# OUR DAILY BREAD

M. A SCHWEPPENHAUSER

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M. A. SCHWEPPENHAUSER

*Department of Crop Science, University of Zimbabwe*

THE STORY OF our daily bread, in the literal sense, is older than civilization and is of prime concern today in the global context of plant food productivity. Appropriately perhaps, our story starts with the Book of Genesis, with Adam and his love for a woman in the Garden of Eden. For this error he was thrice sentenced, firstly he had his garden confiscated, and then he begat two agriculturalists.

Abel the herdsman was slain rather early in a successful career by his elder brother Cain, the tiller, who without implements, was unable to come up with the goods and expended his wrath during a now-infamous brotherly altercation. And so for the good of his soul Cain was sentenced to earn his daily bread by the sweat of his brow. This he did in the face of great floods, droughts and pestilence, and to this day crop agriculturalists are similarly afflicted.

Here endeth the first lesson!

Long before the Book of Genesis was written, ancient scribes told on stone tablets of the earliest agricultural activities. Probably the first 'schoolbooks' were tablets recording farmers' instructions to sons on how to grow and harvest the grain (Leonard, 1974). Archaeologists reach back even further so that we may use the intriguing quality of hindsight that a sense of history gives us, to revisit the beginnings of the New Stone Age and gain insight into the activities of the earliest Cains and Abels in the Nuclear Region of South West Asia.

One of the archaeological digs dates back to about 9000 B.C. at Tell Mureybit in Northern Syria (Fig. 1) where under a four-metre mound lie the remains of much of the early kindred of our modern small grains (Darlington, 1978). In different ancient village settlements along the nuclear crescent the story of the earliest tillers of the agricultural revolution has been unearthed to tell of the pre-eminence of grain-growing as the engine of human evolution. The cereals that were swept into growers' baskets were genetically greatly diverse and variable. They were amenable to selection, change and adaptation whenever and wherever cultivators took them across the Old World in a way we tend to forget now after over a hundred centuries of human migration.

The history book for this period is the Old Testament. It is the anthropological record of an extended and crucial transition from the nomadic way of our ancestors who had marched and roamed for a million years on the

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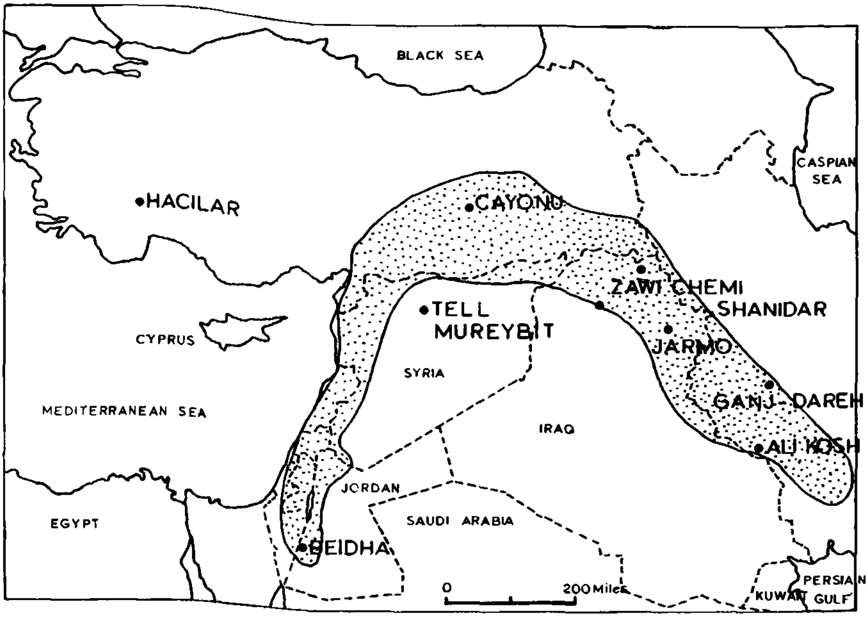


*Figure 1:* SITES OF VILLAGES ASSOCIATED WITH EARLY FARMERS IN THE NUCLEAR CRESCENT.

frontiers of the last ice age. Bronowski (1973) aptly describes the immemorial nomad's activities as one 'whose most advanced technique was to attach himself to a moving herd as the Lapps still do'. Civilization took off from the cultivator's need to settle: to nurture his grain.

Agricultural man's migrations were slow, dominated by the pace that domestication of plants and animals dictates. Man, in turn, was dominated by the plants and animals that he nurtured, for they became more and more interdependent on each other for survival. This symbiotic relationship was the physical means of man's extraordinary success, for with his biological gifts of hand and brain, he manipulated and moulded selected living forms, and so set himself apart from the cogwheels of the natural ecological system. Man's agri-culture ensured his survival and expansion, but as it turns out was also the avenue to a direct confrontation with nature and the root of his dilemma today: that of accommodating his population size to his sustainable food supplies.

*Homo sapiens* has always been a highly fertile species; he has had to be in order to survive a precarious balance between his high birth rate and high death rate for over 99 per cent of the lifetime of his species. Three developments have significantly redressed the balance in his favour, namely the Agricultural and Industrial Revolutions which have dramatically increased his ability to wrest bounty from nature, and the brilliant developments of modern medicine which have greatly reduced his death rate and extended his life span.

And now, suddenly in the last decade, a series of phenomena have culminated in the development of an awareness of a possible global confrontation with Malthusian prediction. It is widely anticipated that population growth will outrun sustainable food supplies within the time-span of one or two generations. We need to examine the evidence for this possibility against a backdrop of two scenarios, namely food-production capacity and population growth.

Whereas on a global scale the total human population is expected to double in forty-six years, the technologically under-developed countries of Africa and Latin America will predictably double in about twenty-five years—which is three times the population growth rate of technologically developed areas of North America and Europe (Chrispeels and Sadava, 1977). Population growth rate between 1970 and 1975 has slowed down by about one-third in North America and East Asia, and by almost one-half in Western Europe (Brown, 1978). In 1976 the United Kingdom and Belgium had achieved population stability whereas East and West Germany, Luxemburg and Austria had achieved negative growth rates (Brown, 1978). This demographic trend in West Germany is referred to as 'Der Pillenknick' (the pill pinch). The Scandinavian countries, France, Italy, Switzerland and the U.S.A. have birth rates below 15 per 1,000, while most Eastern European countries, the U.S.S.R., Japan, Australia and New Zealand have birth rates between 15 and 20 per 1,000 (Brown, 1978)

The lowest population growth rates, as well as achievements in decreasing these rates, generally occur in the temperate regions of the world where agricultural productivity is greatest. The highest population growth rates, generally in excess of 30 per 1,000, occur in tropical countries which incidentally also have limited agricultural productivity. It is inevitable that the food situation will considerably worsen in Africa, and Central and South America.

In a general consideration of humanity's food prospects we may recognize four biological systems: Croplands, Grasslands, Forests and Oceanic Fisheries. In that these are biologically renewable resources they form a foundation to the global economic system. It is essentially to croplands that humanity must look for future increases in food supply, particularly in the three staple cereals (wheat, rice and maize) to which over half the world's cultivated land is devoted and which constitute the largest proportion of plant foods produced (Fig. 2).

All plant foods combined provide an estimated 88 per cent of the calories (carbohydrates and fats) and 80 per cent of the protein that human beings consume on a global basis and the balance is derived from animal products (Chrispeels and Sadava, 1977). This situation applies particularly to the underdeveloped countries, in contrast to the affluent countries of North America, and to some extent Europe, where more or less half of the protein consumed may come from animal products. When any one of the grains is consumed as a single staple it is likely to lead to protein malnutrition because grains are generally deficient in one or two of the amino acids essential for growth and health.

