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Gordon Conway

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Feeding the World: Ecology, Biotechnology and Farmers as Experimenters

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The Green Revolution was one of the great success stories of the second half of the 20th century. Food production in the developing countries kept pace with population growth. Both more than doubled. And the benefits reached many of the world's poorest people. Forty years ago half of the world's population did not get enough to eat, compared with one-fifth today. If the proportion had remained unchanged, the hungry would be in excess of two billion—more than double the current level. Since the 1970s, world food prices have declined in real terms by over 70%. Those who have benefited most are the poor, who must spend the highest proportion of their family income on food.

These are achievements of which we can all be proud. The Rockefeller Foundation was one of the architects and initial funders of this revolution. The technological innovations and their implementation were the result of a highly productive partnership between the research institutes (and their forerunners) of the Consultative Group on International Agricultural Research (CGIAR) and key national research and extension systems in the developing world.

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Viewed globally, food is plentiful. If we were to add up all the world's production of food and then divide it equally among the world's population, each man, woman and child would receive a daily average of over 2700 calories of energy.[1] This is just about enough to prevent hunger and probably sufficient for everyone to lead an active healthy life.

Yet the harsh reality is great inequality. While in Western Europe and North America the average person eats more than 3500 calories a day, people in sub-Saharan Africa and South Asia subsist on less than two-thirds of this amount (Figure 1). The people of 35 developing countries, including nearly half the countries of Africa, have an average supply of less than 2200 calories a day. According to

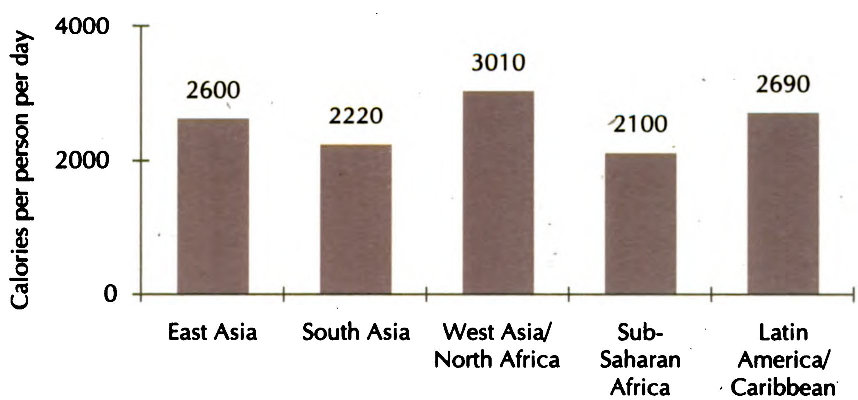

Figure 1 Average per capita calorie supplies in the developing world. The figures omit food fed to livestock.[3]

recent estimates, over 800 million people, equivalent to 13% of the world's population, get less than 2000 calories per day. They live a life of permanent or intermittent hunger and are chronically undernourished.[2]

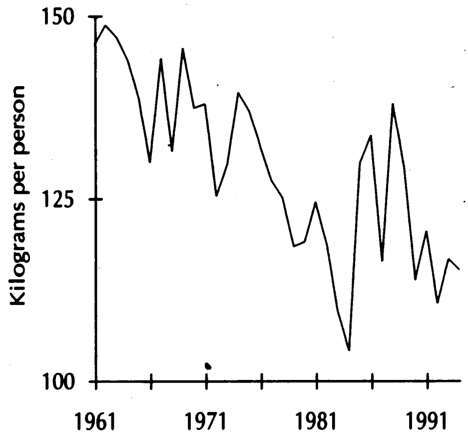

Figure 2 Cereal production per capita in sub-Saharan Africa.[4]

The Green Revolution has been least successful in sub-Saharan Africa (Figure 2). Here, cereal yields have little changed over the past 40 years and cereal production per capita has steadily declined. The amount of land that is irrigated is tiny—only about 6 million hectares, less than 5% of the arable land. Where cereal production has increased, it has tended to come from expanding available lands, either by opening up marginal lands or by reducing the fallow period. The important food staples over much of the continent are maize, millets, sorghums and root crops for which, with the exception of maize, few high-yielding varieties have been produced.

HUNGER AND POVERTY

Most of the hungry are women and young children of extremely poor families. More than 180 million children under five years of age are severely underweight— that is, they are well below the standard weight for their age. This represents a third of the under-fives in developing countries. Young children crucially need food because they are growing fast and, once weaned, are likely to succumb to infections. Seventeen million children under five die each year, and malnourishment contributes to at least a third of these deaths.

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Lack of proteins, vitamins, minerals and other micronutrients in the diet is also widespread. About 100 million children suffer from vitamin A deficiency.[5] Lack of this vitamin causes eye damage. Half a million children become partially or totally blind each year, and many subsequently die. More serious, recent research has shown lack of vitamin A weakens the protective capacity of children's epithelial cells and immune systems. Children deficient in vitamin A are thus more likely to develop infections and the infections are more likely to be severe.

Iron deficiency is also common. About 400 million women of childbearing age (15–49 years old) are afflicted by anaemia caused by iron deficiency. As a result they tend to produce stillborn or underweight children and are more likely to die in childbirth. Anaemia has been identified as a contributing factor in over 20% of all postpartum maternal deaths in Asia and Africa.[6]

Despite 20 years of rapidly declining world food prices, hunger is common in many developing countries. Although often there is enough food to meet demand, large numbers of people go hungry. Food prices may be low, but they remain high relative to the earning capacity of the poor. Market demand is satisfied, but there are many who are unable to purchase the food they need and, hence, they are completely unaware of the market. Poor people have few assets, are unemployed or earn less than a living wage and thus cannot produce or buy the food they need. According to World Bank estimates, over one billion people, that is a third of the developing world's population, are in poverty, defined as living on less than one US dollar a day.

