Agriculture and Environment, 2 (1975) 291—309

ENVIRONMENTAL IMPACTS OF INCREASING THE WORLD'S FOOD PRODUCTION

MARGARET R. BISWAS

15 Rothwell Drive, Ottawa, Ont. (Canada)

ASIT K. BISWAS

Office of the Science Advisor, Department of the Environment, Ottawa, Ont. (Canada)

(Received November 11th, 1975)

ABSTRACT

Biswas, M.R. and Biswas, A.K., 1975. Environmental impacts of increasing the world's food production. *Agric. Environm.*, 2: 291—309.

World demand for food is expanding more rapidly than ever before in history due to rising population and increasing affluence. The urgency of increasing food production should not be underestimated. It is vitally important, however, to ensure that the strategies adopted to increase food production on a short-term basis can be sustained and effectively integrated with long-term policies. With many of our present policies, there is a very real danger that in our efforts to increase food production in the short-run on a crisis basis, we may adopt strategies which are self-defeating in the long-run. Any strategy to increase food production on a sustained basis that does not explicitly consider environmental factors is doomed to failure, sooner or later. Strategies developed must work with nature and not against it.

Within this philosophical framework, the major parameters that could improve yield of food grains and could possibly deteriorate the very ecological base on which food production depends, and thus ultimately jeopardize the production process itself, are discussed. Among the parameters reviewed are food loss and wastage during production, storage and distribution; environmental constraints in relation to the use of pesticides and fertilizers; problems arising due to improper land use planning and irrigation practices; effects of climatic changes on food production; and problems of technology transfer and use.

INTRODUCTION

World demand for food is expanding more rapidly than ever before. The developing countries are now engaged in a desperate race to keep food production growing at least as fast as population growth. Viewed in global terms, the food-population equation during the 20-year period, 1951 to 1971, was quite reasonable. The production of cereal grains, the principal source of world food supply, and that which dominates the world food economy, more than doubled, while there was a less than 50% increase in population. This means that the cereal availability per capita increased by about 40% in 20 years.

Because of regional disparities, this increase, however, was very unevenly distributed. More than half the increase was accounted for by the richest 30% of mankind, and the balance, less than 50% of the food supply, was left for the poorest 70%. Even this amount was inequitably distributed, ranging from a high per capita annual increase of 0.9% in Latin America to an actual per capita decline of 1.1% in Africa during the 1953—1971 period. (Revelle, 1974). According to FAO estimates, the minimum requirement is to increase the average annual rate of food production in developing countries from 2.6%, over the last twelve years, to at least 3.6% during the next twelve years (UN World Food Conference, 1974). If this minimum increase in production is not made possible, the developing countries as a whole might well face annual deficits of 85 million tons in normal years and over 100 million tons in years of bad harvest (UN World Food Conference, 1974).

Until recently, the demand for food was almost exclusively a function of population growth. This scenario, however, is changing very rapidly. Rising affluence is rapidly emerging as a major new claimant on the global food resources, and nearly 20% of the present food consumption can be attributed to this cause (Biswas and Biswas, 1976). The effect of the purchasing power and its demand on the nature and type of food consumption can be simply illustrated by the following example. In the developing countries, the average annual grain consumption amounts to nearly 400 lbs/head/year. Most of this amount is consumed directly: very little is taken in the form of animal protein. In the more affluent countries, the grain consumption is five times as much, most of which is consumed indirectly in the form of animal protein — milk, eggs and meat — and only 150 lbs is consumed directly. Thus, the agricultural resources necessary to support one inhabitant of a more affluent country can support on an average five citizens of Bangladesh, Uganda or Colombia.

Food production and environment

The urgency of increasing food production should not be underestimated. It is vitally important, however, to ensure that the strategies adopted to increase food production on a short-term basis can be sustained and effectively integrated with long-term policies. There is a very real danger than in our efforts to increase food production in the short-run on a crisis basis, we may adopt strategies which are self-defeating in the long-run. In other words, we may find ourselves in a far more precarious situation in the mid or late-1980s, when the demand for food would be much higher than what it is today, due to both higher population and increased levels of affluence, if food production starts to level off, or in fact even decline, because of our present acceptance of, and reliance on, short-term, ad hoc, and self-defeating strategies. History is full of similar examples from all corners of the world.

Any strategy to increase food production on a sustained basis that does not consider environmental factors explicitly is doomed to failure, sooner or later. The FAO Conference at its Seventeenth Session (10—29 November, 1973) stressed that "the major environmental problems facing agriculture, forestry and fisheries were not only the avoidance of environmental pollution but the ensuring, in the development process, of the maintenance of the productive capacity of the basic natural resources for food and agriculture through rational management and conservation measures." (FAO, 1974). It also "recognized that agricultural development and world food security depended on the careful husbandry of living resources, on their biological laws and ecological balances, as well as on the adjustments of production, supply and reserves to demands." (FAO, 1974). The productive capacity of the biosphere can only be sustained and improved by adopting strategies that are ecologically and environmentally sound. The aim of these strategies should not be growth at the cost of environmental deterioration or destruction of natural resources, but rather development with due concern for conservation of environment and resources. If these concerns are not explicitly incorporated within the development strategies, growth may be greater in the short or even medium-terms, but will degrade the environment, which will eventually undermine the development process itself. If we accept the fact that the ultimate aim of both development processes and environmental management is to optimize man's social, economic and mental conditions, there is no contradiction between development and environment: they are in a real sense, cut out of the same cloth.

With this background, the major parameters that could improve yield of food grains and at the same time have the potential of deteriorating ecological and environmental conditions, and thus ultimately jeopardizing the food production process, are briefly discussed.

Food loss and wastage

A multitude of organisms compete with man for the available food supply. Among these are rodents, different species of birds, locusts, termites, snails and a variety of other animals, including monkeys, antelopes, elephants, kangaroos, dingos and flying foxes. Currently, the losses encountered during storage, processing and handling of the foods produced could easily feed hundreds of millions more people. These losses occur in all countries, irrespective of whether they are developed or developing or whether they are in temperate or tropical regions.