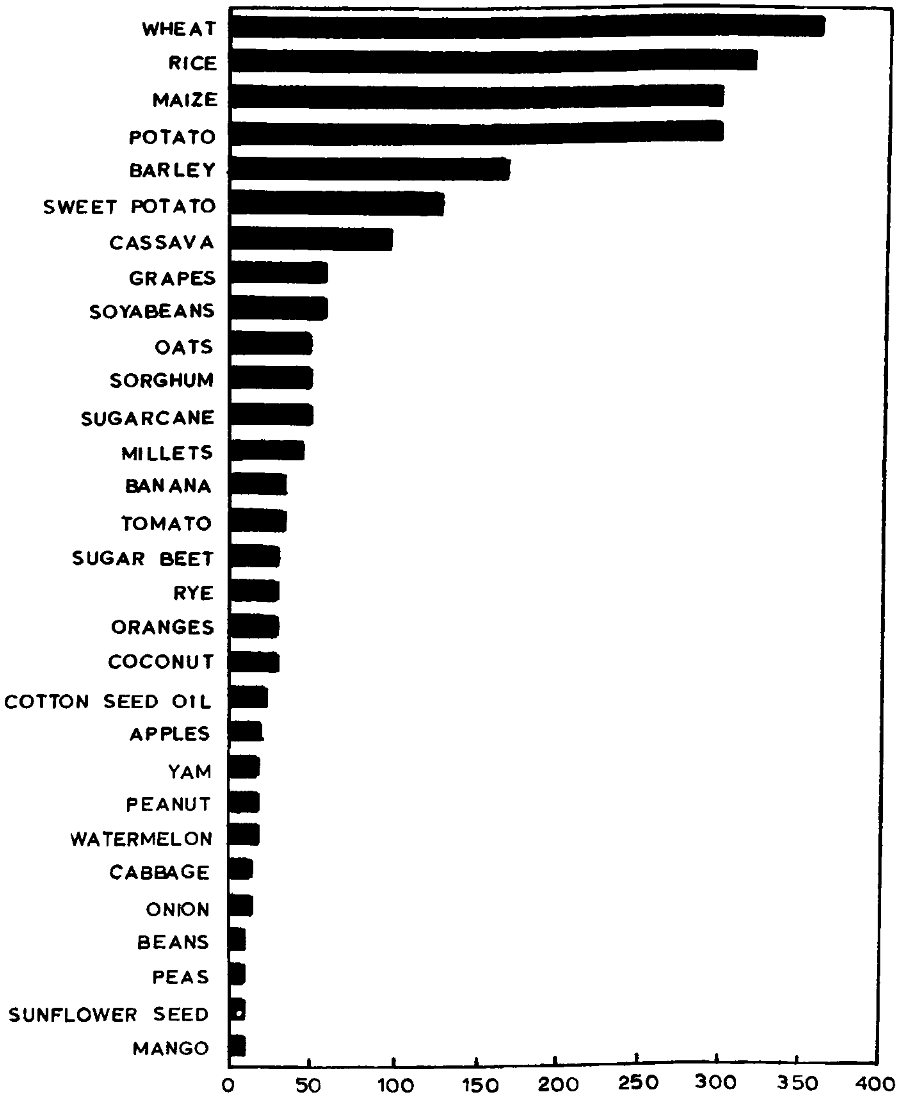


*Figure 2:* APPROXIMATE ANNUAL PRODUCTION OF PLANT FOODS (MILLIONS OF METRIC TONS).

In contrast to wheat and rice, which is consumed directly by man, about three-quarters of world maize production is fed to livestock, especially in the U.S.A. and Canada, but also in France, Italy, the United Kingdom and the U.S.S.R. (Chrispeels and Sadava, 1977). Conversion of plant protein to animal protein for human consumption is expensive, especially for non-affluent societies, as only 10 to 30 per cent of the energy ingested in the grain is available to the next consumer — man. The rest is used up in metabolic, muscular and nervous activity.

To put this in theoretically quantitative terms the present world plant-food production could at best support either 15 billion (15,000,000,000) vegetarians or about 5 billion people who derived half their energy and protein from animal products. On a unit of land basis, 1 hectare could support 14 vegetarians or 4 to 5 people on the mixed diet. Given the present increases in world populations, humanity's lot will increasingly be with plants as the major source of food, supplemented with animal food products that will differ in each country to the extent that agricultural and population policies and good management will allow.

The 'poor man's' meat is the protein-rich seed of legumes which derive most of their nitrogen from bacterial fixation in the roots. The most protein-rich legume is the soya bean which has undergone extensive increase in world production in recent years, especially in the U.S.A. where about two-thirds of the world crop is grown. China grows about one-fifth of the world crop of soya beans and Brazil grows about one-seventh. Soya beans are grown for animal consumption, while human consumption is at present limited to the oil by-products.

Increased demand for soya beans led to a doubling of the world price in 1973 and more and more land converted to soya production. For example in Brazil a considerable area of land normally devoted to growing table-beans, the staple protein diet of the low-income masses, has been converted to soya beans in recent years, and exemplifies the fact that world trade is not usually concerned with nutrition. Furthermore any means which promotes the acquisition of foreign currency for the purchase of petroleum has become of prime concern in international trade.

The Soviet Union has become one of the principal importers of soya beans although not to anything like the extent of her importation of wheat from North America. The U.S.S.R., forced by her increasing population to produce more wheat, opened up new wheat-growing areas north of the forty-ninth parallel in areas which have insufficient rainfall and harsh winters. A series of massive harvest failures (Fig. 3) led to the large Soviet purchase of American wheat in 1972, and brought to an end the era of large surplus world food stocks. Furthermore subsequent Soviet grain contracts made with North America, which commands over 96 per cent of the world export wheat trade, helped put an end to the era of American food aid to underdeveloped nations, and also helped push the world price of wheat from US$2.00 per bushel in 1972 to nearly US$5.00 per bushel by 1974.

Concerned non-affluent countries of the Third World, now virtually starved of North American food aid, demanded increased food handouts at the 1974 World Food Conference. These same countries, at the World Population Conference in the same year, rejected suggestions that they should curb their rapid population growth rates. Also at about that time a four-fold increase in the price of petroleum heralded the energy crisis. The food situation was considerably exacerbated by the serious downturn in world grain reserves (Fig. 4).

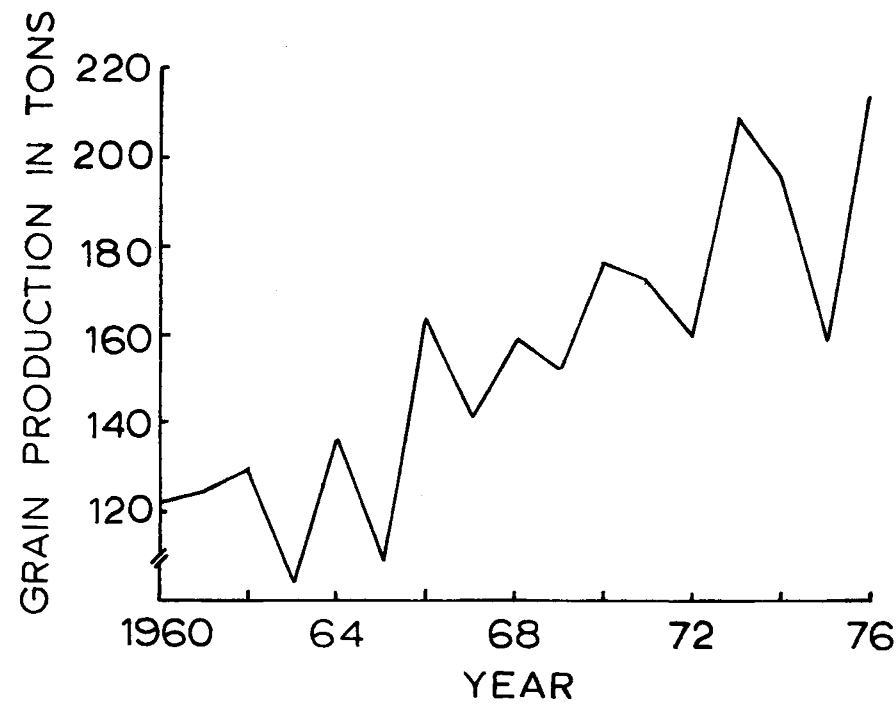


*Figure 3:* GRAIN PRODUCTION IN THE U.S.S.R. (*Source:* Chrispeels and Sadava (1977), 223).

