From Hunting and Gathering to Agriculture

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In planning for the coming century we necessarily build on the knowledge we have accumulated from past experience. The past is an enormous domain. The immediate past may provide a base for simple extrapolation of current trends in nutrition and food provision to an equally immediate future; the distant past does not have this easy relevance. The great web of human history and prehistory can, however, illustrate the basic problems that have always confronted man in his search for an adequate diet; lead to identification of the determinants of the changes that have taken place in food provision; and show the instabilities that have been encountered and so, in a general way, point to the potential difficulties that lie ahead. I wish first to describe changes in food provision from eras of prehistory to the present, before identifying the determinants of change and their consequences for the future.

BACKGROUND

The vast span of time to be considered is illustrated in Table 1. This can be reduced somewhat by considering only that period from the retreat of the ice sheets in Europe and the movement of people to repopulate the north. This period is the junction between the Pleistocene and the Holocene, dated to 16,000–12,000 years before the present. The time span to the present is characterized by enormous changes in how food has been provided, beginning with hunting-and-gathering economies and culminating in our present food system, in which modern agricultures produce primary commodities; sophisticated food technologies convert commodities to highly varied items of diet; and complex networks distribute these items over vast distances to meet the nutritional needs of people. In these systems hunting is limited to the procurement of fish, and gathering to very minor activities undertaken more for pleasure than subsistence. Limiting considerations to the last 12,000–16,000 years ignore the fact that during the whole of the preceding four million years tool-using hunter-gatherers have existed. Some communities without agricultures still exist. In these, hunting predominates at latitudes above 60°, and gathering at latitudes below 50° (1). These “primitive” communities may be similar to those of the post-Pleistocene or earlier epochs; if they are, then the absence of change within them can, in a negative
sense, provide evidence about the determinants of change in the way that man obtains his food.

Diet in Prehistory

Increasingly, archaeological investigation has been concerned with how prehistoric peoples obtained their food and how they were organized socially. Such tasks are immensely difficult. First, sites for study must be found; these may be small temporary winter or summer camps rather than permanent abodes that can be readily identified by evidence of construction. Whether sites can be found varies considerably with the nature of the soil and overlay. This leads to a bias toward arid sites with high pH and wet sites with partial anaerobiosis, both of which provide better preservation. Since the advent of carbon-dating techniques, the dating of sites is not much of a problem. Pollen analysis, studies of faunal remains, and paleoclimatology provide the essential information regarding the nature of the potential food resource that was tapped. Identification of what was brought to the site and consumed largely comes from interpretation of plant and animal remains. Whether man or wild animals

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TABLE 1. A chronology of the world to place the emergence of crop and animal domestication in perspective

<table>
<thead>
<tr>
<th>Year BP*</th>
<th>Event</th>
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<tbody>
<tr>
<td>600,000</td>
<td>First evidence of hunting-gathering by hominids</td>
</tr>
<tr>
<td>40,000</td>
<td>Emergence of <em>Homo sapiens sapiens</em></td>
</tr>
<tr>
<td>30,000</td>
<td>Colonization of the Americas</td>
</tr>
<tr>
<td>20,000</td>
<td>Colonization of Australasia</td>
</tr>
<tr>
<td>12,000</td>
<td>Main racial groups of man established</td>
</tr>
<tr>
<td></td>
<td>Rice growing in Southeast Asia</td>
</tr>
<tr>
<td></td>
<td>Harvesting of wild grasses in Southwest Asia</td>
</tr>
<tr>
<td></td>
<td>Dog domesticated</td>
</tr>
<tr>
<td>11,000</td>
<td>End of the last glaciation</td>
</tr>
<tr>
<td></td>
<td>Sheep domesticated</td>
</tr>
<tr>
<td>10,000</td>
<td>World topography stable following Ice Age</td>
</tr>
<tr>
<td>8,000</td>
<td>Harvesting of wild grasses in Europe</td>
</tr>
<tr>
<td></td>
<td>Cattle and pigs domesticated</td>
</tr>
<tr>
<td></td>
<td>Copper smelting discovered</td>
</tr>
<tr>
<td>7,000</td>
<td>Horse domesticated</td>
</tr>
<tr>
<td></td>
<td>Bean and maize cultivation in the New World</td>
</tr>
<tr>
<td>6,000</td>
<td>Civilization of Sumer (3300–2000 BC)</td>
</tr>
<tr>
<td></td>
<td>Irrigated agriculture well established</td>
</tr>
<tr>
<td>5,000</td>
<td>Old Kingdom in Egypt (2600–2150 BC)</td>
</tr>
<tr>
<td>4,000</td>
<td>Domestication of the New World camelsida</td>
</tr>
<tr>
<td>3,000</td>
<td>Iron smelting replacing bronze</td>
</tr>
<tr>
<td>2,000</td>
<td>Birth of Christ</td>
</tr>
<tr>
<td>1,000</td>
<td>Horse beginning to replace ox for motive power</td>
</tr>
<tr>
<td>300</td>
<td>Introduction of root and forage crops in Europe</td>
</tr>
<tr>
<td>75</td>
<td>Dependence of agriculture on industrial inputs</td>
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</tbody>
</table>