To the casual observer, poverty seems to be worse in the cities, but in reality, the urban poor fare better. Although the cost of living may be low in rural areas, there are fewer opportunities for making a living. At the extreme, the urban poor can at least beg or steal. About 130 million of the poorest 20% of developing country populations live in urban settlements, most of them in slums and squatter settlements.[7] Yet 650 million of the poorest live in rural areas. In sub-Saharan Africa and Asia most of the poor are rural poor, and the majority live where the agricultural potential is low and natural resources are poor.[8]

How, asks Harvard economist Amartya Sen, are the poor to gain their rightful entitlement to the food they need?[9] Part of the answer to this question is political. The end of the cold war has not brought about an

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increase in global stability. While conflict between East and West has declined, there is a fast-growing divide between the world of the peoples, countries and regions who 'belong', in global power terms, and those who are excluded. At the same time, the growing interconnectedness of the world—the process commonly referred to as globalisation—holds the promise of alleviating, if not eliminating, poverty and hunger. Globalisation, while threatening on the one hand to concentrate power and increase division, on the other contains the economic and technological potential to transform the lives of rich and poor alike. Much depends on where our priorities lie and, in particular, whether the poor will have sufficient access to the economic opportunities that the products of the new technologies create.

PROSPECTS FOR THE YEAR 2020

We have little time. If we do nothing new, the numbers of poor and hungry will grow. Partly this is because most populations in the developing world are still growing rapidly. By the year 2020 there will be about an extra 1.6 billion people in the developing world (in sub-Saharan Africa the population will have doubled by 2020 to about 1.2 billion).[10] They are in addition to the three-quarters of a billion people who are chronically undernourished today. If the proportion of the population of the developing countries deprived of an adequate diet remains the same, by the year 2020 the number of undernourished could be greater than a billion.

What is the prognosis for feeding the world's population in the 21st century? It is not possible to foresee, with any accuracy, the situation in the latter half. Predicting the next 20 years is more feasible, and this will be the most critical period; after 2020 the annual increments in world population will begin to decrease significantly. If we can achieve a well-fed world by 2020, it should be possible to

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meet future demands, providing we adequately protect the resource base.

Most econometric models forecast that the growth rate of the world's population will be matched by the growth in food production and that food prices will continue to decline.[11] Even so, developing countries as a whole will not be able to meet the demand of their people for food. In a model that the International Food Policy Research Institute (IFPRI) has created, the total shortfall by 2020 is some 190 million tonnes, which would have to be imported from developed countries (Figure 3).

Much of this imported grain will go to livestock feed. We are witnessing a Livestock Revolution in the developing countries as the more prosperous populations are turning to non-staple foods—vegetables and fruits, and in particular livestock products, fish and other aquatic products (Figure 4).[12] Since the early 1980s milk production has grown by 3% a year and meat production by 5% in the developing countries. One of the biggest growth rates has been in China. At 32 kilograms a head, China now consumes more meat other than poultry than does the USA, although the main component is pork rather than beef. Over the next 20 years, grain consumption for livestock feed in the developing countries will grow at nearly 4%, double the rate for human food.[13]

Of the 190 million tonnes that will be exported to developing countries in 2020, only 50 million tonnes will go to satisfy the demand for human food in sub-Saharan Africa and South Asia, rather than go to livestock. In these regions, food production will be hard pressed to keep up with population increase for a long time to come. According to the IFPRI model, by the year 2020 the excess of market demand for grain over production in sub-Saharan Africa will be nearly 26 million tonnes; this compares with current net imports of 9 million tonnes.

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Inevitably, models of this kind raise more questions than they answer. The most important omission from the calculations is the food needs of the poor and hungry. As in the real world, they are simply priced out of the market and their needs are hidden. The gap between demand and supply that the model closes is the market gap. If we convert the market

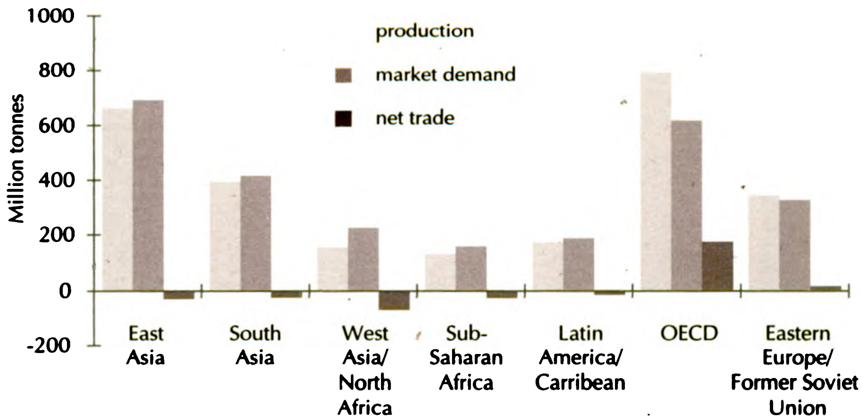

Figure 3 Grain production and market demand (for human and livestock feed) from the IFPRI model for the year 2020 (OECD - Organization for Economic Cooperative Development).[14]

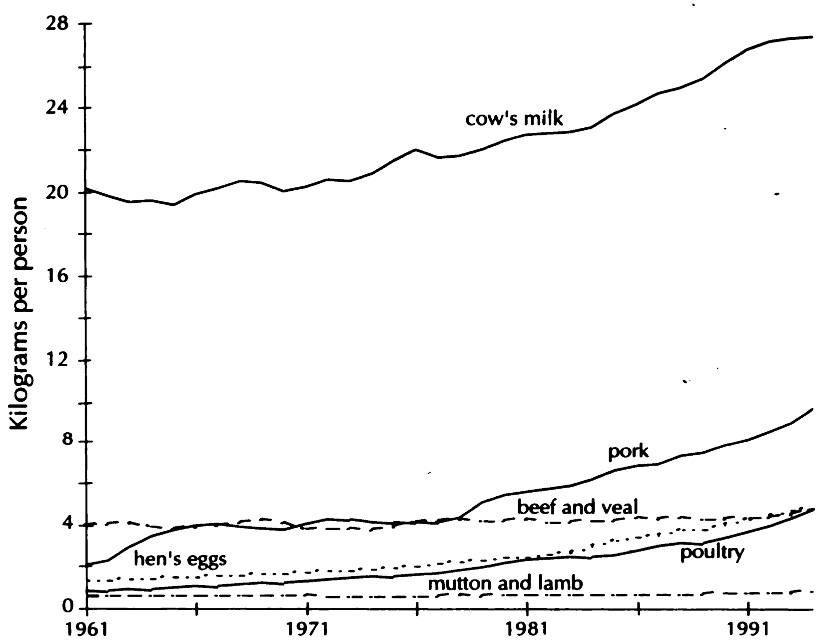

Figure 4 Per capita livestock production in the developing countries.[15]