The under-developed countries have been left largely to fend for themselves in a situation described by ecologist Garret Hardin (1974) as 'lifeboat ethics'. This situation depicts a series of lifeboats occupied by the developed nations. The people of the Third World, hungry and in deep water, must be prevented from getting into the boats lest everyone drown. The face of morality shifts in the light of a transforming world food economy.

Meanwhile world grain yield per hectare is levelling off at a time when it is taking only eleven years to add the fifth billion to the world population, and when the list of food-deficit countries reads like a United Nations roster. The stork has caught up with the plough.

Increases in plant food production may be achieved either by increasing yields on the same land area or by expanding the land area. Increased productivity by yield agriculture has been a fairly widespread world-wide phenomenon for the past three decades. The principal areas of high-yield agriculture are also those with the smallest potential area increases, namely North America, Europe, China, Japan and South-East Asia. A few developing countries in South America and Africa have achieved relatively modest increases in grain production via both avenues.

The classic instances of countries turning to yield agriculture are Japan in rice production and the U.S.A in maize production. The Japanese success occurred as a result of national mobilization of political, social and scientific

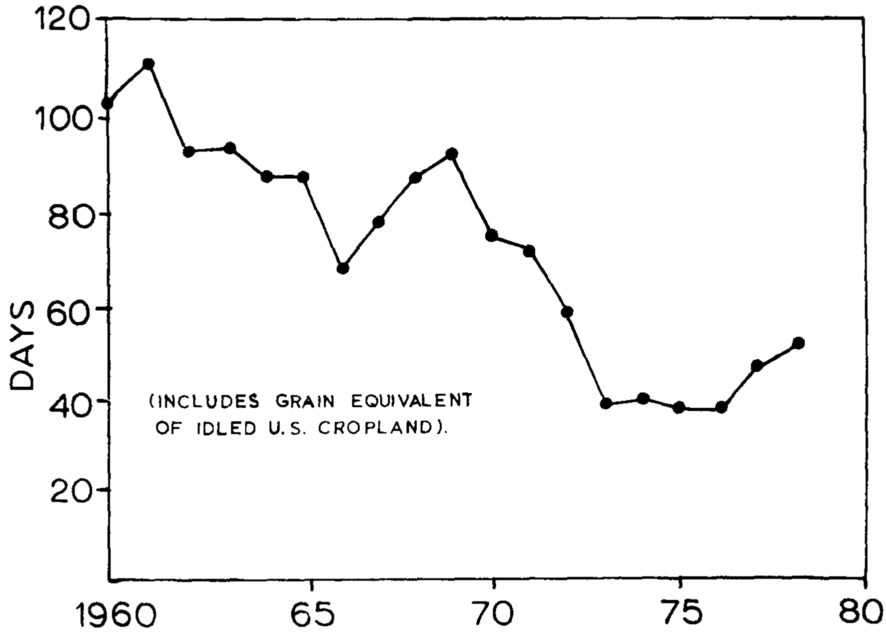


*Figure 4:* WORLD GRAIN RESERVES AS DAYS OF WORLD CONSUMPTION, 1960 - 78 (*Source:* Brown (1978), 132).

resources, whereas the American achievement was mainly due to the breeding of new genetic hybrid varieties backed up by advanced scientific crop-production practices. High agricultural productivity in the temperate and sub-tropical regions of the northern hemisphere is generally the result of advances in yield agriculture to the extent that yields are closely approaching the maximum biological ceiling for high productivity. In terms of the S-shaped biological growth curve (Fig. 5) the point of inflection where progressive acceleration gives way to progressive deceleration appears to have been generally reached for grain productivity outside the tropics. It is pertinent to note that it is in these regions that significant reductions are being achieved in human population growth rates.

The most critical situation concerning increasing food deficiency is occurring in under-developed tropical countries in terms of a widening gap between food production and food consumption (Fig. 6). Conversely these areas, particularly Africa and South and Central America, have by far the largest world reservoir of uncultivated arable land (Fig. 7) mostly in the form of woodlands and forests. If these areas were brought into crop production it would be possible to at least double or even triple the existing 1.3 billion hectares of land cultivated in the world today.

There are, however, major constraints to crop expansion in the tropics. Firstly the continuous cropping system so successful in temperate zones is

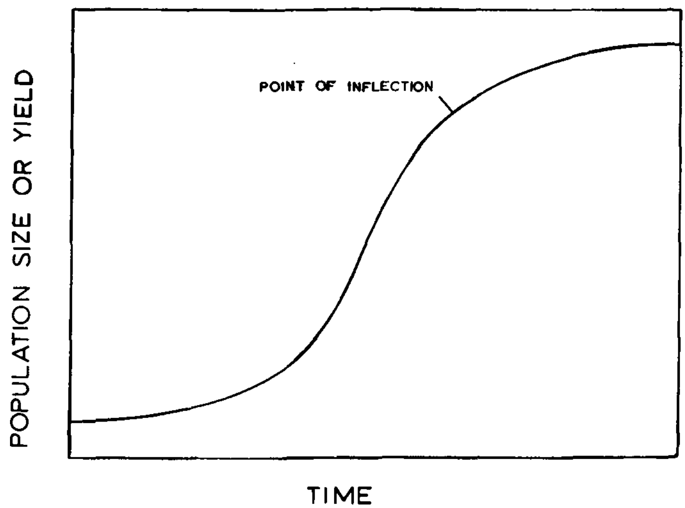


*Figure 5:* THE S-SHAPED BIOLOGICAL GROWTH CURVE.

seldom successful in the tropics for a variety of reasons of soil and climate. There is for example an overabundance of highly weathered soil in the tropics, and a disproportionately large share of available nutrients resides in the dense vegetation cover. Removal of this cover by deforestation and cultivation leads to a removal of nutrient supply, loss of residual soil fertility by leaching, rapid oxidization of organic matter in soils exposed to the sun, and a tendency for considerable soil compaction.

Tropical agriculture also has to contend with a host of pest and disease problems typical of warm climates. Futhermore, particularly in Africa, droughts are periodic, dry seasons are long and warm, and rainfall is unevenly distributed and of high intensity. To these natural constraints must be added the prohibitive cost of converting land to agriculture and the building of a complex agricultural infrastructure with its transport requirements, marketing systems, credit institutions, technical advisory needs, and research and education organizations.