* Year BP = Year before present.
brought them to the site may be a matter for conjecture. What has been preserved over thousands of years consists of those parts of plants and animals that have resisted decay and dissolution. Fleshy, non lignified parts of plants do not survive; most plant remains consist of carbonized seeds or highly lignified seed coats. Bones of large animals and molluscan shells are the most obvious remains; bones of very small animals and of fish survive less well, and invertebrates without considerable chitin hardly at all (2).

Modern methods of flotation separation, however, do provide better recovery of fish bones and scales and of carbonized plant fragments (3). Identification of the fragments of plants and animals provides the base for estimating what may well be incomplete faunal and floral assemblies. These are then used to construct the Paleolithic diet. Considerable ingenuity has been employed to do so (4). The frequency of occurrence of remains of each identified animal is used to estimate the proportional number of animals brought to the site and, using estimates of the edible component, the contribution of the species to total intake of animal food. The interpretation of plant remains is much more difficult. Evidence of preparation of food can be adduced and the presence of artifacts likely to have been associated with preparation is a help. Occasionally coproliths have been found, which provide a sample of what has been excreted by man. Some plant and animal remains can be identified within them to give a partial estimate of what was consumed.

Although the recent careful work has at least dispelled the idea that primitive man simply existed on hazelnuts (the shells of which survive well), limpets, and large mammals, bias in estimation of the components of diet, in favor of the durable items, remains. What emerges is that many sites, where hunting may be inferred to have taken place, early man used many species of animal. This is illustrated in Fig. 1 (5). With gatherers the same can be inferred from the archaeological evidence. While they date from the later period of the early Iron Age, the stomach contents of the Danish bog people found at Tolland, Jutland, tend to support the conclusion that a number of different plants were used (6). The diet consisted of a gruel of barley, oats, linseed, and a Polygonatum, which were probably cultivated together with dozens of other plants now regarded as weeds. A further conclusion to be drawn from the many hundreds of sites examined is that there were considerable variations in what foods were consumed from place to place and from time to time.

In the last decade, other approaches—based on isotopic and elemental analyses of human skeletal remains (7) to the problem of identifying the nature of the diet have been adopted. Collagen can be isolated from bones that are up to 100,000 years old, and the carbon and nitrogen of its constituent amino acids are not subject to diagenesis (post-depositional chemical change). The ratio $^{13}$C/$^{12}$C in collagen can be employed to distinguish between diet types as shown in Table 2. The ratio $^{15}$N/$^{14}$N can be used to distinguish between diets based on leguminous and nonleguminous plant diets or marine sources. Because of biological discrimination, the ratio of strontium to calcium in the body is less than that in the diet. It follows that a man subsisting on a plant diet will have a higher Sr/Ca ratio in his bones than he would if subsisting on animals that consumed a similar plant diet. Other trace elements present in the
skeleton have been employed to distinguish animal from plant sources. Generalized expectations are that Mg, V, and Sr are concentrated in plant foods, and Cu and Zn in animal foods.

The C and N isotope methods have been tested using data from modern societies. Combined with the Sr/Ca ratio method they have been applied to skeletons on Spitsbergen of Dutch whalers of the 18th century to reconstruct the diet. The results appear to accord with contemporary records (8). Refinement is still required but the methods have been used to estimate the dependence of European man on marine sources of food and to time the introduction of the maize culture into North America. Neither the classical archaeological approach nor these chemical ones provide mea-