Man's most important competitors for food are rodents. According to some estimates, rodents, on a global basis, eat or destroy an amount equal to the average food consumption of nearly 200 million people. In a country like India, the rodent population was recently estimated at 2.4 billion, which means that they outnumber people by five to one (Indian Institute of Socio-Economic Studies, 1974 — see Tristam, 1974). Even the most conservative estimates place the loss at a million tons per year, roughly the amount needed to feed India's annual growth in human population. Paradoxically, as more land was cultivated, more food was available for the rodents, which contributed to their increase in population. They were also helped by ecological side-effects of the clearing of the land, which killed their natural predators for example, snakes.

Even in a developed country like the United States, the rodent population has been estimated at well over 120 million. The U.S. federal authorities estimate that a rat eats nearly forty pounds of food or feed-stuff annually, and destroys or contaminates at least twice as much. Their cost to the U.S. economy is well over one billion dollars/year.

There are other major competitors for food. For example, in Africa, where nearly 30% of all crops are lost in storage (this would feed an additional 55 million Africans/year), the quelea (weaver bird) presents a serious problem (Tristam, 1974). Despite the extermination of more than 1 000 million queleas in one year in its main breeding belt stretching from Senegal and Mauritania to the Sudan, Ethiopia and Tanzania, its numbers were little affected. It still invades in flocks of millions.

Insects eat or destroy a significant portion of the world's food production. In the United States, where no commercial crop is produced without the application of pesticides, insects destroy five percent of the wheat crop — an average of more than one million tons of wheat/year. In the late sixties, the U.S. Department of Agriculture estimated that losses due to insects accounted for 4—5 billion dollars/year. This loss is equivalent to cultivating another 62.75 million ha — 36.45 million to compensate the losses in the field and 26.30 million for storages losses (Borgstrom, 1969).

This clearly indicates that even in the most developed countries, food losses and wastes are often appallingly high, despite the sophisticated crop handling and storage techniques available. For example, more than 13% of the Canadian wheat harvest in 1968 was badly damaged by damp because commercial driers could not cope with the amount.

If this is the situation in the most developed countries, the conditions in other countries are bound to be worse. Food losses from various forms of pests and insects could reach 10% (20% in critical years) in temperate climates and may reach as high as 50% in tropical countries (nearly half of the sorghum crop in tropical Africa is lost to insects) (Biswas, 1975). This, the prevention of losses and wastes during the storage, processing, or handling of food is one of the most important parameters to improve the world food situation.

Pesticides

The word pesticides, in the context of the present paper, includes any form of chemical used for the control of unwanted herbaceous plants (herbicides), woody plants (arboricides), insects (insecticides) or any chemical that has biocidal activity affecting rodents, arachnids or any other population. The loss of food due to these latter agents on a global basis has been demonstrated to be quite significant in the previous section, and hence if man could effectively control these "pests", more food would be available for human consumption. It was estimated in 1969 that if the insects of tropical Africa could be kept under control and possibly eliminated as competitors to man, Africa would be able to feed two billion people, eight times as many as those living in that continent (Borgstrom, 1969).

After the Second World War, the use of chlorinated hydrocarbons as pesticides increased tremendously. In United States, some one billion pounds of pesticides are used each year, nearly 5 lbs per person (Henning, 1974). Their success in controlling pests on a short-term basis cannot be denied, but their long-term effectiveness in controlling pests or their overall effects on ecosystems (including human health) and environment has to be seriously questioned on two major counts. These are: increasing concentration of pesticide residues as they move up the food chain; and rapid evolution of new breeds of pests that are immune to the pesticides applied.

In contrast to the organophosphate group of pesticides that are biodegradable, the chlorinated hydrocarbons do not easily decompose. They are gradually dispersed to ecosystems other than the one intended by evaporation and subsequent precipitation, or by drainage waters. England, for example, receives nearly 36 metric tons of chlorinated hydrocarbon as fallout per year (Boughey, 1971). These dispersal mechanisms mean that pesticides can be detected in areas far away from the points of application. Thus, significant quantities of pesticides, including DDT and its derivatives, have been found in Antarctic animals (penguins and their eggs, skua and fish), where there is no agriculture, no insect life and no use of pesticides.

The pesticides are most commonly distributed through ecosystems by selective concentration, as they pass unchanged through successive levels of food chains and food webs. For example, in Lake Michigan, the concentration of DDT in lake sediments was 0.0085 ppm. Invertebrate primary consumers concentrated this to 0.41 ppm, their fish predators to 3—8 ppm, and the herring gulls predatory on the fish had levels of no less than 3 177 ppm (Hickey et al., 1966). This means that the level of concentration increased nearly 374 000 times between the lake sediments and the gulls. In Clear Lake, California, a plankton—fish—bird chain concentrated DDT by a factor of 100 000. There are several other similar examples of heavy concentration as pesticide residues move up the food chain (Pimentel, 1971).

The effect of this selective concentration means that the toxic effects of pesticides are most readily noticeable in top carnivores. Thus, U.S. citizens, from 1964 to 1966, had an average daily pesticide intake of 0.08 to 0.12 mg, of which nearly 75% was DDT. Tests in England, in the same locality, showed that human milk had 22.5 times more DDT and 36 times more DDE than cows' milk. American and British babies consume about ten times the recommended maximum level of dieldrin (Egan et al., 1965).

The continued large-scale use of pesticides has resulted, through natural selection and evolution processes, in the appearance and proliferation of new strains of resistant species that generally turn out to be more vicious than their original counterparts. Some pests like the salt marsh sandfly are reported to have evolved resistant strains after only three pesticide applications (Boughey, 1971). Increasing the dosage merely delays the evolution of resistant races. For example, the resistance of the bollworm to insecticides used in its control increased 30 000 times between 1960 and 1965 in the Rio Grande Valley of Texas (Brubecker, 1972).