availability predicted by the IFPRI model to calories per person per day, the improvement over current calories is slight. Then, as now, there is a substantial hidden food gap, particularly in sub-Saharan Africa, where the average calorie availability remains below 2200 calories per person per day, and also in South Asia. On the basis of a minimum need per person of 3000 cereal calories per day—which covers food, livestock feed, seed, storage losses and waste during processing—this translates into a food gap in cereals of 214 million tonnes for sub-Saharan Africa and 183 million tonnes for South Asia in 2020. If all this food were to be supplied by the developed countries it would require nearly 550 million tonnes, nearly three times that predicted by the market model.

In human terms, the hidden gap can be translated into a persistence of large numbers of malnourished children. By 2020 the total numbers will have declined slightly from the current 180 million to 155 million, but in sub-Saharan Africa they will have increased by nearly 50%. And probably there will still be close to three-quarters of a billion people chronically undernourished—the FAO model predicts over 600 million.[16]

YIELD TRENDS

The prognosis for filling the gap is not good. Recent data on crop yields and production suggest a degree of stagnation that is worrying. There is widespread evidence of decline in the rates of yield growth (Figure 5). There are also data indicating greater variability in production in some regions, and there is evidence, albeit largely anecdotal, of increasing production problems in the places where yield growth has been most marked. For example in the Punjab, although wheat yields are still growing, this achievement is now being seriously threatened.[17] Of greatest concern is the growing scarcity of water. In some of the most intensively cultivated districts the ground water table has fallen to a depth of 9–15 metres and is falling at about a half a metre a year. This and other anecdotal evidence from Luzon in the Philippines, Java in Indonesia and Sonora in Mexico suggest there are serious and growing threats to the

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sustainability of the yields and production of the Green Revolution lands.[18]

A combination of causes is responsible. On the best lands many farmers are producing yields close to those in experiment stations, and there has been little or no increase in yield ceilings of rice and maize in recent years. And in parts of Asia declining prices for cereals are causing farmers to invest more in higher-value cash crops. Another contributing factor is the cumulative effect of environmental degradation, partly caused by agriculture itself. Virtually all long-term cereal experiments in the developing countries exhibit marked downward trends in yields.

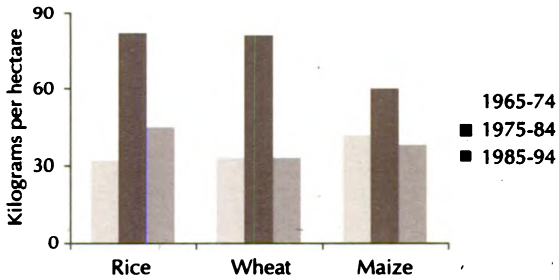

Figure 5 Average annual increase in developing country cereal yields by periods.[19]

AGRICULTURE AND THE ENVIRONMENT

The litany of environmental degradation is familiar.[20] Soils are eroding and losing their fertility, precious water supplies are being squandered, rangelands overgrazed, forests destroyed and fisheries overexploited. The heavy use of pesticides has caused severe problems. Human morbidity and mortality are increasing. At the same time, pest populations are becoming resistant and escaping from natural control. In the intensively farmed lands of both developed and developing countries, heavy fertiliser applications are producing nitrate levels in drinking water that approach or exceed permitted levels, increasing the likelihood of government restrictions on fertiliser use.

> The heavy use of pesticides has caused severe problems.

Increased—and inefficient—use of pesticides and nitrogen fertilisers produces severe pollution, but it is mostly local in its effect. Other agricultural pollutants have the potential to damage on a much larger scale. While industry is often to blame, agriculture is becoming a major contributor to regional and global pollution, producing significant levels of methane, carbon dioxide and nitrous oxide (Figure 6).[21] Natural processes generate these gases, but intensified agriculture worldwide has increased the rates of emission. For example, ammonia and methane emissions have increased as a result of livestock intensification. Individually or in combination, these various gases are contributing to acid deposition, the depletion of stratospheric ozone, the buildup of ozone in the lower atmosphere, and global warming. Each of these in turn can have a deleterious consequence on agricultural production.

THE DOUBLY GREEN REVOLUTION

These concerns, I believe, add up to a formidable challenge. The answer does not lie in encouraging the developed countries to continue to