There are nevertheless a few tropical countries where a sufficiently developed agricultural infrastructure existed along with unusually good irrigation potential and sufficient Government support to enable the so-called 'green revolution' to occur. This was an area in some developing countries characterized by the introduction and spread of new high-yielding short-strawed varieties of wheat and rice. Outstanding plant-breeding achievements gave the new varieties a package of new genes: (a) for short straw less prone to lodge, (b) for efficient utilization of up to three times higher doses of fertiliser

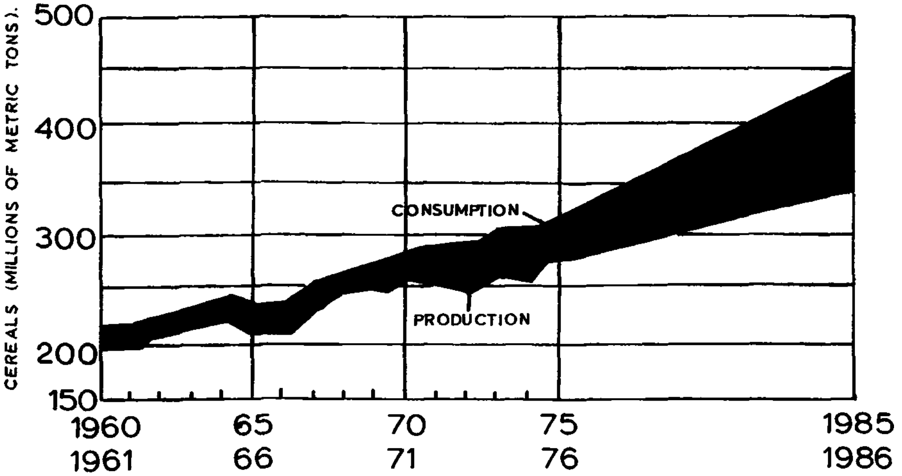


*Figure 6:* WIDENING GAP BETWEEN FOOD PRODUCTION AND FOOD CONSUMPTION IN DEVELOPING COUNTRIES.

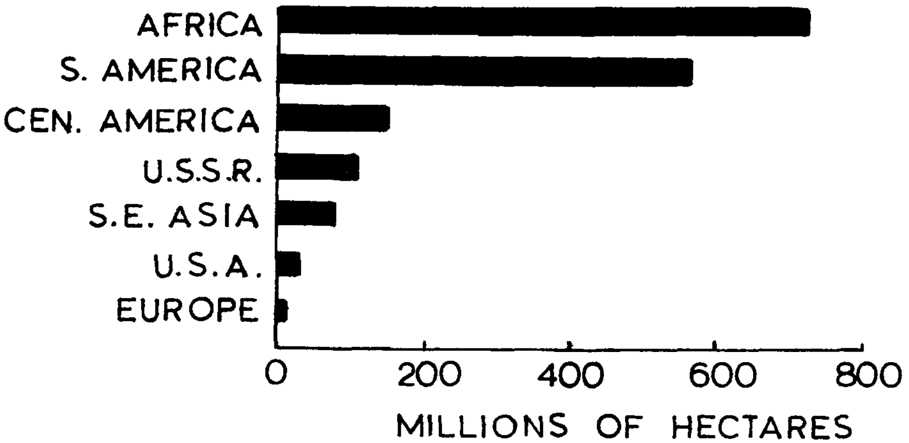


*Figure 7:* UNCULTIVATED ARABLE LAND IN THE WORLD (*Source:* Crispeels and Sadava (1977), 141).

compared with the old commercial varieties which sometimes decreased in yield with higher fertilizer inputs, (c) for resistance to several pests and diseases, and (d) for inherent adaptability to a wider range of climatic conditions.

By the late 1960s about 13 million hectares had been planted to the new 'miracle' varieties and had expanded the Asian food supply by about 16 million tons, or enough to feed about 90 million people (Brown, 1978). Massive famine was further allayed by expansion of the green-revolution into the mid-1970s at a time when food-aid from North America was being effectively cut off for other reasons.

The impact of the green revolution in individual countries was miraculous.

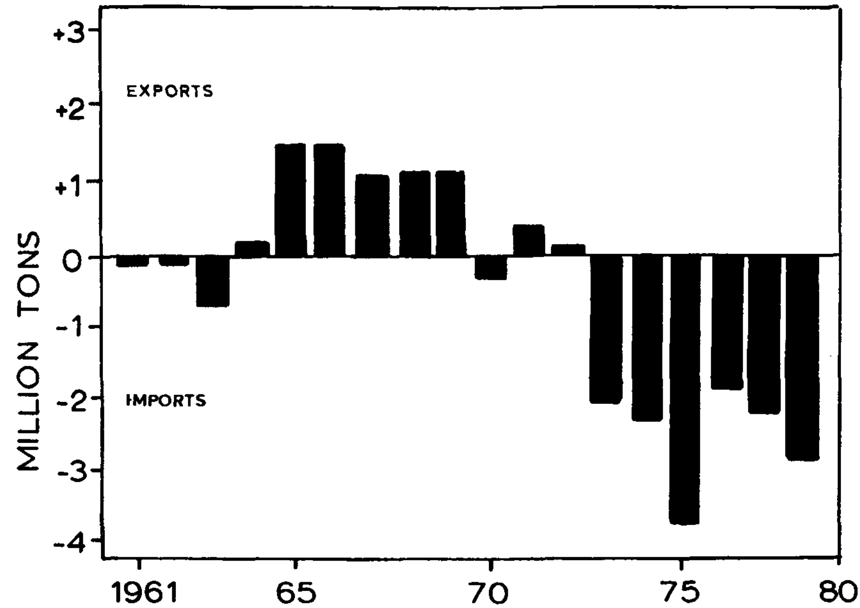


*Figure 8:* MEXICO : NET GRAIN TRADE, 1961 - 78 (*Source:* Brown (1978), 149).

In India wheat production doubled in the six-year period 1966 - 72, and Mexico and Pakistan achieved similar dramatic yield increases in wheat production. In a similar time period Columbia more than doubled its rice production on the same hectarage planted, and other green-revolution countries such as Sri Lanka, Indonesia, Malaysia, and the Philipines followed suit.

Like that celebrated phenomenon in Physics, it was a quantum jump, and rivalled the story of an even earlier miracle when the five thousand were fed with two fish and five loaves of bread. The leader of the green-revolution team of plant breeders, Nobel Laureate Dr Norman Borlang, had predicted (Brown, 1970) that the green revolution would buy time, perhaps ten or twenty years, during which Governments could bridle population growth. Alas, it acted more like a fertility pill! Population is again outrunning food supply in country after country. For example as Mexico's high population growth rate continued its inexorable path she turned from a grain exporter in the last half-decade of the 1960s to a substantial grain importer in the 1970s (Fig. 8), and treads a well-worn path for sustenance to her northern neighbour.

Only China used the reprieve as Borlang envisaged, by launching an effective family-planning programme, boosting its food supply with the miracle varieties of wheat and rice, and damming and diverting rivers to bring one-third of her arable land under irrigation.

The green revolution which took off with such success and optimism, was hit by global economic constraints related to energy costs which affected fertilizer prices in particular, and ran out of countries with the necessary resource potentials. By this time only Mexico had completely converted to

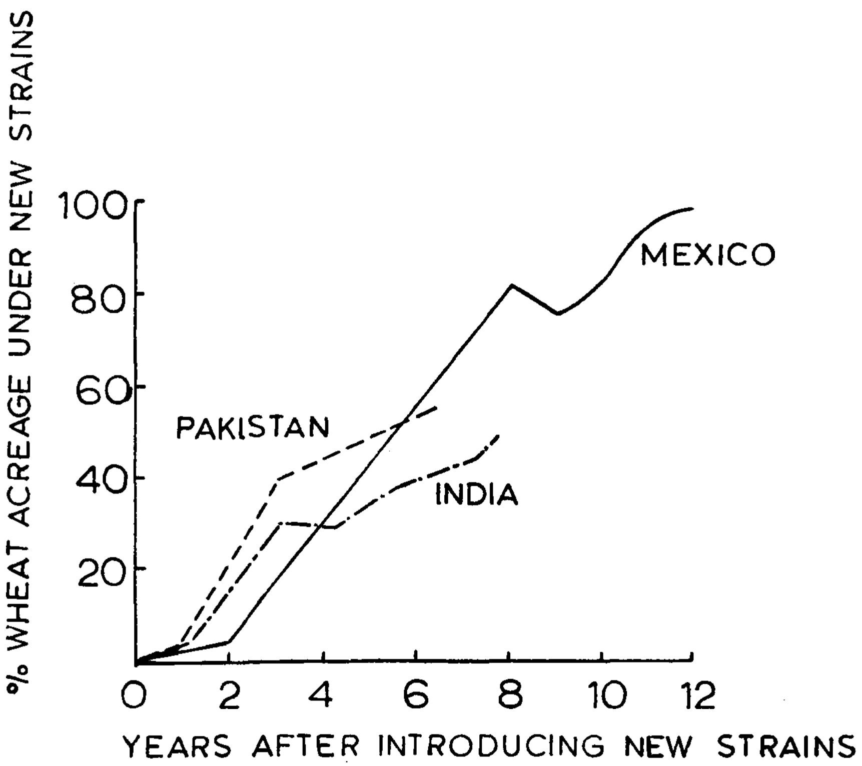


*Figure 9:* CYCLES OF ADOPTION FOR HIGH-YIELDING VARIETIES OF WHEAT (*Source:* Chrispeels and Sadava (1977), 212).