<table>
<thead>
<tr>
<th>Diet type</th>
<th>Value for diet (%)</th>
<th>Values for consumer (%)</th>
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<tbody>
<tr>
<td>C³ plants only</td>
<td>-26.5</td>
<td>-21.5</td>
</tr>
<tr>
<td>Meat from herbivores eating C³ plants</td>
<td>-25.5</td>
<td>-20.5</td>
</tr>
<tr>
<td>C⁴ plants only</td>
<td>-12.5</td>
<td>-7.5</td>
</tr>
<tr>
<td>Meat from herbivores eating C⁴ plants only</td>
<td>-11.5</td>
<td>-6.5</td>
</tr>
<tr>
<td>Marine plankton only</td>
<td>-19.5</td>
<td>-14.5</td>
</tr>
<tr>
<td>Meat from marine herbivores</td>
<td>-18.5</td>
<td>-13.5</td>
</tr>
<tr>
<td>Meat from marine carnivores</td>
<td>-17.5</td>
<td>-12.5</td>
</tr>
</tbody>
</table>

From Price TG (7).
sures of the amount of food and hence of nutrients consumed; they all predict with an acknowledged error the proportions of broad categories of food that made up the diet.

The Transition to Agriculture

The older view of the transition from hunting and gathering to agriculture was based on ideas of culture derived from the interpretation of artifacts (9). Simplifying, the view was that a sedentary population was a prerequisite for change, the emergence of agriculture coincided with the invention of pottery and clay-lined storage pits, and a transition from flake tools to ground and polished ones more suitable for clearing undergrowth and cultivating the soil. The interface was between the Paleolithic and Neolithic cultures, in which a Mesolithic culture was tentatively inserted. It was further postulated that agriculture originated in Southwest Asia and diffused out through migration of peoples. By analogy, similar centers of discovery with consequent outward diffusion were postulated for the Americas.

These views have been slowly eroded, but not entirely dispelled, by subsequent findings. Permanent settlements and pottery that date from pre–Neolithic times have been found, as well as Neolithic sites showing evidence of agriculture but no pottery. No centers for diffusion have been identified in the Americas. Land was probably more often cleared by fire than by the use of the adz. Such evidence has been assembled by, among others, Bender (10) and Dennel (11). How agriculture developed is presently an open question.

A primary problem is how to recognize that domestication of a plant or animal species has occurred. With animals the major criteria relate to the proportional make up of the assemblage of bony remains, the size of the individual animals deduced from them, and certain morphological changes. It is assumed that hunters killed at random from wild herds but that “farmers” culled their herds, killing animals past their prime and surplus young (mostly male), so as to maintain a breeding stock. The assemblage from hunting would thus cover a greater age range and contain more species. The counterargument is that hunters would kill those easiest to kill—the old and the young—that there could be species preference, and that no difference would necessarily occur. It is stated that domestication inevitably results in a reduction of body size and that the presence of smaller—as distinct from younger—animals is indicative of domestication. Why this phenomenon, which is accepted by archaeologists, should be is unknown (see 12). It could have arisen from the initial selection of genetically small specimens to be domesticated. It could equally have arisen from malnutrition. Jarman and Wilkinson (13) have produced evidence that at the time of domestication there was also a reduction in size of wild animals, due perhaps to climatic change. Morphological changes certainly are associated in the long term with domestication. The morphological divergences seen in breeds of present livestock and companion animals are examples. How fast such changes took
place on initial domestication, when selective breeding could hardly have occurred, is unknown.

What is remarkable, however, is the small number of animals species that have been domesticated. Evidence from the Old Kingdom and elsewhere in antiquity suggests that species other than our present domesticated species were at least tamed. It is strange that, despite the obvious reliance placed on the wild red deer in Eurasia, this animal was never domesticated.

The problem of deciding whether plants are wild or cultivated is much more difficult. The usual criterion is the abundance of the species in the assemblage, an assessment rendered difficult by the paucity of remains. As long periods of time elapse, morphological changes occur in grains, due no doubt to selection, but initially there are few diagnostic differences between wild and cultivated plants. The presence of storage pits and querns is not unambiguous evidence of domestication because gathered wild seeds could also have been stored and processed.

It is certain that gathering coexisted with cultivation of plants for a long while in both Europe and the Americas and that, over a similar long period, animals were obtained for food through hunting, various sorts of management of wild herds, partial domestication, and confinement at settlements. In Eurasia there is evidence of a westward progression of a food production economy based on barley, wheat, legumes, and sheep; in America some evidence of a northern progression of a maize, bean, and squash economy. It is not known whether this progression was due to a migration of people who had acquired the new skills to new areas—similar to Europeans transporting their technology to colonize the Americas in the present millennium—or an expansionist diffusion in which there was spread of material and ideas by contiguity. The spread of wheat and barley cultivation in Europe is shown in Fig. 2 (14).