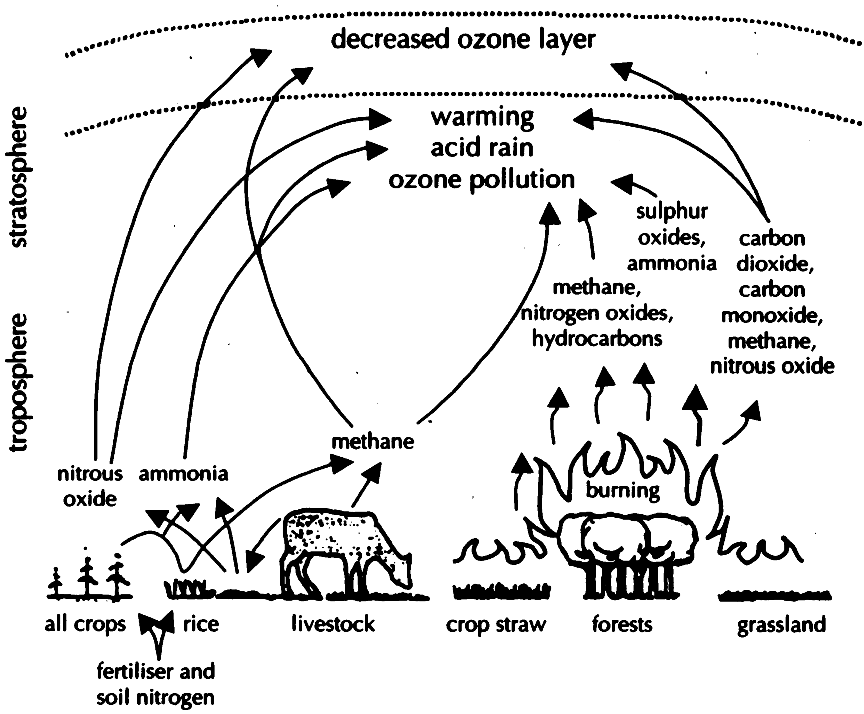

Figure 6 Global pollution caused by agriculture.[22]

produce food well in excess of their requirements and to subsidise the export of this excess to meet the demand of the developing countries. This would be costly, in both economic and environmental terms, and more important, it would exclude a large proportion of the population in the developing world from participating in global economic growth. The alternative scenario is for the developing countries to undertake accelerated broad-based growth, not only in food production, but in agricultural and natural resource development, as part of a larger development process aimed at meeting most of their own food production needs, including the needs of the poor. Implicitly, this scenario recognises that food security is not a matter solely of producing sufficient food. It depends as much on employment and incomes as it does on food production, and agricultural and natural resource development is crucial in both respects.

Developing countries [must] undertake accelerated broad-based growth.

I believe these and other arguments point to the need for a second Green Revolution, yet a revolution that does not simply reflect the successes of the first. In effect, we require a Doubly Green Revolution, a revolution that is even more productive than the first Green Revolution and even more 'green' in conserving natural resources and the environment.[23]

Food security is not a matter solely of producing sufficient food.

Over the next three decades it must aim to repeat the successes of the Green Revolution, on a global scale, in many diverse localities and be equitable, sustainable and environmentally friendly.

The complexity of these challenges is daunting, in many respects of a greater order of sophistication than has gone before. I believe the challenges can be met only by exploiting two key recent developments in modern science.

BIOTECHNOLOGY

The first is the emergence of molecular and cellular biology, a discipline that with its associated technologies is having far-reaching consequences on our ability to understand and manipulate living organisms.

Conventional crop and livestock breeding is reliant for its undoubted success on the existence of naturally occurring genes capable of being easily transferred from one plant or animal to another. But it is limited by the random nature of normal crossing and by the relatively slow nature of the process. Biotechnology, and especially genetic engineering, offers a faster and potentially more precise route and also the means of tackling the particularly intractable problems of drought, salinity and toxicity that typically face the poorest farmers living and working on marginal lands.

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A good start has been made in improving rice varieties using these technologies. In 1984 the Rockefeller Foundation launched its International Program on Rice Biotechnology to help create Asian centres of excellence in biotechnology. To date over US$80 million has been spent on collaborative programmes with laboratories in the industrialised world, involving a network of some 700 researchers, fellows and advisers. Practical results include the development, through tissue culture, of a new rice variety in China, named La Fen Rockefeller, now widely grown in the Shanghai area and producing yields 25% above previous varieties. Scientists at the West Africa Rice Development Association have used another culture to cross the high-yielding Asian rice varieties with traditional African varieties. The result is a new plant type that looks like African rice during its early stages of growth—in particular, it is able to shade out weeds—but becomes more like Asian rice as it reaches maturity, resulting in higher yields with few inputs.

One of the most exciting developments has been the introduction of genes that produce beta-carotene in the rice grain.[24] Beta-carotene is present in the leaves and other green tissues of rice. But, despite decades of searching, no rice genes have been found that produce beta-carotene in the endosperm of the rice grain. So breeders have turned to genetic engineering, transferring three genes for the necessary enzymes, one from a daffodil, the other two from bacteria. The resulting transgenic rice grain has a light golden-yellow colour and contains sufficient beta-carotene to meet human vitamin A requirements from rice alone. These same scientists and others have also added genes to rice that increase its bio-available iron content over threefold.

Similar potential benefits are on the horizon for livestock biotechnology (see box on p. 14). Livestock breeders at ILRI and elsewhere are already exploiting such techniques as embryo culture, sex selection, diagnostics for detecting pathogens and marker-aided selection.

Genetic engineering offers three possibilities for livestock improvement: better forage crops, better vaccines and other medicines against livestock diseases and pests, and higher-quality livestock products.

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Pigs and chickens need lysine in their diets but the content in cereals is poor compared with content in legumes such as peas and lupins. On the other hand, legumes are poor in the sulphur amino acids methionine and cysteine, necessary for cattle and sheep if meat, milk and wool productivity is to be increased. High levels of these amino acids are present in sunflower seeds and the chicken egg protein ovalbumin, and the encoding genes have now been cloned and inserted into peas. The next step is to insert the same or similar genes in forage legumes, such as alfalfa and clover, with suitable promoters so that they are expressed in the foliage. An alternative approach is to introduce genes for sulphur amino acid biosynthesis, present in the bacterium *E. coli*, direct into sheep, bypassing the need for improved fodder.

Another challenge is to reduce the effects of antinutritional factors, which can be poisonous to ruminants.[25] For example, reducing the phytic acid content can increase feed conversion of maize. An alternative is to introduce microbes that will detoxify the antinutritional factors.

