Better crops for food

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Better crops for food

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Chairman's introduction

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The topic of our meeting, better crops for food, is one that is likely to become increasingly important as the years go by. Some of us were involved with the Darwin centenary in 1982 but the bicentenary of James Watt's first patent on a steam engine which drove machinery efficiently may be much more important to this symposium. That development, followed by the development of the internal combustion engine, totally changed the world. It also revolutionized agriculture and food production by making it possible for fertilizers to be extracted from the ground on a large scale by the use of mechanical excavators driven by fossil fuels. These fertilizers could then be transported over great distances by trains, trucks and ships, all of them burning coal or oil, and used on farms worked with tractors and irrigated by mechanical water pumps.

It is important to recognize that the fuel oils and coals are themselves a plant resource, although a dead plant resource. Using these oils and coals we have been able to raise the standards of living in the West to unprecedented levels. At the same time population levels almost everywhere have been increasing too. When Watt patented his steam engine there were about 1000 million people in the world. In 1960 there were 3000 million, in 1980 there were 5000 million, and the estimate for the year 2000 is some 7000 million people.

With the development of the steam engine Victorian England and the rest of the affected parts of the world assumed that at last the human race had control over nature. But looking at it in retrospect, and thoughtfully, we can see that what James Watt did was to show us how to open the world's savings bank and spend the money. The money in the world's savings bank is coal and oil, the fossil plants. We have basically two sources of money available to us: the day-to-day income represented by the products of living plants, and the money in the bank represented by the fossil reserves formed from plants. Outside my office there is a tree, *Sophora japonica,* with a plaque stating that it was planted in 1759 for Princess Augusta who lived at Kew. That tree which is growing and flowering at Kew now was growing and flowering before the Industrial Revolution. Within the life of this single tree we shall have used up much of the world's coal and oil reserves. In the life-span of one tree, or three human generations, we shall have spent the savings represented by thousands of generations of trees spread over millions of years. When the coal and the oil have been used—and whether that takes 50 years or 500 makes not the slightest bit of difference in terms of the history of the world—we shall be dependent once more on the living plants for many of those things we now obtain from coal and oil. We shall have to live on our income instead of on the world's savings, just as our pre-eighteenth century forbears did.

Tragically, however, we are destroying much of this possible income by destroying the plant reserves of the world. We are using bulldozers to remove large sections of the undeveloped and wilder parts of the world. Tropical rain forests, a popular theme now, may largely disappear by the end of the century if we continue treating them as we are doing at present.

When one makes remarks like this, one is sometimes accused of being a pessimist and people say 'They'll find something else before it has all gone'. Who actually is going to find something else I am not sure. There are, we are told, alternative sources of energy, and this is perfectly true. One can develop nuclear power, wave power, wind power and make more use of the sun, so we shall not be totally dependent on biomass for our future energy supply. The really critical problem is to find a source, other than plants or fossil plants, of compounds with more than one carbon atom in them. Only plants, using their photosynthetic processes, can convert carbon dioxide from the atmosphere into carbohydrates and ultimately into other compounds with hydrocarbon chains and rings with the efficiency and on the scale needed. Ultimately there will be a shortage of carbohydrates and chemicals containing hydrocarbon skeletons rather than an energy crisis. Of course many of these compounds we are talking about are foods. For better or worse we have to eat so it is really a food crisis I foresee and this is the subject of our symposium. Other problems, such as the disappearance of oil and coal-based drugs and chemical intermediates, are all relevant but they are not our immediate concern at this meeting.

What are we going to do about this crisis? If we can no longer boost food production by adding fertilizers then we have to look at other ways of boosting it; we have in effect to make plants produce more effectively in their natural environments. In the past, using fertilizers, we have changed the habitat to suit the crop plant. When we can no longer do this, we shall need to change the plant to suit the habitat. This we can achieve by improving established crop plants, developing underdeveloped crop plants, or bringing into cultivation plants which have not been used before.

The question of developing underdeveloped or partly developed food crops is one dear to my heart because I think there is great potential for this. When we look at the major crops of the world, such as wheat, rice, barley, potatoes, maize and so on, we are forced back to the conclusion that these were not developed by agricultural scientists like ourselves. They were in the first instance developed by primitive peoples living in their various environments and studying the plants that grew around them. We are therefore indebted to these people, whom we condescendingly call primitive, for some of the biggest developments in agriculture.