The Development of Agriculture

The earliest cropping husbandries were based on cycles of clearing land and cropping it until fertility was exhausted. These activities supported small groups of people. Later, when the civilizations of Mesopotamia and Egypt arose, the alluvial soil brought down by the great rivers allowed continuous cultivation of the same land and the development of irrigated land farming. Animal husbandry—pastoralism—tended to be a separate activity on rain-fed land distant from the city centers. The invention of the plow drawn by oxen, which initially only scratched the soil rather than inverting it, reduced the amount of manual labor involved in cultivation and allowed expansion of cropping from the river valleys. A structure of land ownership, laws, taxation, and trade—both in food and other commodities—developed as a larger hinterland was cropped.

It was these technologies of rain-fed farming and animal husbandry that were eventually adopted in Europe. Initially those who produced food and those who consumed it were the same people; even then any small surplus production was
bartered or, as in the Roman era, sold to support larger groups of nonproducers. Market economies eventually developed in which food producers catered to the needs of cities and towns as well as their own. Even in medieval times, food in excess of the needs of producers was small. The ratio of yield of grain to amount sown was less than 4:1 and not only did seed have to be saved for the next crop but only a half or a third of the land could be cropped each year—the remainder being left bare in fallow. Long sequences of years with bad weather—such as that in the 14th century—resulted in low yields, and the declines in the population of Europe at that time reflect poor nutrition of the population as much as they do the ravages in bubonic plague (15). A similar decrease in population had occurred in the 6th century.

Considering only the more recent past, many technological changes have taken place in food provision. A major one was the closer integration of livestock with cropping. Manure from animals was needed to maintain the fertility of land, and the introduction of root crops and fodder crops such as legumes on land formerly fallowed enabled more animals to be kept, more manure to be produced, and higher yields to be obtained. Introduction of the potato and of maize into Europe resulted
in a greater return of food energy than from temperate cereals. Replacement of the ox by the horse as a draft animal increased the rate at which land could be tilled, although it entailed using somewhat more feed for the purpose. It also improved transport of commodities to the towns. Improvements in implements mostly led to economies in labor rather than to increases in output, but they too represented considerable advance.

The greatest change in food provision has taken place in the last century. Agriculture had always received some input from conventional industry and the non-agricultural sector—iron to replace the wooden implements and town refuse as manure are examples. In the last 75 years, however, draft animals have been replaced by gasoline engines, and fertilizers and agrochemicals produced by industry have been used to increase yields of crops. Continuous cultivation of cereals on the same land without dependence on livestock to maintain fertility is now commonplace. The ratio of yield to seed for wheat in the whole of the United Kingdom is now in excess of 40:1, massively above that achieved even ten generations ago. Concomitantly, sophisticated food technologies have arisen together with distribution networks for packaged items of food that are of continental dimensions. These modern food systems are no longer wholly dependent on biological resources but on continuing inputs from nonagricultural industry. For every joule of food consumed in countries with such food systems, about 10 J or more of energy derived from oil, natural gas, or nuclear power are expended in its production, processing, and distribution (see 16).

ANALYSIS AND CONJECTURE

Man is a most successful mammal. At the end of the Pleistocene world population was about 10 million and now it exceeds 5,000 million. The increase has not been uniform in time, as is shown in Table 3 (16). There were long periods in which falls occurred; nor has population growth been geographically uniform. It follows that, averaged over a period of more than 10,000 years, man’s food supply has been sufficient for his numbers to increase. Food provision has always been and will continue to be a major activity of man. In the last century and a half industrialization of Western societies has changed the balance between the sectors concerned with food production, processing, and distribution and those concerned with other activities. This has only been possible because a reliable, nutritionally adequate supply of food has been achieved.

I began with the premise that the overriding problem confronting man throughout history and prehistory has been how to obtain a secure and sufficient food supply, stable over time. A reliable food supply is indeed a prerequisite for man’s other activities.

The methods employed to achieve food security have varied over time. Movement of people in response to seasonal changes in food availability was an early device that still persists in some communities. The transport of food to settlements and its storage—initially limited to nonperishable items—is a later one, and a more recent
one has been the use of food preservation methods. There has always been competition from other organisms for food resources. Man was not the only hunter; there were other carnivores and equally those of his own kind competing for the wild animal resource. Wars have been fought for the possession of the resource of land. Large-scale migrations of people can equally be regarded as a result of competition for land and the food resource it represents. Competition from pests and disease organisms affecting food supplies was not solved until the present era. Earlier solutions to this problem may well have been the use of a variety of food sources rather than reliance on a single staple. The famine in Ireland following phytophthora infestation of potatoes is a recent example of the problem of reliance on a single staple.