Application of different types of pesticides is gradually contributing to the evolution of "super pests" that are immune to the chemicals. Thus, one brand of fly that pesters cattle became arsenic-resistant in 1937, resistant to benzohexachloride in 1948, and to DDT in 1956 (Borgstrom, 1967). There are several strains of flies, ticks, bedbugs, cockroaches, mosquitoes, moths and hemiptera that are now resistant to both chlorinated hydro-carbon and organophosphate types of pesticides.

Continued heavy reliance on pesticides to protect vast areas of monoculture is ultimately bound to be a self-defeating strategy. Such a practice kills all useful insects that could naturally keep the pest population down, and ensures continual increase in the doses of application and continual development of new forms of pesticide-resistant species. Thus, the number of applications of pesticides to cotton in recent years has risen from 8 to 40 in some Central American countries (FAO, 1974), and evolution of new strains of cotton pests necessitates the use of new forms of pesticides every three years or so in Egypt.

The Canete Valley in Peru is an example of an ecological disaster that could occur due to heavy reliance on pesticides. The area covers some 22 000 ha of irrigated land on which cotton was grown. During the period 1949—1956, use of pesticides was constantly increased to control the cotton pests. New pests appeared in the crops because of the destruction of predators and parasites, and the pests themselves started to develop resistance to the chemicals used. The cost of greater application of pesticides increased tremendously, and gradually all useful insects were destroyed. By 1956, the situation had become critical and nearly 50% of the crop failed (FAO, 1974).

The use of pesticides as the exclusive form of control was banned in 1957. Synthetic organic insecticides were completely prohibited, and mineral insecticides were used. Enemies of cotton pests were reintroduced and cropping practices were changed, based on a study of the ecology of the cotton fields. The equilibrium of the valley's ecosystem was eventually restored several years later (FAO, 1974).

There are several similar examples of eventual reduction in crop production due to heavy reliance on chemical pesticides. What is necessary is to develop effective new concepts of integrated pest management, which can be broadly defined as an ecological approach to pest control by optimal combinations of biological and chemical control technologies. This would be based upon information about individual pests, their environment and natural enemies. Farming practices are modified to control the pest and aid its natural enemies. Realistic economic injury levels of crops would be used to determine the need for suppressive measures. For example, during the first 30 days and for stages after 100 days after planting, cotton can withstand up to 50% defoliation. During the period of fruit formation (30—100 days), the economic level for defoliation drops to about 20%. Integrated pest management takes advantage of these types of sensitivities, and the measures undertaken might include releasing biological control agents or pest-specific diseases or, when necessary, applying pesticides in limited amounts.

Integrated pest managament provides better pest control at lower cost, and with significantly fewer environmental problems than exclusive reliance on chemical pesticides. This type of systematic approach has progressively reduced the average number of pesticide applications in the cotton fields of Nicaragua from 28 (range 16—35) during the 1967—1968 season to 22 (range 14—30) in 1970—1971, and to 18 (range 10—25) in 1971—1972. It has also reduced pest control costs by about 40%, and has lowered the pesticide residues in adjacent crops, livestock and dairy products (FAO, 1974).

One of the major problems of existing modes of application of chemical pesticides is their extremely low efficiency rates. Several studies indicate that nearly 70—75% of pesticides applied by aircraft never reaches the target (Akesson et al., 1971), and this could damage sensitive nontarget plants in the near vicinity in addition to creating totally unnecessary ecological hazards. Widespread drift effect from aircraft applications has been noted, for example, in California, where in applying propanil to rice acreages, fruit tree damages were observed some 55 miles downwind.

Thus, it is essential that instead of placing unwarranted emphasis on increasing the use of chemical pesticides, we should concentrate on increasing the efficiency of pesticides applied. The objective should not be just "more pesticides" but "more efficient use of pesticides". Such a strategy would improve the effectiveness of the already available pesticides by several orders of magnitude. In addition, the pesticides used should be target-specific and not indiscriminately harm the natural enemies of the pest or other useful insects. In other words, man should work with nature, not against it, as seems to be the case at present.

Fertilizers

Fertilizers are indispensible for increasing food production but their excessive use has occasioned much concern as a possible environmental threat. Chief among these concerns are the contribution of phosphate and nitrogen fertilizers to eutrophication, and excessive concentration of nitrites in water, which could result in methemoglobinemia in infants.

Laboratory experiments indicate that very small quantities of nutrients (15 parts per billion of phosphorus and 0.3 ppm of nitrogen) are necessary to support algal blooms. Thus, if we consider a field treated with 7.3 kg of phosphate per ha, and only a 1% loss of the fertilizer, the resulting nutrient could support noxious blooms in nearly 1 000 m^3 of water (Brubecker, 1972). The crucial link between use of fertilizer and aquatic plant growth is the leaching or erosion of fertilizer from the agricultural fields to watercourses. The evidence at present is circumstantial rather than direct. This is due to the fact that few experimental studies are available on nutrient balance over a long period. This state of affairs is not surprising because until recently fertilizer was cheap, and it was easy to convince farmers that marginal returns exceeded marginal costs. Thus, no one really looked into what happened to excess fertilizer once it was applied to the field.

On the question of the presence of nitrites in water however, there is evidence that under certain conditions and for certain crops fertilizers do contribute to it. Studies in the Rheingau area of Germany have shown that water from sources beneath vineyards had a nitrate content of over 40 mg/l compared with 10 and 5 mg/l respectively for water whose source lay beneath arable land and forest (Jung, 1972). The high nitrate levels in wells in the Moselle Valley of Germany have been attributed mainly to nitrogen fertilization of vineyards. Lysimeter studies have confirmed that vines take up little nutrient and therefore a relatively high leaching rate results (Pfaff, 1963).

