alarming soil erosion and water run-off problems (Pimentel et al, 1987). Although erosion might be more serious in green revolution than in traditional farming, erosion and associated run-off are especially serious farming problems because they decrease the productivity of the land. Then the reduced productivity requires added fertilizer, irrigation, and pesticides to offset soil and water degradation. This starts a cycle of more agricultural chemical usage and further increases the production costs the farmer must bear.

Poorer farmers are finding that they are unable to afford the needed fertilizers and pesticides for the Green Revolution crops. It seems unlikely that agricultural development will substantially reduce family size or slow population growth in developing countries.

Conclusion

Agricultural development itself has never slowed population growth in the history of human societies. All available evidence suggests that it will not provide a solution to this serious problem in the future.

Farm families generally are much larger than families in urban areas. Children are cheap to raise and care for in rural areas. Indeed, children often are less expensive than the best draft animals and for this reason are commonly exploited in developing country farming. A large family of children provides economical farm labor, as well as economic security for the parents as they grow older. This is especially true for farmers with small acreages and landless farmers.

There is no indication that the size of Green Revolution farms, whether large or small, will curtail the rate of population expansion – population growth will probably continue at a rapid rate in rural areas. If a nation could industrialize while agricultural development occurs, then although the farms might increase in size, the labor released from farming could be absorbed by the industrial sector.

Of course, one has to ask another question: How many developing countries can industrialize like Japan, Korea and Singapore? Further, are there sufficient markets for TVs, automobiles and other material goods to support a work force comprised of 80 to 90 percent of the population currently employed in agriculture in developing countries?

Humans now face an enormous dilemma – should the population goal of the world be about 1 billion people who enjoy a high standard of living characteristic of the industrialized nations of the west or 15 billion who must survive at the poverty level? About 200 years of careful planning and dedication to population control will be needed by each nation to reduce its numbers by 80 percent and achieve a world population of about 1 billion. Most would agree that the reward is great for both countries and individuals. If achieved, then there would be abundant food, a sustainable agriculture and environment, plus a relatively high standard of living for everyone.

Without planning and sacrifice, we are on the road to 15 billion humans or more! To provide minimal food needs will mean that most forests will have to be removed and planted to crops (more than half of the world forests have already been destroyed during the past 30 years), natural grasslands converted to pastures and/or crops and some mountainsides terraced for crop production.

Nature has always limited all biological populations in the past and will do so with human populations, if individuals and nations do not find ways to limit their numbers to the "carrying-capacity" of the earth. Already many natural environments vital to human survival have been destroyed beyond repair. •

[*References may be obtained by contacting the offices of The Social Contract Press, 1-231-347-1171.*]