Innovation in the Provision of Food

Given the premise that achievement of food security has been the main problem throughout history, and acknowledging the massive changes that have taken place
in food provision over millennia, one can inquire about the factors that have been responsible for change. Change comes about through the widespread adoption of new technology (17). I contend that in seeking explanations for change, a search for the primary inventor of a new technology is less important than is analysis of the factors responsible for its adoption. The rate of adoption of new technology has accelerated throughout history as means of communication have improved. It took 3,000 years for wheat cultivation to move from Southwest Asia to western Europe 7,000 years ago; 200 years elapsed between the invention of the seed drill in the 17th century and its general adoption in the UK early in the 19th century; at present, if regulatory authorities in different countries agree, it will have taken less than 10 years for bovine somatotropin to become a component of modern dairy farming on an international scale. Speed of adoption has certainly increased. However, whatever the speed of technological change, those who adopt new methods must perceive advantage over existing practices and a necessity to change before doing so. Necessity is the father of adoption of new technology; it may have little to do with its primary invention!

Necessity in this context implies that the existing food system does not or cannot provide a secure, sustainable food supply. This obviously applies to primitive subsistence groups and to peasant societies in which the relationship between procurement and consumption of food is direct. In complex food systems change results from decisions made by some or all of its multiple components to whom the necessity is not that of providing a stable and adequate food supply but to ensure survival or profit of the firm concerned. Market forces mostly ensure that such individual decisions work toward a common weal, but governments in all countries adopt policies in food and agriculture to place some constraint on the operation of such forces.

Inability of a food system to cope arises from failure of food resources to meet demands made by the population that depends on them. Population growth which places greater demands on the primary resource, progressive reduction in the carrying capacity of land under particular food procurement methods, changes in weather or climate affecting the productivity of the resource, and failure of storage, transport, or distribution of food are the factors that necessitate change and lead to adoption of new technologies.

This argument provides an explanation of human progress in food provision. It also can account for the survival of “primitive” or “old-fashioned” cultures. In these the overall system could cope; there was no necessity for change. Thus there does not appear to have been pressure from population growth in existing hunter-gatherer cultures (18) and, despite effects of climatic change, their food resources have always been under-exploited.

Prediction

To predict the future entails asking whether present food systems are likely to continue to provide a secure and sufficient food supply, stable over time; that is,
whether there are possibilities of failure of food resources to meet future demands by the world’s population. There are reasons for concern. Population is increasing and, because of the momentum that past growth imparts, will continue to grow. Land resources for food production cannot augment at this rate because most land capable of cultivation is being cultivated; land is increasingly being used for industrial purposes, infrastructures, and housing; and there are limits on the extent to which clearance of forests and native grasslands can contribute to the stock.

Current methods of maintaining and increasing the productivity of unit area of land now depend on the use of industrial inputs in the form of mechanical power, fertilizers, and agrochemicals. These in turn depend on energy derived for the most part from fossil fuels, and the secondary processing—packaging, transport, and distribution of food—is equally dependent on these energy sources. The system as a whole is not stable over time. Furthermore, dependence on fossil fuels as energy sources leads to carbon dioxide accumulation and the possibility of global warming. Temperature increases sufficient to elevate global temperature to that experienced 6,000 years ago seem possible.

Over the last 10,000 years solutions have been found to the primary problem by modifying food procurement—domestication of plants and animals, inception of agriculture, land reclamation, irrigation, colonization of new areas, genetic improvement of plants and animals, rotational farming, mechanization, and the use of chemicals. New technologies to be applied to food production will be required in the next century because our present system is not stable. These may well arise from current discoveries in genetic engineering. In the search for new ways of achieving an equilibrium in the man–food relationship, however, the most obvious solution would be to control the number of people competing for the food resources of the world.

REFERENCES


DISCUSSION

Dr. Harper: Diseases such as AIDS are going to reduce the productive population. There will be a fall in the average age and a large number of orphans. Reduced productivity in the remaining population seems inevitable.

Sir Kenneth Blaxter: The situation is complicated and uncertain. Some of the American models with a joint epidemiological-demographic approach to HIV infection suggest that there would be a reduction in the working proportion of the population, but my preferred models indicate no gross change in the population structure. Much of this depends on the extent of vertical transmission of the infection, however.