Livestock biotechnology for developing countries

Cellular and molecular techniques

- Marker-aided selection for trypanotolerance in African cattle
- Embryo culture, cryopreservation and transfer to improve herd quality
- Sex selection and manipulation in livestock
- Monosex production in tilapia
- Diagnostics for detecting pathogens in vectors, animals and meat products

Genetic engineering

- Improved nutritional content of forages and feed
- Reduced lignin and antinutritional factors in forage crops
- Manipulation of rumen microflora
- Recombinant vaccines against theileriosis, trypanosomiasis, rinderpest, brucellosis, rabies, Newcastle disease, and coccidiosis
- Reduced vectoring capacity of insects
- Higher lean-to-fat ratios and lower cholesterol levels

Most of the fibre in livestock fodder is not digested, and tropical forages have particularly high fibre and lignin content. Poor digestibility results in lower food intake and slow liveweight gain. One approach is to use gene shears to block the pathway that produces lignin. 'Brown midrib' mutants with this effect sometimes occur in maize, sorghum and millet. They produce 50% less lignin and are 10 to 30% more digestible. Research is now aimed at cloning these genes and inserting them into forage legumes.

Some of the most promising current applications of genetic engineering in animals, as with plants, are directed at pest and disease control. Considerable progress has already been made in producing genetically engineered vaccines. Hitherto vaccines have consisted of viruses or other pathogens that are dead or are live but attenuated. The pathogens in this form are harmless but they provide the antigens that stimulate production of antibodies in the vaccinated animal and hence give it protection if invaded by the live, virulent pathogen. However, this traditional method of vaccination can be hazardous. Live vaccines, in particular, carry material other than the antigens, which may cause undesirable side effects. The advantage of genetically engineered vaccines—produced by cultures of bacteria that contain antigen-encoding genes—is that they consist solely of the required antigens.

Genes coding for resistance to pests and diseases can also be directly transferred from one animal to another.

Genes coding for resistance to pests and diseases can also be directly transferred from one animal to another or even, in some cases, from plants to animals. Blow flies that burrow into the skin of livestock animals are killed by chitinase, the enzyme that breaks down the chitin that composes their exoskeleton. As genes coding for chitinase are found in various plants, another possibility is to introduce the *Bt* gene into livestock.

Over the next decade we are likely to see much greater progress in introducing multiple genes that focus on output traits or on input characteristics that are difficult to achieve. It may be possible to increase cereal yield ceilings, for example, through more efficient photosynthesis or improved regulation of stomata. In livestock, one of the quests is for higher lean-to-fat ratios in the meat and lower cholesterol levels.

The potentials for genetic engineering are almost endless. But there are serious hazards, some easily perceived, others yet to become apparent.[26] The current debate is particularly impassioned in Europe. Some of it is motivated by anti-corporate or anti-American sentiment. But underlying the rhetoric are genuine concerns about lack of consumer benefits, about ethics, about the environment and about the potential impact on human health.[27]

The potentials for genetic engineering are almost endless.

Much of the opposition tends to lump the various risks and to assume there are generic hazards. However, as Pretty points out, 'genetically modified organisms are not a single, homogenous technology. Each poses different potential benefits for different stakeholders, each poses different environmental and health risks.[28] Calls for general moratoria are not appropriate. Each new transgene and genetically modified crop needs to be considered in its own right. And well-planned field tests are crucial, particularly in developing countries where the risks of using or not using a genetically modified crop may be quite different from those in industrialised countries. For example, the risks of gene flow to wild relatives may be higher in developing countries; wild relatives are often common and cultivated land is more mixed with uncultivated land.

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Each new transgene and genetically modified crop needs to be considered in its own right.

More important than the potential hazards, at least to my mind, is the question of who benefits from genetic engineering. In recent years, the privatisation of genetic improvement activities has resulted in rapid expansion of corporate ownership of key technologies and genetic infor-mation and materials. This is threatening the rights of developing countries to use their own genetic resources and the freedom of their breeders to use new technologies to develop locally adapted varieties.

More important than the potential hazards, is the question of who benefits from genetic engineering.

Inevitably the competitive pressure on the new multinational biotechnology companies to capture world market share as rapidly as possible has forced them to focus on developed-country markets where potential sales are large, patents are well protected and the risks are lower. Rural poor farmers are unlikely to take up the new varieties and breeds unless they are provided free or at nominal cost. Biotechnology for them will require heavy public investment, by national governments and donors, at times in collaboration with the private sector, both in the research and in the subsequent distribution of seed and technical advice. And it will need to include the food staple crops and livestock of Africa, where the need is for increased stability of production as much as increased production.

THE APPLICATION OF ECOLOGY

The second development that is crucial to the success of the Doubly Green Revolution is the emergence of modern ecology, an equally powerful discipline. Ecology is rapidly increasing our understanding of how agricultural and natural resource ecosystems are structured and their dynamics, and it is providing clues about how to manage them productively and sustainably.

The widely successful application of integrated pest management to control rice pests in South-East Asia is proof of what can be achieved. Integrated pest management looks at each pest situation as a whole and then devises a programme that integrates various control methods in light of all the factors present. As practised today, it combines modern technology, including the application of synthetic yet selective pesticides and the engineering of pest resistance, with natural methods of control, including agronomic practices and the use of natural predators and parasites. The outcome is sustainable, efficient pest control that is often cheaper than the conventional use of pesticides alone.

Integrated pest management looks at each pest situation as a whole and then devises a programme that integrates various control methods in light of all the factors present.

The next challenge is to extend the principles of integration established in this kind of control to other subsystems of agriculture—to conserving nutrients, and to managing soil, water and other natural resources, such as rangelands. Of great potential value is the development of highly integrated crop–livestock systems, where soil structure and nutrients benefit from both livestock manure and the nitrogen-fixing capacity of forage crops. As African scientists have shown, use of inorganic fertilisers alone can lead to stagnation of crop yields, but fertilisers combined with manure can sustain steady yield increases (Figure 7). Careful ecological management of crop–livestock systems can create virtuous circles:

Careful ecological management of crop–livestock systems can create virtuous circles.