Basically there is no difference between the objectives of farmers and environmentalists, since both would like to maximize food production consistent with minimum environmental disruptions. Both of these objectives can be achieved if fertilizers are used with the maximum efficiency on the farm, for this will reduce the tendency of their overuse. If the right fertilizer is chosen for the crop, correctly formulated and applied in the right quantities at the appropriate times, it would minimize the amount of nutrients that are liable to be leached into the drainage water. Thus, what is necessary is to develop new types of fertilizers which can be held in an insoluble form in the soil but can release their nitrogen as nitrate into the soil solution during the growing season at a rate comparable to the crop's need for nitrates. Technically this can be done, but currently there is still no satisfactory slow-release fertilizer available for general agricultural use.

Another associated problem which is rapidly becoming quite serious in several countries is the disposal of animal manures from feedlots. The volume of wastes is growing faster than disposal technology. In earlier times, animal manure was largely returned to the land as valuable nutrients, but in the existing economic climate it is more expensive to collect and spread feedlot manure than mechanized application of chemical fertilizers. In terms of waste production, a cow is equivalent to 15—16 men, and a pig or sheep to 2—2.5 men. In large feedlots, cattle may be allowed only 50 square feet of space per animal. Even if this space is increased ten-fold, annual excretion of nitrogen per animal will amount to nearly 20 tons/acre of feedlot. The best disposal method of animal manure would be to return it to the soil, where it would provide necessary nutrients and would also improve soil structure. However, when the density of animals exceeds a certain threshold value, such disposal becomes economically unattractive, and it becomes very difficult to prevent contamination of local water resources by soluble inorganic and organic constituents.

Land-use planning

Land use may be defined as man's activities on land which are directly related to the land. Use of land generally depends on its location, natural qualities, including its surface and subsurface characteristics and vegetative cover, price, ownership (tenure) and improvements that can be made to and on land, viz., reclamation, levelling, filling, drainage. With the increase in world population and standard of living, land in many parts of the world is coming under intense pressure from a variety of uses, chief among them being residential, industrial, commercial, recreational, transportation, agricultural, pastoral, forestry, mining and mineral extraction, and preservation of natural habitat.

Ideally, activities that are to be carried out upon a tract of land should depend upon its natural qualities, and this is especially relevant for agriculture. Pressure to expand the area under agriculture has resulted in more and more utilization of marginal land, for which either technology is not available for farming on a sustained basis, or, if available, has been disregarded for social, economic, or political reasons. Thus, the expansion of agriculture to steep hillsides has led to serious erosion in Indonesia; increasing pressure of slash-and-burn agriculture is destroying tropical forests in the Philippines; deforestation in the Himalayas is contributing to the increase in frequency and severity of flooding in India, Pakistan and Bangladesh; and overgrazing and deforestation is contributing to the southward march of the Sahara in the Sahelian Zone of Africa. There are numerous other similar examples where short-term agricultural benefits have resulted in long-term environmental costs which eventually completely negated the increased food production.

Rational management of arable agricultural land is increasingly becoming a very critical factor for the future survival of mankind. A high percentage of the arable land is already being used — 47% in North America, 63% in Europe (excluding U.S.S.R.) and 74% in Latin America (FAO, 1974). The total area of biologically productive soil that has been destroyed and degraded in the past is estimated at 2 000 million ha. In comparison, our total present arable agricultural area is 14 000—15 000 million ha (Kovda, 1974). Between now and the year 2 000, if the present trends continue, 650—700 million ha of good farm land will be lost. Thus, more and more good agricultural land is being lost every year due to erosion, salinization, urban and industrial development, and a host of other reasons.

Soil erosion is one of the most pressing and difficult problems facing the future of mankind. A historic example is North Africa, which was the fertile granary of the Roman Empire but is currently a desert or semidesert which has to import much of its food. The "dust bowl" experience of the 1930s in the United States was followed by similar experiences in the U.S.S.R. and South Africa. Nearly 80% of the land in Madagascar has been swept away by severe erosion. The U.S. Soil Conservation Service estimates that more than 3.2 billion metric tons of soil is lost each year through erosion from approximately two-thirds of the U.S. land which is privately owned (Council on Environmental Quality, 1973). The Service further estimates that soil loss from cropland adequately treated against erosion averages less than 11 metric tons/ha/year, from pastureland less than 4.5 metric tons/ha/year, from rangeland about 33 metric tons/ha/year and from forest land about 1.1 metric tons/ha/year. (Council on Environmental Quality, 1973).

Nature's geological cycle has been continuously producing topsoil over millions of years, but its pace is too slow to be useful to man. Man is destroying this precious resource by bad management practices within a mere fraction of the time nature took to produce the soil.

Overgrazing can create serious problems. For example, in the Patagonia region of Latin America (78 million ha in Argentina and 24 million in Chile) — a vast semi-desert area — sheep were introduced toward the beginning of this century. The sheep thrived, and by 1912 their number was well over 25 million. Sheep, which are highly selective in their grazing habits, started to eat up the best pastures, which gradually reduced the fodder production, which in turn has reduced the sheep population to below 20 million during the last decade. Overgrazing also led to a serious problem of wind erosion, which was further accentuated by the strong wind characteristics of the region (FAO, 1974). Similar problems due to overgrazing have been observed in the Sahelian Zone, and several other areas. Thus, for sustained long-term productivity, the carrying capacity of land should be carefully evaluated.

Deterioration of soil fertility and loss of agricultural land due to increase in salinity or alkalinity is a common problem in many parts of the world. At one time, Pakistan alone was losing 24 300 ha of fertile cropland every year, and currently, nearly 10% of the total Peruvian agriculture is affected by land degradation due to salinization (FAO, 1974). Among other major areas affected by salinization are Helmud Valley in Afghanistan, Imperial Valley and Colorado Basin in the United States, Punjab and Indus Valley in the Indian subcontinent, Mexicali Valley in Northern Mexico, and the Euphrates and Tigris Basins in Syria and Iraq. A study of major modern irrigation schemes in the Punjab shows that seepage from unlined canals has, in the first 10 years of operation, raised the water table 7—9 m above the long-term levels recorded since 1835. On a global scale, at least 200—300 thousand ha of irrigated land is lost every year due to salinization and waterlogging (Kovda, 1974). Current estimates indicate that 20—25 million ha of land that is saline at present was fertile and productive at one time (Kovda, 1974).