the high-yielding strains (Fig. 9), while other countries such as India and Pakistan, having received massive economic support from their Governments, are faltering at the half-way stage, in the face of rapidly increasing production costs.

Any assessment of the potential of tropical countries in particular, and the world in general, to increase its plant-food productivity commensurate with increasing human aspirations must take into account several important constraints to crop productivity, such as soil erosion, deforestation, overgrazing, loss of cropland, air pollution, increasing energy costs, and pests and diseases.

In any brief survey of such constraints soil erosion must be accorded a fundamental priority. While plants are the primary producers in food chains, the soil is the placenta for their growth. Misuse of soils invariably leads to its removal by water and wind — and this constitutes the oldest lesson in agriculture, going back to the now desiccated but once most fertile area of the nuclear crescent. It is also the most important lesson to be learned if the fragile ecosystem of tropical agriculture is to be intelligently utilized for sustained crop productivity.

Often the first step to soil erosion is deforestation. The French philosopher

Chateaubriand (quoted by Brown, 1978) knew this when he said, 'The forests come before civilization, the deserts after them'. The global scale of conversion of forests to fields and grasslands by 1970 was estimated (Ehrlich *et al.*, 1977) to be between 18 and 20 per cent of the area of continents, although this has considerably increased during the 1970s by rapid deforestation in tropical zones.

For at least one-third of mankind firewood remains the poor man's oil; and like its liquid cousin, resources are rapidly dwindling, especially where the vast majority of the population in developing countries, such as Zimbabwe, are fuel-wood users. Furthermore, unlike the U.S.A.and U.S.S.R.which still exercise good forest-management programmes, the majority of countries have not backed long-term national forestry plans with sufficient funds or political commitment. The world-wide escalating cost of newsprint attests to an unhealthy relationship between the level of demand and the sustainable yield of forests. Other than the fact that firewood is still a principal energy source in under-developed countries, wood is a primary building material everywhere. Furthermore paper is the principal raw material for the bureaucratic world, and for the expanding world of literacy and education.

Forests constitute one of humanity's most valuable but most heavily cropped and exploited resources. Throughout the Middle East, India, South East Asia, Africa and Central and South America, in almost every country undergoing rapid population growth, deforestation is under way on an increasingly intensive scale.

In many of these areas overpopulation has forced farmers into the hillsides, and taking agriculture uphill is a losing proposition because soils tend to be marginal and erosion is rapid. As the topsoil washes downhill the people are never far behind. One of the first consequences of deforestation is annual downstream flooding and this is occurring today on a scale as never before, particularly in Iran, India, Pakistan, Nepal, Ethiopia, Nigeria and, more recently, Brazil; and the result is a considerable loss of croplands and grasslands.

About one-third of the world's remaining natural forest lies in that half of Brazil which constitutes five million square kilometers of the Amazon Basin. In an attempt to settle about five million peasants on new 100-hectare farms the Brazilian Government allowed about one-quarter of the forests to be cleared (Lewis, 1979). Deforested areas which had previously recycled half of the rainfall quickly lost their thin humus cover to expose unproductive laterite soils which the new farmers cultivated unsuccessfully.

The scheme floundered in the face of a lack of relevant agricultural training and advisory assistance, which was the only way of coming to terms with a new and difficult tropical environment, and serves as a lesson to all tropical countries under pressure to open new areas for peasant agriculture. The exodus of the Brazilian peasant farmers was assisted by other elements of a hostile environment in the form of a formidable array of stinging insects, reptiles and unfamiliar sicknesses. Areas cleared and planted to African grasses for ranching have been successful where annual fertilizer inputs were sufficient to maintain the required level of fertility, but cutbacks in fertilizer applications due to increased energy costs have inevitably led to considerable grassland deterioration, overgrazing and soil erosion.

The practice of overgrazing is as old as agriculture, and constitutes a serious constraint on world crop productivity, not only in the sense that the best grazing land is being made over to cropland, but also in that it results in a deterioration of the animal-based industry which provides draft energy for about one-third of the world's croplands. In arid areas overgrazing often leads to desertification as is occurring in parts of the sub-Saharan countries of Africa where the current ecocatastrophe from overgrazing is making ecological refugees of hundreds of thousands of herdsmen as thousands of hectares of range and cropland are lost each year. It is a formidable task to persuade herdsmen to decrease their herds to suit maximum-carrying capacities. This situation, described by Hardin (1968) as 'The Tragedy of the Commons', is as real and insoluble today as it was when first propounded by Lloyd (1833).

Loss of cropland, by whatever means, is also becoming a major constraint on crop productivity in developed agricultural societies in temperate regions. Thus the United States Council for Agricultural Science is concerned that loss of cropland due to loss of topsoil will lead to an extensive decline in their agricultural productivity by the end of this century. This loss may be partly ascribed to putting fallow land back into production to help meet increasing world demand for grain. In the American Mid-West severe dust storms, reminiscent of the Great Dust Bowl of the 1930s are not infrequent. Furthermore thousands of hectares of arable cropland are lost each year to highways and urbanization, particularly in North America and Europe.

The human prospect is tied to the size and condition of its cropland base. It is the foundation not only of agriculture but of civilization itself, and each year a part of this life-support system is washed away, blown away, scraped away or covered away. In technologically developed countries another way of covering croplands is with polluted air. Resultant declines in yields can be high and tend to vary from crop to crop as shown in Table I derived from Californian data (Brown, 1978). Potential damage of this kind to crop yields in the U.S.A. is predictable to the extent that data is available concerning number of potential days of air pollution and the extent and concentration of acid rain (Ehrlich *et al.*).

The most serious recent constraint on crop productivity is that of rising energy costs. Over half of world agriculture is highly energy-intensive in that mass production is achieved by mechanical means in land preparation, planting, cultivating, irrigating, and harvesting. The most energy-demanding requirements in crop production are concerned with the manufacture of nitrogenous fertilizer and pesticides. Compared with agriculture in the developed countries of North America and Europe, the agriculture of Africa and South America uses an almost negligible amount of fertilizer. With rising costs of fertilizer the trend in the Third World is actually to import less fertilizer than before.

The energy crises will predictably adversely affect potential grain productivity in North America. For example in the U.S.A., where the energy consumption per capita is double that of the next highest consumer, the pattern of energy consumption is rapidly increasing despite decreasing U.S crude oil production. The U.S.A. is thus in a real energy predicament and faces an uncertain future with only a small share of proven world reserves of crude oil. Canada is no better off. The ability of North America to continue to be the breadbasket of the world, and to continue to export large quantities of grain, particularly to the U.S.S.R., is questionable.