Dr. James: The model you prefer is therefore different from the one that is being put about in Africa, where the concept is that people are infected from roughly the ages of 16 to 50, with newborn babies also being infected. Is it your assumption that the 2 to 15 year age group will grow up sufficiently rapidly to maintain agriculture when their parents are dying and thus sustain the population’s productivity?

Sir Kenneth Blaxter: Yes, this is the Anderson and May model from Imperial College.

Dr. Hulse: One of the best nutritionists in central Africa is now entirely occupied with the problem of AIDS rather than infant malnutrition. Because of AIDS other aspects of nutrition and public health are being seriously neglected.

Dr. Olson: The priority given to AIDS is also evident in hospitals in the developed world. In my own medical school the allocation of resources in clinical nutrition has been preempted by patients with AIDS who have a totally untreatable form of malnutrition. This problem is going to be with us until a definitive method of preventing or treating AIDS is developed.

Dr. Vis: In central Africa, at the core of the AIDS epidemic, AIDS is a disease of the cities and not of the rural populations. The demographic spurt and accompanying nutritional problems are much more important in the rural areas. Do the models take these differences into account?

Sir Kenneth Blaxter: Not as far as I know. Anderson and May took overall national statistics. How this affects the primary problem of the availability of the work force is not clear.

Dr. Jéquier: In relation to food production required at population equilibrium you suggest an increase per capita of about 30%, i.e., from about 10 MJ to 13–14 MJ per day. Is this not too high an estimate for a mean energy requirement?

Sir Kenneth Blaxter: I don’t think that the FAO/WHO estimates of food needs are sufficiently accurate so I have made an entirely moral judgment and said that it is right and proper that people throughout the world should have the same choice and availability of food as those in the West. I have not based my statement on any nutritional estimates.

Dr. James: The 14 MJ figure refers, I think, to food supply, so it takes into account the problems of distribution and waste. The moral judgment is therefore right in the context. It also has a dimension in agricultural policy because if you specify what the actual requirements
are for every single person in the world to be fed properly, then the average figure would indeed be much less.

Dr. Georgala: Could you comment on how the models might be affected by changes in animal versus vegetarian diets, given their different efficiencies in terms of food supply? A change in vegetarianism based on health concerns is seen in developed countries but the opposite trend is occurring in developing countries, where meat consumption is seen as a desirable objective.

Dr. James: In this regard, FAO economists consider that whenever a country becomes more affluent its people demand more animal foods. This implies a bigger demand for and importation of cereals. One economist predicts that if China meets her demand for meat in 5 to 10 years’ time there will be a catastrophic rise in world cereal prices as she tries to import sufficient cereals to feed her pig population.

Sir Kenneth Blaxter: Animals are not just eaters of cereals and competitors of man. They consume a whole series of agricultural and other wastes as well as being able to feed off land that is uncropable. I cannot see a massive increase in demand for cereals on this account. When a country moves to cereal surplus then the animals are usually fed on the surplus. China has one-third of the world’s pigs, but they do not compete to any large extent with human requirements because most of them are fed on household refuse and other waste materials. Thus they are commensals rather than competitors. I think it is quite wrong to draw the conclusion that if only animals were removed from the economy everything would be all right and the human race would have food for evermore.

Dr. Kumar: I think we can be optimistic about the sustainability of the food supply. We have witnessed a revolution in agricultural efficiency over the past 75 years and I think there is a long way to go before we see this process arrested, though there is of course concern over whether its sustainability is ecologically sound. We have seen both in the USA and in the UK a reduction in land under cultivation, yet the amount of food produced is much greater than before. I don’t know what the time scale is for us to see the same phenomenon on a worldwide scale, and population growth rates are clearly an important part of the scenario. The increase in grain production and the reduction in land area under cultivation would both also contribute to the potential for animal production.

Sir Kenneth Blaxter: The past few years have certainly shown a massive increase in productivity and one can extrapolate, but over what time scale? I don’t think you can extrapolate up to the middle of the next century and come up with sensible answers if you accept that an increase in productivity of around threefold will be needed from a defined area of land. Records obtained from crops around the world suggest that yields within 5% to 10% of the theoretical maximum can be achieved under ideal conditions. In many countries average yields are now approaching 50% of theoretical maximum. If this is so, you cannot increase production threefold; thus in terms of the population demand in the middle of the next century I don’t think the argument about what is happening to agricultural productivity at the moment is really relevant.