Equally important is the loss of good productive agricultural land to other competing uses such as urbanization or for recreation due to poor planning. This problem is now prevalent all over the world — in developed and developing countries, in both food-rich and food-poor countries. As much as one million acres of U.S. cropland has been taken over by nonagricultural uses in recent years. In Egypt, in spite of the recent major irrigation development schemes like the Aswan, the total area of irrigated land has substantially remained the same over the last 20 years.

There are two ways of expanding world food supply from conventional agriculture — expansion of the cultivated area, and raising of the yield per unit area. Thus, if we continue to lose up to 6—7 million ha of soil annually, we have to bring a significant amount of new land under cultivation every year, with its attendant heavy investment costs, just to retain status quo with regard to food production. To have a perspective on the magnitude of the cumulative loss, one has only to consider that currently nearly 1.5 billion ha of land are used for crop production compared with nearly 2 billion ha of land that have already been lost (Kovda, 1974). Thus, if we plan to provide adequate food to all of the world's continually expanding population, we can no longer afford to lose good agricultural land at such a phenomenal rate.

It is a sad commentary on man's planning capabilities that we allow good agricultural soil to be lost by bad management practices, and then the pressure for expanding food production to feed ever-increasing population makes us farm marginal land, which often proves to be ecologically disastrous within a short period of time.

Irrigation

Man has practiced irrigation to increase crop production for several thousand years, but the real momentum to use irrigation on a large scale started in the nineteenth century with several major undertakings in India (Biswas, 1965), Egypt and other countries. The irrigated acreages of the world increased nearly 5.5 times during the nineteenth century - from 8.1 to 45.5 million ha. Currently, 230—240 million ha are under irrigation, the main crop on two-thirds of this land being rice, followed by cotton, oil-bearing crops, fruit trees, cereals and other crops.

The high yielding variety of crops currently used requires more moisture (often 2—3 times) than previously. Generally, the amount of water consumed is proportional to the biomass produced, but the actual water requirements vary with crops, climate, soil and other factors. Thus, rice in the tropics requires 1 000 kg of water for each pound of organic matter produced, and wheat in the United States requires 160 kg of water/pound of organic substance compared with water requirements of 390 kg in Australia.

Irrigation increases crop yields by improving water availability for intensive agriculture, but it also creates severe ecological and environmental problems (Biswas, 1971b). One of the main problems of irrigated agriculture — secondary salinization and alkalinization, which has turned millions of hectares of productive land into saline barren deserts through the absence of proper drainage systems, has already been discussed. Groundwater resources of many areas have been steadily depleted because water was constantly extracted for irrigation withought considering the natural replenishment rates. This has happened in Saudi Arabia, Israel, South Africa, Texas, Arizona and Southern California, India and many other regions. The history of most of these regions is very similar. After a short period of increased food production, the yields were significantly reduced and in some cases farming had to be abandoned.

The most serious effect of irrigation, however, is the spreading of water-borne diseases, and the consequent suffering of millions of human beings and animals. In the tropical and semi-tropical regions of the world, irrigation schemes have enhanced and often created favourable ecological environments for parasitic and water-borne diseases such as schistosomiasis, liver fluke infections, filariasis and malaria to flourish. These diseases are not new; for example, schistosomiasis was known during the Pharaonic times. But our unprecedented expansion of perennial irrigation systems has introduced such diseases into previously uncontaminated areas (Biswas, 1971a).

In early days, when agriculture depended primarily on seasonal rainfall, the relationship between snail host-schistosome parasite-human host was somewhat stabilized, and infection rates were low. Snail populations increased during the rainy season when agriculture was possible, and this provided the contact between man and parasites. During dry periods, however, there was a lull in infection. With the stabilization of water resource systems through the development of reservoirs and perennial irrigation schemes, the habitats for snails were vastly extended, and they also had a prolonged breeding phase which substantially increased their population. It also provided more human contacts with parasites, which not only raised infection rates but also greatly increased worm load per man. The incidence and extension of these diseases can be directly related to the proliferation of irrigation schemes, the stabilization of the aquatic biotope and subsequent ecological changes.

This relationship has been conclusively demonstrated in several countries of the world. In Egypt, the replacement of simple primitive irrigation with perennial irrigation has caused a high incidence of both *S. mansoni* and *S. haematobium*. Where basin irrigation is still practiced, the incidence is much less. Infection rates in four selected areas,within 3 years of introduction of perennial irrigation, rose from 10 to 44%, 7 to 50%, 11 to 64% and 2 to 75% (Lanoiz, 1959). The life expectancy of males and females in heavily infected areas are estimated to be 27 and 25 years respectively. In Sudan, with the introduction of perennial irrigation to 900 000 acres under the Gezira Scheme, the incidence of blood flukes rose greatly (Van der Schalie, 1971). It also increased the incidence of flukes in cattle and sheep. In Kenya, the Lake Victoria is hyperendemic for schistosomiasis. *S. mansoni* infection in school children is up to 100% in areas associated with irrigation schemes (Alves, 1958). In Transvaal, South Africa, the *S. mansoni* infection rate in European farms was 68.5% compared with only 33.5% in the reserves, because the former had irrigation (Anneche, 1955). Similarly, in the Far East, irrigation has not only increased schistosomiasis, but also liver fluke infections, eosinophilic meningitis and bancroft filariasis (Bardach, 1972).

In addition to contributing to health hazards, dams built for irrigation and other purposes have created other serious ecological and environmental problems. The Bennett Dam in Canada, until strong counter-measures were taken, created several environmental problems which very quickly contributed to the deterioration of the life-style in the Peace-Athabasca Delta. Ecological effects on the fish and animal populations of the area soon reverberated to the people who lived in that area - primarily Treaty Indians and Metis. Their income was substantially reduced, and the social and economic dislocation effects were considerable. The Aswan Dam in Egypt has lowered the fertility of the Nile Valley because of lack of sediments, and artificial fertilizer has to be currently applied in many areas. Salinity levels in Middle and Upper Egypt have increased. Availability of plankton and organic carbon has been substantially reduced, and this, in turn, has reduced the sardine, scombroid and crustacean population of the area. (Biswas, 1971a, 1973).