*Table I*

YIELD DECLINE DUE TO AIR POLLUTION (CALIFORNIA 1977)

| *Crop* | *% Decline in Yield* |
|---|---|
| Alfalfa | 38 |
| Beans | 32 |
| Lettuce | 42 |
| Sweetcorn | 72 |
| Radishes | 38 |
| Ponderosa Pines | 75 (over 30 years) |
| TOTAL ANNUAL CROP DAMAGE = US$25 million | |

*Source:* Brown (1978), 42.

Even though over half of world agriculture is energy-intensive only about one-quarter of the energy used in the food system goes into the on-the-farm production phase. The rest — and this is where some opportunity exists for conserving energy used in food production — goes into the distribution end of the system: transport, processing and packaging. It is not unusual that the package in which the food is wrapped embodies more energy than the food itself. The cost of superficial glitter in packaging is a form of waste of energy that applies to many commodities besides food.

Nevertheless the largest constraint on crop productivity is not energy but pests and diseases. At least 50 per cent of the world's total crop production is lost each year (Russell, 1978) through insects, nematodes, fungi, bacteria, viruses, vertebrate pests and parasitic weeds. Each crop has its share of pests and diseases; rice, for example, has sixty-six diseases (Table II), and is probably typical of most major crop species. Pests and diseases tend to be natural parasites which have evolved with the species.

Modern crop agriculture rests on vast acreages of homogeneous plants growing close together, with a genetic rigour that makes 100 million plants shoot on the same day, be ready for harvest on the same day, and each have the same innate capacity for a host of morphological and physiological characteristics that regiment yield and quality.

*Table II*

DISEASES OF RICE

| *Agent* | *Plant Organ Attacked* | *No. of Diseases* |
|---|---|---|
| Virus | leaf | 12 |
| Bacteria | leaf | 4 |
| Bacteria | grain | 3 |
| Fungus | leaf | 11 |
| Fungus | stem, root | 10 |
| Fungus | seedling | 5 |
| Fungus | grain | 10 |
| Nematodes | root | 11 |

*Source:* Chrispeels and Sadava (1977), 162.

And yet, this very hard-won genetic uniformity, so essential for commercial agriculture and the daily bread of billions of people, constitutes the Achilles heel of crop productivity. Diseases can spread like wildfire, attain epidemic proportions, destroy homogeneous plant-food supplies within days, and persist from season to season. Agricultural literature abounds with examples of crop destruction by diseases, such as blight epidemics in potatoes and oats, and more recently in maize, and numerous rust epidemics in wheat. There are many instances of disease epidemics in many crops in many countries.

Breeding disease-resistant varieties has greatly put the brake on the destruction of crops, but some disease organisms, particularly fungal types, have their own genetic equipment for survival which can more than match man's attempts to outwit them in the process of engineering resistant genes into previously susceptible cultivars. The parasite has all too frequently demonstrated an ability to selectively side-step such breeding achievements on a gene-for-gene basis. Like chess, it is a tit-for-tat reaction, but with the parasite always one step ahead owing to its chameleon-like mutational armoury. For over half-a-century North American wheat breeders in particular have waged this battle, and always on the defensive. Fortunately this chain-reaction situation does not apply to all plant diseases.

But of all the long-term goals in crop science which could result in food productivity, no investment will pay greater dividends in raising the standard of living and health throughout the world than the continued development of disease-resistant crop varieties. Inevitably this will go hand in hand with the use of pesticides but, it is hoped, chemical control can be minimized. Although often essential, pesticides tend to be increasingly expensive, have inherent problems concerned with residues and pollution, and demand high standards of control and monitoring.

From instances of breakdown in disease resistance we are learning that man is not the supreme ruler of living matter. It is not possible to obliterate diseases at will by breeding for immunity against them. Our humility has been hard-won in this respect and has led us to learn to live with our plant parasites. Nevertheless instead of giving them free rein to live and reproduce, the aim is to achieve a level of genetic resistance in the host plant so that small populations of parasites may survive in circumstances where their reproductive potential is limited. Would that we could find a similar recipe for human populations!

The hope and promise of achieving increased productivity, particularly in food crops, is greatest when disease resistance is sought against many economically important pests and diseases simultaneously. Hence multiple-disease resistance must head the list of long-term crop-science goals:

Multiple disease resistance,
Increase nutritional quality,
Rechannel primary productivity,
Improve nitrogen fixation,
Maximize photosynthesis,
Aqua-culture of kelp,
Processing of plant proteins,
Substituting animal product analogues,
Processing leaf protein.

In all the centuries of plant manipulation we have consciously or unconsciously shuffled and reshuffled the gene pools of plants and subjected an infinite diversity of gene combinations to the formidable forces of artificial selection. Man and not nature has been the arbiter of fitness and has developed plant architectures that nature would not tolerate on her own. In the process we have unwittingly discarded a multitude of genes that could now be useful to us in pursuing our long-term crop-science goals. And so we are retracing our steps now, back to the centres of origin and diversity in different continents to collect the ancient and possibly valuable weed parents of our modern crop species.

On creating these germplasm banks we are beginning to rediscover the bounty of nature, by finding genes for multiple-disease resistance and greater nutritional quality. We are already producing varieties of maize and sorghum with increased concentrations of the generally deficient amino acids, lysine and tryptophan (Table III).

The man-made evolution of crop plants has largely been an exercise in channelling a higher proportion of primary productivity into the reproductive organs, such as increasing the size of the maize cob from about one inch to more than one foot in length over a period of three thousand years. Using modern knowledge in plant physiology and genetics this re-channelled development process is continuing even although it may seemingly be at a comparative crawl on the frontiers of scientific knowledge.

Because yields are approaching maximum ceilings of known genetic potential in many crops cultivated in the best agricultural regions, and because these same crops are in fact being grown and will increasingly be grown in marginal areas throughout the world, the emphasis in research is now starting to incorporate this hitherto largely neglected area. One aim is to breed plant strains with an improved plant - water efficiency, where for example a smaller transpiration ratio might be useful. There is considerable potential for research gains in this area of investigation.

*Table III*

AMINO ACID CONTENT
(% OF PROTEIN IN MAIZE AND SORGHUM)

| | *Lysine* | *Tryptophan* |
|---|---|---|
| Normal Maize | 2.7 | 0.7 |
| Opaque - 2 Maize | 4.0 | 1.3 |
| Normal Sorghum | 2.0 | 0.9 |
| High-Lysine Sorghum | 3.3 | 1.7 |

*Source:* Chrispeels and Sadava (1977), 201.

A difficult but exciting area now being researched, is the increase in efficiency of nitrogen-fixing organisms in the roots, even in non-leguminous plants. Some grasses are now known to be capable of this symbiosis, and since our major crops are essentially grasses, the argument goes, why not give them the relevant genetic ability for nitrogen fixation? The consequences would be revolutionary in terms of reduced nitrogenous-fertilizer requirement. At this stage it is a theoretical possibility rather than a probability, as many complex problems will first need to be resolved.

One of the most important advances that might be made would be to maximize photosynthesis. All living entities are in a sense heliophagus (sun-eating), for we ingest daily, or burn as fuel, products of the radiant energy that has flashed across the void of space since, as Genesis correctly puts it, the earth was without form and void.

We are predominantly a water-covered planet, and the sea traps three-quarters of incoming solar energy. The chain of life begins here in nutrient-rich coastlines — that lambent-blue-green area about one-fifth the size of the land masses. Energy conversion by photosynthesis begins with the tiniest of plants, phytoplankton, which are consumed by zooplankton and then in turn by crustaceans and fish, and so on up the trophic scale. Life and death at all levels creates a rain of organic detritus which over millions of years forms thick blankets of globugerina ooze on the ocean floor. Under great pressure and heat these layers form into gas and the oil that provides petroleum energy.

In 1818, the poet Byron could write:
Man marks the earth with ruin,
His control stops at the shore.