'Cowpea thus feeds people and animals directly while also yielding more milk and meat, better soils through nitrogen fixation, high-quality manure, which, used as fertiliser, further improves soil fertility and increases yields.[29] Forages identified by ILRI for intercropping have led to increases in wheat yield of 30 to 100% and increases in fodder protein up to 300% while fixing 55 to 155 kilograms of nitrogen per hectare.[30]

Another application of modern ecology is in managing rangelands. In Africa and elsewhere, such lands are commonly characterised by low or erratic precipitation, poor drainage, extreme temperatures, rough topography and other physical limitations that render them unsuitable for cultivation. But they support most of the developing world's population of cattle, sheep and goats.[31]

A high proportion of rangelands are 'degraded'. For many years, conventional wisdom has attributed this degradation to overgrazing, but recent research has suggested that concepts of overgrazing and degradation as applied to rangelands in developing countries have been seriously oversimplified. Misapplication

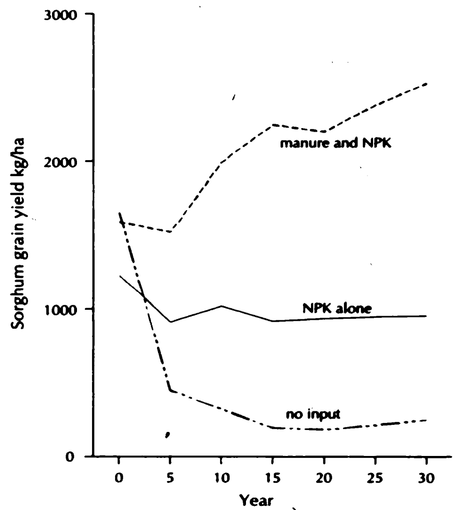

Figure 7 Effects of applying manure and inorganic fertilisers on sorghum in Burkina Faso over 30 years.[32]

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has been at the heart of the problem: management theories developed to maximise beef production on temperate grasslands in developed countries have been transplanted to tropical rangelands—unsuccessfully.

In 1979, Graeme Caughley proposed a model of the relationship between animal numbers and vegetation that distinguishes ecological and economic carrying capacity (Figure 8). At the far right of the upper curve there is a small population of animals and a large standing crop of plants. As the number of animals increases, the amount of vegetation decreases until a point is reached—the ecological carrying capacity—where the production of forage equals its consumption and the animal population ceases to grow. At this point there will be many animals but they may not be in good condition and the vegetation will be much less abundant. If the range manager wants denser vegetation or healthier animals, then animals must be culled. The lower offtake curve indicates various combinations of animals and vegetation that will produce sustainable meat yield. Its maximum is the economic carrying capacity.

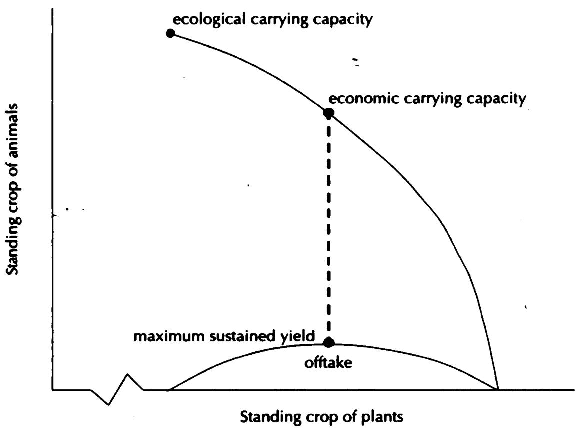

Figure 8 The relationship between animals and plants in a grazing system.[33]

For beef production in temperate pastures, being close to the economic carrying capacity is the appropriate goal, but in sub-Saharan Africa and elsewhere in the developing world, the objectives and the circumstances, particularly the climatic conditions, may produce a very different target. If a rangeland, such as the Serengeti savanna in East Africa, is being managed as a wildlife park and a tourist attraction, the aim may be to maximise the numbers and diversity of wildlife. The target of sustaining its 'camera-carrying capacity', in the words of Roy Behnke and Ian Scoones, will lie somewhere towards the ecological carrying capacity.[34] On the other hand, if the wildlife is being culled for meat, then a much lower population, close to the economic carrying capacity, will be logical. Other aims—to produce high-grade meat or trophy specimens for hunters, or to preserve special plant communities—will result in different targets on the curve. Finally, for the pastoralist, the principal user of much of the world's rangelands, where the aim is to maximise a range of livestock products other than meat—milk, blood, traction power and transport—it is profitable to maintain a large stocking rate since the offtake does not usually require slaughter.

'Overgrazing' is relative to the aims of the rangeland managers, as is 'degradation'.

In these highly different circumstances, 'overgrazing' is relative to the aims of the rangeland managers, as is 'degradation'. There is no objective measure of either overgrazing or degradation. Inevitably, the state of the vegetation will vary considerably, being much poorer at the ecological carrying capacity than at the other extreme, where the range is managed for trophy hunters or high-grade meat. The critical question for sustainability is how reversible are the soil and vegetation conditions, simply by reducing the stocking rate.

Since many rangelands exist in regions where the rainfall is highly variable and unreliable, there is no permanent target point on Caughley's curve to aim at—the curves move with the rainfall. The state of the vegetation changes dramatically from year to year, often more as a result of the rainfall than the animal stocking density. Stable conditions are rare and carrying capacities difficult, if not impossible, to estimate. In addition to climatic variability, disease outbreaks, political upheavals and policy changes add to the disturbances. Pastoral livestock populations thus tend to go through periodic cycles of 'boom and bust'.