There are many similar cases in Africa, Asia and South America where man has had to pay heavy prices for irrigation schemes in terms of the overall health of the region as well as in ecological deterioration. Thus, irrigation does not necessarily bring unmitigated benefits to mankind: it can extract high costs as well. What is necessary is a determined attempt to minimize the costs and maximize the benefits on a long-term basis. This can only be done if we consider ecological and environmental principles in our overall planning framework.

Effects of climatic changes on food production

Weather has always been an important factor for crop production, for throughout recorded history food production has been plagued by droughts and floods. Its overall effects on agricultural yields are somewhat complex to assess since different crops have different requirements for the same climatological factor. For example, corn thrives at warm temperatures, but wheat will suffer to some extent and barley to an even greater extent at the same range of temperatures. Furthermore, climatic effects are much greater for all types of crops at certain stages of their critical growing periods. In other words, a crop is more vulnerable to certain climatic conditions at one stage of its development and growth than to identical conditions at another stage. Thus, the exact timing of occurrence of the climatological factors with relation to the critical crop growth periods is most important.

The yield of crops depends on several important climatological parameters. Among these are precipitation, temperature, evaporation, occurrences of frost and winter conditions, and wet and delayed springs which could affect the length of the growing season. An objective appraisal of the influence of climatic changes on the world food production can be made only by analysing their effects crop by crop. In spite of these complexities, however, some general statements can be made.

World climate is not fixed, it is subject to considerable variation. During the first half of the twentieth century the atmospheric circulation in the Northern Hemisphere was predominantly zonal, west to east, which resulted in a relatively stable weather pattern. Since then, the circulation has developed a more pronounced wavelike pattern with greater north-south and south-north flows, resulting in more perturbations in weather. Overall, the main trend seems to be toward more frequent extreme weather conditions such as floods, droughts, and cold and warm spells, in widely separated areas. Changes in the Southern Hemisphere appear to be less significant.

The cumulative effects of the climatic anomalies that occurred in 1972 had catastrophic results on the world food production. Droughts and floods seriously affected agricultural production in several parts of the world — U.S.S.R., Central America, Sahelian Zone of Africa, Southern Asia, China, Australia and the U.S. Mid-West. While these aberrations did not occur at random, one cannot be sure about the precise causes of these events. Equally, one cannot ignore the possibility that important changes are occurring, or have already occurred, in the climatic bases of certain areas. For example, monsoon rains over the South Sahara extended well to the north from the 1920s to 1960s. This favourable trend has now been reversed over the past six years, with seasonal rainfalls considerably below the previously recorded averages. Since 1971, the world snow and ice cover has increased by at least 10 percent (Kukla and Kukla, 1974).

Effects of these types of climatic changes on food production in marginal agricultural areas have been quite severe. Persistent drought has steadily reduced the total area of millet cultivation in Chad from 1.23 million ha in 1961 to 0.80 million in 1972. The yield during the same period has decreased from 842 to 540 kg/ha. Average reduction of midsummer temperature by 3.5°C in Iceland (average 11°C), in 1970, reduced the potato yield to 8 200 kg/ha from the 5-year average of 15 000 kg/ha. Severe flooding in the Central Luzon area of the Philippines reduced the rice yield in 1972 to 1 493 kg/ha compared with 1 717 kg/ha in 1970 (Biswas, 1975). All these developments clearly indicate that world food production still depends to an unusual extent on the vagaries of weather.

In recent years, man has been depending more and more on high yielding varieties of crops to feed an ever-increasing population. One of the biggest disadvantages of these types of crops is that they need intensive energy inputs in terms of fertilizer, fossil fuels, pesticides and water to produce optimal results (Biswas and Biswas, 1974, 1975a, 1975b). Energy crisis has greatly increased the price of fossil fuels and fertilizers, and pesticides are now in short supply. If, in addition, climatic changes affect the availability of water for food production, man is in serious trouble. Without the availability of these high energy inputs, high yielding varieties of crops will generally produce less yield than the indigenous varieties they replaced under identical conditions.

It is critically important for man to develop better capabilities for predicting climate, especially of the crop climate for the coming year. Such expertise currently just does not exist, nor has adequate effort been made to develop it. There is an urgent need to develop climatological models that go beyond the present generation of physical climatic models and interface them with models of agricultural production. In the absence of a proper theoretical base, empirical studies should be conducted to understand and predict the interconnections between simultaneous climatic aberrations in various regions of the world, similar to the events of 1972. Currently, the world just does not have enough resources to handle even two to three 1972-type consecutive climatic anomalies. Such an event would result in serious world-wide food shortages and widespread starvation.

Technology transfer and use

The agricultural history of the present century is replete with examples in which straight transfer of technology from developed to developing countries, or from one region to another, has created additional problems. A few select examples are the deep-plowing of the rice paddies in Java by the Dutch, corresponding operations by the British in Burma, failure of the ground-nut scheme in Tanzania and broiler production in Gambia, and the folly of cultivating marginal lands which should never have been broken in Kenya and several Latin American countries (Biswas, 1975).

Probably the most spectacular failure was the British plan to develop large-scale groundnut plantations after the Second World War in what was then known as Tanganyika. The area selected covered 3.25 million acres, 70% of which was uninhabited, for what later turned out to be good reasons. All sorts of experts were recruited for the ambitious project. Bulldozers were extensively used to remove deep tree roots. The soil, as in several other similar cases in the tropics, could not stand up to the machines, and there were severe losses due to wind and rain. Artificial fertilizers used were not effective because of lack of water, and germination turned out to be difficult in hard-packed soil. The project was eventually abandoned after six years of desperate efforts and capital investment of some one hundred million dollars (Biswas, 1975).