But in this century we have breached and extended our boundaries to embrace the underwater resources contiguous to our coastline. Today we go down to the sea to acquire this ancient energy, for we need it to win our daily bread.

With optimism we had thought in the 1950s and 1960s that the largess of the sea would provide almost unlimited food for humanity's future needs, but in 1970 we achieved the maximum sustainable yield from the ocean. These off-shore and upwelling zones which provide our fish catch (90 per cent of the ocean is a biological desert in this regard) also comprises humanity's largest dumping ground for waste products, and the highway for oil tankers which have been described as 'accidents looking for a happening'. Without such pollution it is possible that commercial fish yields could double, but such a prospect is unlikely to eventuate.

Meanwhile overfishing of the oceanic 'commons' has become a pervasive global problem since catches of most of the thirty-odd leading species of table-grade fish has either attained or passed the point of inflection on the S-shaped biological growth curve. Despite their large fishing fleets, Japan and the U.S.S.R. are supplementing their declining yields of oceanic protein with larger imports of feed grains and soya beans to sustain their livestock production.

Fishing is achieved by hunting, and on land this is a paleolithic occupation. Not surprisingly, some claims have been made that an aquaculture revolution —shades of its agricultural predecessors perhaps—is in the making. At present aquaculture provides about four per cent of the global fish harvest but estimates are that not more than a tenfold increase is possible (Bardach *et al.*, 1972). Aquaculture for plant production is a further possibility by processing kelp into carbohydrate-based foods. The U.S. Navy is working on a 100,000 acre kelp farm to be in operation by 1985 (Chrispeels and Sadava).

Seaborne enterprises notwithstanding, the earth is a plant-oriented planet, and the land will continue to be the traditional supplier of most human food. As pressures of exploitation of arable land increase man will turn to using more processed foods. In terms of processing protein-rich foods, the most promising are soya beans, groundnuts and cottonseed. When man learns to process a better quality flour for cooking, this food source could theoretically develop into a multi-million-ton industry, especially in the more under-developed countries. However, as experience has shown to date in South America and Southern Asia, we have a long way to go before we learn to make these foods acceptable even to hungry people.

Animal-product analogues are also catching on, following the successful substitution of margarine for butter, vegetable oils for lard and plant products for dried milk, cream and whipping cream. The production of plant-derived meat analogues is experiencing early successes in terms of consumer acceptability, costs of production, nutritional value and long refrigeration-free shelf-life. One method is to heat mixtures of wheat, soyas and milk solids and form them into frankfurters or bologna. Another method is to gel an aqueous paste from soya bean protein, wheat, oils and flavours and use as a sandwich spread. A third method involves producing soya protein fibres coated with proteins, fats, vitamins, minerals, colouring and flavourings and bind them together into nutritious cubes, slices or granules. As much as 20 per cent of all processed meat in the U.S.A. will probably be replaced by soya bean-based meat analogues within the next year.

Another promising recent food-source innovation is the processing of protein from leaves. Leaf protein is the world's largest source of readily available protein and is already being processed for use in animal feeds. Furthermore a colourless, tasteless leaf-derived 95 per cent protein powder is now being tested as a nutritious additive in beverages and foods (Chrispeels and Sadava). Yields of 25 tons of protein per hectare are possible from wheat and barley leaves and this food source could have a significant impact on human nutrition. No doubt we will be consuming such protein in one way or another in the near future, relatively cheaply, and probably without undue knowledge or concern as to its source. Such protein is also likely to arrive in human foods long before single-cell protein from micro-organisms, where considerable research remains to be done before large-scale commercial feasibility can be achieved.

In the face of rapid population growth, and given that long-term crop-science goals and food additives could achieve a significant measure of increased food productivity and nutrition, what are the food prospects for humanity? There is no unequivocal answer and can be none until populations stabilize. If the projected United Nations pattern of population growth in the major areas of the world (Fig. 10) is anything to go by, then it would mean feeding about twelve billion people, that is three times the existing population. If every hectare of arable land in tropical countries were brought into full-scale high-level production, it might be theoretically possible to feed such a world population. However, the practical realities of the 1970s belie such an eventuality on a world-wide scale.

In the first place international constraints, economic and physical, have rapidly reduced world food trade, and this trend will inevitably continue. Each country will therefore be increasingly pressurized to achieve its own food - population balance, and create its own food reserves to meet inevitable harvest failures. Greater priority will be given in national budgets for rationalized agricultural development. Furthermore, irrespective of any success in population policies, there will be a long lag-period during which the rapidly increasing population will need to be fed, and the soil will be the major supplier of such food.

During our lifetime, cheap energy has shaped the global economic system, helped multiply and remultiply the output of food, and goods and services, and generally sighted the aims and expectations of the masses at levels which cannot be sustained. In every sense it has been a growth ethic. The 1970s have, however, proved to be the hinge-period in modern history. It has been a decade of discontinuities, in terms of the energy crises, food shortages,

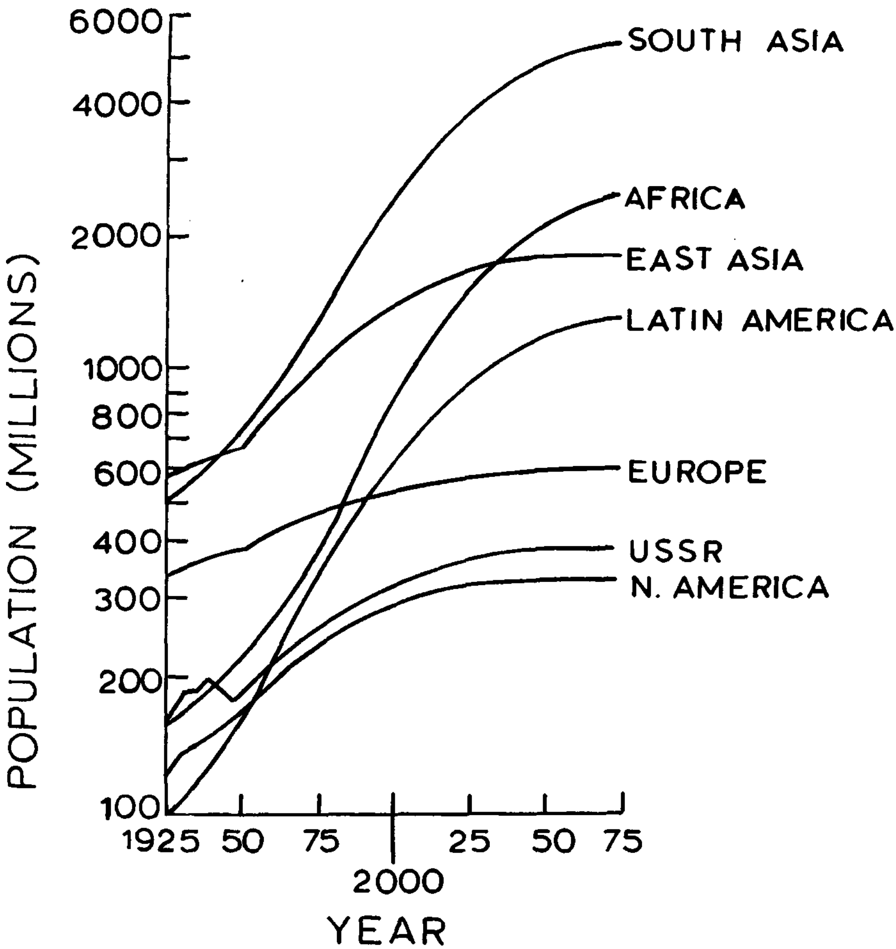


*Figure 10:* PROJECTED POPULATION GROWTH IN MAJOR AREAS OF THE WORLD (*Source:* Ehrlich *et al.* (1977), 226).

rapidly increasing food prices, the levelling off of the world fish harvest, excessive deforestation, loss of cropland through flooding and urban sprawl, a turnabout in the international political power structure, and excessively high global inflation and economic decline.