In a detailed study of pastoral communities in southern Zimbabwe, Ian Scoones has shown the remarkable array of adaptive strategies used to cope with uncertainty.[35] The land traditionally exploited by the pastoralists is a complex mosaic of different habitats. In normal years, and when droughts are not too severe, livestock are moved from the top lands to riverbanks, drainage lines and valley wetlands or bottom lands, known as *dambos,* where moisture levels are high and grasslands available. Sometimes animals have to be moved between ecological zones—from clay soils, where grass production collapses early in a drought, to sandy soils, where production is maintained. In a particularly severe drought, when all local grazing areas are exhausted, livestock may be moved over considerable distances to seek suitable grazing land. Other adaptive strategies include supplementary feeding with hay, cut grass and the branches, leaves and fruits of trees—including acacia pods—and the slaughter and sale of cattle as drought sets in. Losses during severe droughts can be considerable and the instability of the system is high, but pastoralists, by dint of circumstance, have learned to be opportunists and can cope with the periodic droughts, providing government policies aid rather than interfere.[36]

Governments need to explicitly recognise the central importance to pastoralism of the heterogeneity of rangelands.

In these circumstances, government policies can be supportive if they are aimed at creating greater stability and reducing losses. As a first step, governments need to explicitly recognise the central importance to pastoralism of the heterogeneity of rangelands. This has far-reaching implications, not least for land tenure and respect for traditional land-use rights. It would result, in times of drought, in removing restrictions on movement between areas. And it would justify programmes aimed at protecting and enhancing the key drought resources—the riverbanks, *dambos* and drainage lines—by reseeding degraded areas with improved species. Explicit recognition of the inherent instability of pastoral systems would also encourage governments to support supplementary feeding during severe droughts and to facilitate rapid destocking and restocking at the beginning and end of droughts through livestock markets explicitly designed for this purpose.[37]

PARTICIPATION

Finally, I believe that a successful Doubly Green Revolution will not come by applying biotechnology or ecology alone. The first Green Revolution started with the biological challenge inherent in producing new high-yielding food crops and then looked to determine how the benefits could reach the poor. This new revolution has to reverse the chain of logic, starting with the socio-economic demands of poor households and then seeking to identify the appropriate research priorities.

Biologists will have to listen as well as instruct.[38] There will be no easy solutions and few, if any, miracles in the new revolution. Greater food production will come from targeting local agroecosystems, making the most of indigenous resources, knowledge and analysis. More than ever before, we will have to forge genuine partnerships between biologists and farmers. It will not be enough simply to test new varieties or breeds on farmers' fields at the end of the breeding process. Experiments in many parts of the developing world are showing very effective ways of involving farmers right at the beginning, in the design of new varieties and breeds and in the breeding process itself.[39]

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Participation has long been a slogan of development, but for the first time we now have effective techniques to make it a more practical proposition. Under the heading of 'participatory learning appraisal' there is a formidable array of methods that permit farmers to analyse their situations themselves and, most important, to engage in productive dialogue with research scientists and extension workers. Participatory learning appraisal arose in the late 1980s out of earlier participatory approaches by combining semi-structured interviewing and diagram making.[40] One of the first examples was a workshop that Robert Chambers and I led in Wollo Province, Ethiopia, in 1988.[41]

During the workshop we developed a number of techniques that demonstrated the great wealth of knowledge and insight that farmers

Farmers possess a great wealth of knowledge and insight about their farming practices and their environment.

possess about their farming practices and their environment. On one occasion farmers were able to give us a remarkable history of rainfall in the area based on their memory of how their crops had done over a 10-year period (Figure 9).

On another occasion, I developed a technique known as pairwise ranking that elicited farmers' preferences for different tree species (see box on p. 24). Farmers assessed a set of six species that we presented to them in all possible pairwise combinations. The farmers were asked to indicate which tree of each pair they would prefer if they could grow only one and to give their reasons. Their accumulated ranking revealed the great range of usage for which different species were suitable.[42] When the process was repeated with a group of foresters, the ranking was very different. The foresters emphasised the ease and reliability of a species in the nursery, which was their main responsibility, while the farmers placed a higher premium on versatility.

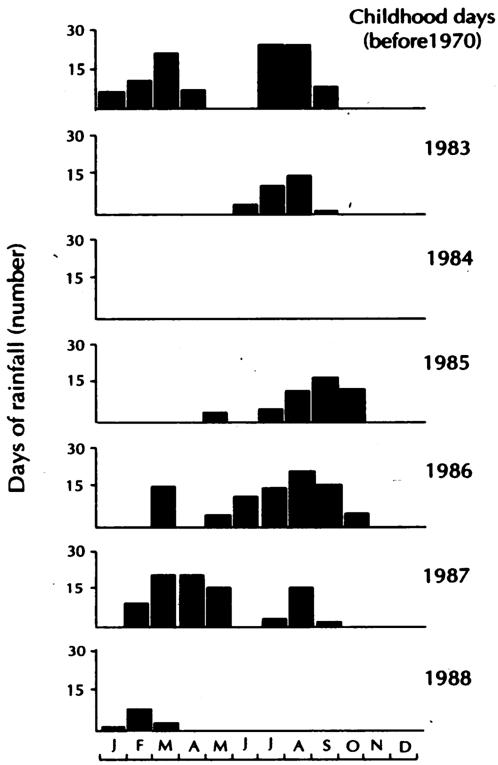

Figure 9 Rainfall recorded by two farmers in Gobeya, Ethiopia (the childhood pattern is probably idealised).[44]

These techniques enable rural people to take the lead—they produce their own diagrams, undertake their own analyses, develop solutions to problems, recommend changes and

Farmers' ranking of cultivated trees in Wollo, Ethiopia

TREE	USES
African olive	wood for diverse uses, including digging sticks, yoke and other plough parts, hoes, ox handles; incense from leaves; not attacked by termites; no smoke when used as firewood
Eucalyptus camaldulensis	easy to split, straight, strong for construction, durable; easy to make charcoal
Eucalyptus globulis	high elasticity, good for farming implements and for holding nails; good for firewood but difficult for making charcoal
Juniper	for window and door timber, chair making
White acacia	for house building
Croton	for door construction, but smoky as firewood

Source: Ethiopian Red Cross[46]

introduce innovations. Villagers readily create maps—of the village, or the watershed or a farm—if they are simply given chalk and coloured powder. A threshing floor or a cleared space in the village square is all that is needed to produce such a map, often of considerable complexity.