Technology transfers have often not been successful because of lack of proper consideration of the social, cultural, educational, economical and ecological conditions of the local regions. But equally dismal has been man's performance to date in successfully using technology that is already available. For example, the effects of soil erosion caused by deforestation and flooding were graphically described by Plato some 23 centuries ago, and the need for terracing for agriculture on sloping land was pointed out by Bernard Palissy of France nearly four centuries ago (Biswas, 1972). And yet, any one who has travelled in Kenya, Indonesia, Philippines and many other countries, cannot help wondering why simple countermeasures like the use of terracing are not taken to prevent soil erosion. The technology has been available for centuries, it is widely known, not expensive to implement and urgently needed for medium and long-term conservation measures, and yet it is not used.

In order to improve the agricultural yields of developing countries, some form of intermediary technology is necessary (Myrdal, 1974). Intermediary technology in this context may be defined as the latest scientific and technological developments that have been adjusted to suit the local conditions to the highest possible degree. Their technologies, at the present state of affairs, must be highly labour intensive — in contrast to a high degree of mechanization in developed countries. Otherwise such developments will solve the problem of increasing agricultural yield at the cost of intensifying another, that is, sending a steady stream of migrants to already overcrowded city slums. However, it should be realized that technological developments by themselves will not be able to solve these complex problems. Simultaneous efforts must be made to change the attitudes and institutions of most of these countries that have significantly contributed to their present stagnant situation.

Technological innovations can create some problems as well. In the mid-1960s, the Green Revolution spread new strains of high yielding miracle rice and wheat strains through vast regions of Asia, Africa, Latin America and the Mediterranean nations. These quickly supplanted the native varieties, many of which have now become extinct. For example, in Greece, in the major wheat growing areas of Thessaly and Macedonia, more than 90—95% of wheat grown is no longer indigenous. Native varieties are so scarce now, the cost of recovering the genetic resources of Greek wheat will be very high, and even then it is highly doubtful if all the strains can be collected (Frankel, 1973).

Genetic erosion is quite serious at present because of the laissez-faire attitudes of most nations. This could have serious repercussions on future world food scenarios. For example, most major high yielding crops cultivated are already impressively genetically uniform, and consequently are becoming increasingly vulnerable to epidemics. Also, these strains were developed and selected during the era of cheap energy availability and favourable climatic conditions. With rapidly changing energy situations, with attendant shortages of fertilizers and pesticides, and the prospect of more widely fluctuating climates, yields from miracle grains could be significantly lower. New types of strains may have to be developed that are more flexible to available energy inputs. Thus, crop improvement is not static, it is a dynamic process of continually adjusting the genetic substance of the productive system to changing environmental conditions. Development of new strains will depend on the genetic spectrum available, and this means that the present rate of genetic erosion cannot continue indefinitely.

It is vitally necessary to provide better extension services to take available technology to the field level, and also to ensure that the steps taken provide sustained, rather than short-term, benefits. Even in developed countries, farmers' sources of information about the use of pesticides and fertilizers often turn out to be the sales representatives of the respective industries. Thus, not surprisingly, the advice is often to use more fertilizers and pesticides irrespective of marginal returns to the farmer or total costs to the society. We also need more emphasis to show farmers rational use of water, based on information we already have, rather than further esoteric research in other areas. As a rule, we have not been successful in translating research results into practice, and we have been even less successful in transferring technology from developed to developing countries, with necessary modifications to meet the local needs.

CONCLUSION

Strategies to solve the world food problem must not be developed in isolation, but in full consideration of the web of interdependence that exists with other major problems facing mankind today — those of population, availability of energy and other raw materials at a reasonable price, and lack of development. It is not in any one of them, but in the interaction amongst them, that the future of mankind will be shaped and decided. Increase in population and provision of basic human necessities to each individual means more food, energy and raw materials; intensifying the supply of food means more land, water, energy and fertilizers; the energy crisis and higher oil prices means less energy available to increase food production and fertilizer shortages; and the common denominator in virtually all responses to these problems is more capital, more technology, more co-operation and less inflation (Biswas and Biswas, 1976). Each affects and is affected by the others. The system of relationships is global in scale. That is not to say that all global problems can be met with global solutions — for there are few global solutions. But they can only be understood and dealt with in a global framework, within which there can be a wide variety of national and regional responses.

The unprecedented nature and magnitude of these problems require unprecedented remedies. The short-term strategies adopted to alleviate the immediate crisis should not foreclose long-term options. Short-term ad hoc measures are often deceptive, and could even be diametrically opposed to the long-term development goals of mankind. For example, the history of world agriculture during the period 1951 to 1966 indicates that a 34% increase in production was made possible by the following increases: 63% in farm machinery, 146% in nitrogenous fertilizers and 300% in pesticides. The empirical proportions of these increases are 1:2:5:10 (1 is the increase in agricultural production) (Meadows et al., 1973). In other words, if the present trend continues, chemical fertilizers and pesticides will accumulate in the environment at a much faster rate than food production. Continuation of such practices, in addition to being inimical to the long-term objective of increased food production, will also ensure more damages to the environment and the ecosystem, since, for some of these pollutants, damage increases at increasing rates as concentration levels rise.

All ecological systems have experienced traumas and shocks over the period of their existence, and the ones that have survived have explicitly been those that have been able to withstand these changes. They have developed an internal resilience that gives them a domain of stability. So long as the resilience is great, unexpected consequences of an intervention of man can be absorbed without profound effects. With each such intervention, the domain of stability contracts, until an additional incremental change can change the system to another state. It would generate certain kinds of unexpected consequences, for instance a pesticide that destroys an ecosystem structure and produces new pest species. We now seem to be faced with problems that have emerged simply because we have used up so much of the resilience of the ecosystems. Up to now the resilience of the systems has enabled us to operate on the presumption of knowledge that the consequences of our ignorance are being absorbed by the resilience. As the resilience contracts, traditional approaches to planning might well generate unexpected consequences that are more frequent, more profound and more global. Our future strategies to increase food production must be carefully formulated so that we do not create unnecessary perturbations in the ecological systems.