The new international ethic that is emerging is one of accommodation to the earth's biological systems. Unrestrained materialism is giving way to conservation. Profound social changes are in the making and will exercise increasing pressure for the implementation of more effective political management. Food will stand alongside energy in terms of power. The origins of this change are to a large extent ecological, but the impact of such change will be in the social and economic fields. The processes of achieving change, as has been demonstrated in the agriculture of Japan and China, are political.

The tools of Government have no rivals, in terms of legislation, budgetary taxation, fiscal policies, and the analytical and eduational capacities of its institutions. Power now walks side by side with responsibility as never before.

If history is anything to go by, there will continue to be a succession of scientific developments and inventions which other men can learn, copy and utilize for the creation of rewarding environments. It is the variables in human intelligence and skills that make it difficult to predict the future of any country with any accuracy. Those who cannot learn will be at a disadvantage. The cost of the frequent lack of brains at the bottom of society will be borne by the individual, but when brains are lacking, as they often are, by those who are at the helm of society then the whole society will pay the price.

The saga of establishing an equilibrium between sustainable food supplies and population size is an ongoing problem that will have to be faced by each nation. In Zimbabwe we have on occasions been euphorically and erroneously led to suppose that we are the breadbasket of Central Africa. The truth is that we are of Africa, with all the inherent realities, problems, limitations and constraints on sustaining high productivity in a tropical environment. Our agricultural infrastructure varies from a sophisticated energy-intensive system to that of subsistence community plot-holders where the land is tilled for the retention of usufruct rights, social and old-age security and, above all, survival. Like the vast majority of tillers the world over, life consists of making rational economic decisions relative to hard realities and a spartan life-style. At this level, parameters for growth are almost impossibly restrictive.

At both levels of agricultural productivity, commercial and subsistence, there is reason for deep concern for sustained viability for different reasons. We walk an economic tightrope made slippery by rising costs of energy and the results of civil war. For various political reasons we are in a unique petroleum-energy predicament in terms of procurement costs compared to the rest of the world (Fig. 11). For this reason alone the productivity squeeze for future harvests has tightened considerably for commercial agriculture.

There is a parallel predicament in peasant agriculture where draught animals constitute the appropriate tillage technology for crop production. This arises because of large-scale war-induced stock thefts, and partly because of widespread decimation by diseases and the effects of an increased incidence of tsetse fly and foot-and-mouth disease.

There are no short-term non-political remedies. There are nevertheless promising innovations such as the use of expressed plant oils, particularly from sunflowers, as a substitute for imported dieseline to help power the tractors of commercial farmers. There is also the beginnings of a startling innovation of cropping the wild African buffalo population instead of culling it, and then raising and training a regularly cropped buffalo-calf population to the yolk (Condy, 1979). Immune to the crippling diseases that decimate cattle, the African buffalo, even though a carrier of foot-and-mouth disease, may yet be Africa's answer to the Indian buffalo. Furthermore, the population of African buffalo is totally unexploited in terms of its potential genetic variability, either in the form of selection among the wild population or in

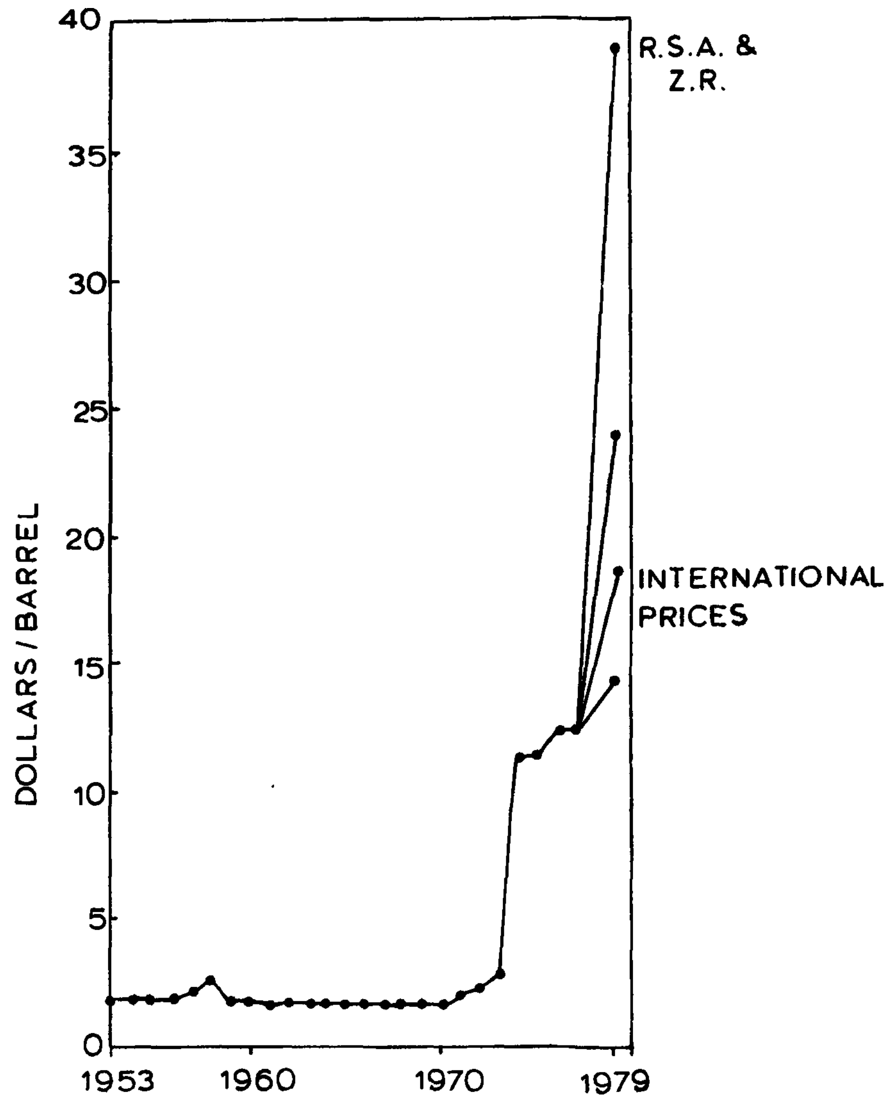


*Figure 11:* WORLD PRICE OF PETROLEUM.

domesticated breeding stock. This animal may well help provide an appropriate technology in small-scale agriculture.

And yet the largest untapped resource in this and other developing countries is, and will increasingly be, the vast potential labour force in the school and the gestation pipe-lines. Of the 922 million additional estimated jobs required in the world between 1970 and 2000 (Table IV), possibly 4

*Table IV*

PROJECTED GROWTH IN WORLD LABOUR FORCE, 1970 - 2000

| | *1970* | *2000* | *Additional Jobs Required* | *Change 1970 - 2000* |
|---|---|---|---|---|
| | | *(millions)* | | *(per cent)* |
| More Developed Nations | 488 | 649 | 161 | +33 |
| Less Developed Nations | 1 011 | 1 933 | 922 | +91 |

*Source:* Brown (1978), 186.

million will be in Zimbabwe, and with good management many of these will find productive employment on the land. If we are not to emulate the failure of agriculture to keep pace with food requirements in so many tropical countries in Africa and Central and South America, it will be necessary to train and utilize, at certificate, diplomate or degree level, our potential human skills.

Whenever and wherever settled agriculture has developed, it has provided the infrastructure of civilizations, and this process will need to be re-enacted between Capricorn and Cancer. In what has come, after 120 centuries of agricultural revolution, to be our little universe, we have returned to the basics of an old human agenda: food, population and energy.

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