The approach has been rapidly taken up with enthusiasm, particularly by leaders of non-governmental organisations eager to find ways of creating greater levels of participation. The range of diagrams has quickly expanded: people who are illiterate and barely numerate can construct seasonal calendars using pebbles or seeds. Pie diagrams—pieces of straw and coloured powder laid out on an earthen floor—are used to indicate relative sources of income.

An issue of *RRA Notes* on livestock PLA describes a wide range of techniques that have proven powerful: maps of grazing lands showing the different sources of fodder and seasonal calendars describing the fodder availability and the incidence of disease throughout the year.[43] Farmers have also proved adept at constructing livestock histories and at using simple diagrams to describe livestock diseases.

Although this in itself is encouraging, it is the use to which the diagrams are put that is important. These diagrams not only reveal existing patterns but point to problems and opportunities. And rural people seize on them to make their needs felt. The diagrams have become a basis for collective planning, and the approach has begun to change the relationship between 'expert outsiders' and village people. In every exercise the traditional position of rural people being passive recipients of knowledge and instruction has been replaced by the productive dialogues that are created. A recent report by ActionAid describes a sophisticated use of maps and preference rankings by the Sanaag people of Somaliland for community-based livestock development.[45]

ILRI's market-oriented smallholder dairy research team has used participatory learning appraisal in collaboration with the Kenyan Agricultural Research Institute and the Kenya Ministry of Agriculture to understand how dairy farmers cope with their circumstances, how they deal with a fluctuating supply of fodder, what is the success and durability of smallholder groups, and what market mechanisms milk vendors employ.

Participatory learning appraisal has now spread to most countries of the developing world. The technique has been adopted by government agencies, research centres and university workers as well as non-governmental organisations. The methods used in the appraisals, which are described by a bewildering variety of names, have evolved according to local needs and customs and reflect local ingenuity.[47] In some ways it has been a revolution—a set of methods, an attitude and a way of working that has finally challenged the traditional top-down process that has characterised so much development work. Participants from non-governmental organisations, government agencies and research centres rapidly find themselves, usually unexpectedly, listening as much as talking, experiencing close to first hand the conditions of life in poor households, and changing their perceptions about the kinds of interventions and the

Participatory learning appraisal has now spread to most countries of the developing world.

research needs that these rural people need.

However, this is only a first stage of a revolution. For a fully participatory involvement of farmers we need to recognise and enhance their potential as innovators and experimenters. David Millar, who works for the Tamale Archdiocesan Agricultural Programme in northern Ghana, asserts that there is no farmer there who is not in some way experimenting.[48] Some are pursuing experiments to satisfy their curiosity. Others are trying to solve problems. Millar describes the trials that farmer Nafa and his brothers have designed using different forms of crop rotation to eliminate the notorious weed *Striga*.

Placing trial plots in farmers' fields has long been a practice, but often the farmers are simply used as labourers, being given little information about the purpose of the trial. The Kenya Agricultural Research Institute is trying out a more fully participatory approach. Farmers are planting out trial plots on their land—investigating varieties, spacing, fertiliser treatments, intercropping, erosion control. They are mixing treatments suggested by the institute's team with their own. They conduct the trials themselves and use pairwise ranking to analyse the results. A committee of farmer researchers has been formed, and the trial results—and the approach itself—are now being taken up by neighbouring farmers. It is possible to see this as a first step towards a radical alternative to traditional extension systems. This alternative involves farmer research, farmer-to-farmer transfer of knowledge, farmer schools and other farmer-led activities.

A radical alternative to traditional extension systems involves farmer research, farmer-to-farmer transfer of knowledge, farmer schools and other farmer-led activities.

CONCLUSION

I firmly believe we can provide food for all in the 21st century. But there is no simple or single answer. It is not just a matter of producing more or enough food. If hunger is to be banished, the rural poor have either to feed themselves or to earn the income to purchase the extra food they need. This requires a new revolution in agricultural and natural resource production aimed at their needs. And this cannot be achieved by ecology alone or by biotechnology alone, or by a combination of these approaches. It requires participatory approaches as well—involving farmers as analysts, designers and experimenters. If we can bring all three approaches together, we can feed the world in a way that is not only equitable but also sustainable.

Gordon Conway

Gordon Conway is the 12th president of The Rockefeller Foundation. He is the first non-American to hold the post, a position to which he was elected in April 1998. An ecologist, he was educated at the universities of Wales (Bangor), Cambridge, Trinidad and California–Davis.

He is a pioneer of integrated pest management, working on evolving control systems in the 1960s in Sabah, North Borneo. From 1970 to 1986, he was professor of environmental technology at the Imperial College of Science and Technology in London. In this period, he lived and worked in many countries in Asia and the Middle East. He then directed the sustainable agriculture programme of the International Institute for Environment and Development, UK. From 1988 to 1992, he served as the Ford Foundation representative in New Delhi. Immediately before he joined The Rockefeller Foundation, he served as distinguished vice chancellor of the University of Sussex and chair of the Institute for Development Studies there.

He has authored *Unwelcome Harvest: Agriculture and Pollution,* sponsored by Earthscan and published by Island Press, and recently, *The Doubly Green Revolution: Food for All in the 21st Century,* published by Penguin in London and Cornell University Press in New York.

Notes

This paper is largely based on Gordon Conway's recent book, *The Doubly Green Revolution: Food for All in the 21st Century* (London: Penguin Books, and Ithaca, New York: Cornell University Press, 1999).

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International Livestock Research Institute
PO Box 30709, Nairobi, Kenya
phone (+254 2) 630743
fax (+254 2) 631499
email ilri@cgiar.org
Web www.cgiar.org/ilri