No strategy to increase food production on a sustaining basis can afford to disregard explicit considerations of environmental and ecological principles. One should also remember the vast number of public service functions rendered by the natural environment. For example, almost all potential plant pests are controlled by natural ecosystems, only those of monoculture being controlled by man. Insects pollinate most of the vegetables, fruits and flowers. Natural vegetation reduces floods, prevents soil erosion and beautifies the landscape. Thus, the strategies developed to increase food production on a sustaining basis must work with nature, and not against it.

REFERENCES

Akesson, N.B., Wilce, S.E. and Yates, W.E., 1971. Atomization control to confine spray to treated fields. Ann. Meet., Am. Soc. Agric. Engin., Chicago, Illinois. Paper No. 71-662.

Alves, W., 1958. The challenge of bilharzia in a developing Africa. Optima, 8: 139—146.

Anneche, D.H.S., 1955. Bilharzia in Transvaal. Public Health, Johannesburg, 18: 2—7.

Bardach, J.E., 1972. Some ecological implications of Mekong River development plans. In: M.T. Farvar and J.P. Milton (Editors), The Careless Technology. Natural History Press, Garden City, N.Y., pp. 236—244.

Biswas, A.K., 1965. Irrigation in India: past and present. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, 91: 179—189.

Biswas, A.K., 1971a. Sociological aspects of water development. Water Resour. Bull., 7: 1137—1143.

Biswas, A.K., 1971b. Social and institutional aspects of irrigation and drainage. In: Optimization of Irrigation and Drainage Systems, American Society of Civil Engineers, New York, pp. 261—264.

Biswas, Asit K., 1972. History of hydrology. North-Holland Publishing Co., Amsterdam, pp. 153—154.

Biswas, A.K., 1973. Socio-economic considerations in water resources planning. Water Resour. Bull., 9: 746—754.

Biswas, A.K., 1975. Climate, economic development and food production. Department of Environment, Ottawa, Canada, p. 12.

Biswas, A.K. and Biswas, M.R., 1974. Energy and the Environment: Some Further Considerations. Department of Environment, Ottawa, Canada, pp. 23—36.

Biswas, A.K. and Biswas, M.R., 1975a. Energy, environment and world development. Can. Geog. J., 91: 4—13.

Biswas, A.K. and Biswas, M.R., 1975b. Man's impact on the terrestrial ecosystem: food-energy interrelationship. Key-note lecture, International Conference of Scientists on the Human Environment, Kyoto, Japan.

Biswas, A.K. and Biswas, M.R., 1976. State of the environment and its implications to resource policy development. BioScience, 26: 19—25.

Borgstrom, G., 1967. The Hungry Planet. Macmillan Co., New York, N.Y., 446 pp.
Borgstrom, G., 1969. Too Many. Macmillan Co., New York, N.Y., 400 pp.
Boughey, A.S., 1971. Man and the Environment. Macmillan Co., New York, N.Y., 372 pp.
Brubecker, S., 1972. To Live on Earth. John Hopkins Press, Baltimore, Md.
Council on Environmental Quality, 1973. Environmental Quality. U.S. Govt. Printing Office, Washington, D.C., p. 317.
Egan, H., Goulding, R., Roburn, J. and O'G Talton, J., 1965. Organo-chlorine pesticide residues in human fat and human milk. Br. Med. J., 2: 66—69.
FAO, 1974. Environment and Development. 13th FAO Regional Conference for Latin America, Panama City, Panama, pp. 1—11.
Frankel, O.H., Editor, 1973. Survey of Crop Genetic Resources in Their Centres of Diversity. FAO-IBP, Rome, pp. 2—3.
Henning, D.H., 1974. Environmental Policy and Administration. American Elsevier Publishing Co., New York, N.Y., p. 110.
Hickey, J.J., Keith, J.A. and Coon, F.B., 1966. J. Appl. Ecol., 3: 141—154.
Jung, J., 1972. Factors determining the leaching of nitrogen from soil, including some aspects of water quality. In: Effects of Intensive Fertilizer Use on the Human Environment, FAO-SIDA, Rome, pp. 101—102.
Kovda, V.A., 1974. Biosphere, soils and their utilization. Institute of Agrochemistry and Soil Science, Academy of Sciences of USSR, Moscow, p. 35.
Kukla, G.J. and Kukla, H.J., 1974. Increased surface albedo in the Northern Hemisphere. Science, 183: 709—714.
Lanoiz, J.N., 1959. Relation between irrigation engineering and bilharziasis. Bulletin, WHO, 18: 1011—1035.
Meadows, D.H., Meadows, D.L., Randers, J. and Behrens, J.J., 1972. The Limits to Growth. Universe Books, New York, N.Y., p. 205
Myrdal, G., 1974. The transfer of technology to underdeveloped countries. Sci. Am., 231: 172—182.
Pfaff, C., 1963. Das verhalten des stickstoffs in boden nach langjahrigen lysimeter versuchen. Z. Acker Pflanzenbau, 117: 77—99.
Pimentel, P., 1971. Ecological Effects of Pesticides on Non-Target Species. Executive Office of the President, Office of Science and Technology, Washington, D.C. pp. 27—28.
Revelle, R., 1974. Food and population. Sci. Am., 231: 160—171.
Tristam, U., June 12, 1974. War on waste. East African Standard, Nairobi, p. 4.
Van der Schalie, H., 1972. World Health Organization project Egypt 10: a case history of schistosomiasis control project. In: M.T. Farvar, J.P. Milton (Editors), The Careless Technology. Natural History Place, Garden City, N.Y., pp. 116—130.
United Nations World Food Conference, 1974. The World Food Problem: Proposals for National and International Action, United Nations, Rome, E/CONF. 65/4, p. 2.