There is, however, a great pool of information which we have not yet tapped. In many parts of the world plants other than the major crop plants are used regularly on a small scale as sources of food, while others are used less regularly as famine foods when everything else fails. There is a great deal of potentially valuable information to be found here and a great deal of empirical breeding has already gone on with such minor food crops.

One way forward is for us to determine whether, using modern scientific methods, we can improve these plants faster than was possible in the past and turn them into wholly acceptable food crops which may have applications in other parts of the world. We must also improve the crops we are already using and we must look for alternative crops. When looking for alternative crops we must bear in mind the needs of conservation. We have great reservoirs of untapped biological material in the wilder parts of the world. When we receive plant material at Kew as many as 20% of the species coming from some areas of South America have never been described before. This emphasizes both the need to conserve wild resources and the enormity of the task of evaluating the economic potential of the world's plants. Side by side with the development of agricultural crops must go conservation to ensure that these wild resources are maintained alive and well, so that in the future we shall still have this natural bank of unexploited species and genes to draw upon. It is foolish in the extreme to destroy all the wild habitats. We clearly can't save them all but we must preserve certain areas and maintain them while encouraging responsible agricultural practices and techniques elsewhere.

In this symposium we have drawn on the expertise of people from many different disciplines who are approaching these problems in different ways. I sincerely hope that at the end, and when we read the book, we can look back and say that the meeting was worthwhile and that it gave a lead to the solution of some of the major problems which confront us.

Better crops for food—an overview

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Abstract. For a discussion of this kind an agreed meaning must be attached to the word 'better'. Crops that are better for the producer are not necessarily better for the consumer and the ultimate consumer is often quite different from the initial purchaser of farm output. In developed countries, a large processing industry operates between the farmer and the ultimate consumer: in developing countries, the hungry have no money to buy food. The purpose of crop production for food is thus neither simple nor obvious and a distinction has to be made between better species for particular purposes and better varieties for the same purpose. For the producer, a better crop is one that improves the crop production system as a whole and this requires an adequate understanding of the system, including its non-biological components. It has to be recognized that technical developments can be rendered ineffective by changes in costs and prices. The judgement of relevance in applied research has to take this background into account and, if 'better' cannot always be predicted, thought needs to be given to how it can be sought.

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The search for better crops, especially for food, seems so obviously worthwhile and important that the question of what is meant by 'better' may be neglected. Yet it is clear that the meaning must vary with the people and the purposes for which the crop is grown.

In general, a crop is better for the producer if it is more profitable to grow, and this does not always coincide with it being productive per unit of land or, indeed, any other resource. To the ultimate consumer, it may be better if it is of higher quality, better colour, more nutritious or cheaper. But the ultimate consumer is often not the purchaser from the grower and, to the purchaser, a crop may be better if it is easily transported, dried or processed, or if it leads to a greater profit.

In the developed world, there are usually intermediaries between producer and consumer and most crops yield products that are subjected to considerable processing before they are consumed (Table 1). Even in the developing

TABLE 1 Percentage of UK food that is processed and packaged before consumption

70%	when meat excluded
	i.e. unprocessed food: eggs, fresh fruit and vegetables and meat
85%	when meat is included as processed

world, most food crops are processed and cooked before consumption, even when the grower is also the consumer.

The purposes of food crop production are therefore numerous and may determine the choice of crop species on the grounds that, for a specified purpose, one crop is better than another. This symposium, however, is more concerned with better versions of particular crop species: if a tomato is required there is no way in which turnips or cabbages can be 'better'.

Nonetheless, it is often argued that some species are better than others in the sense that they would feed more people per unit area of land. This is usually argued in favour of crop rather than animal production. In developed countries, however, this line of reasoning is wholly irrelevant. In the UK, for example, it could be argued that in many areas barley was more productive per hectare, and indeed it occupies 34% of the arable land, but it is grown because it is profitable to the producer and it is mainly used, not for food, but for beer and animal feed (see Table 2).

TABLE 2 Production and utilization of barley in the UK, 1980

	Amount (tonnes × 10^3)	%
Total production	10315	
Total utilized	8645	100
Utilization		
Malting, flaking and roasting	1805	20.9
Distilling	255	2.9
Pearl and pot barley	10	0.1
Animal feed	6005	69.5
Seed	415	4.8
Waste on farm	105	1.2
Waste in distribution	50	0.6

Source: MAFF (1981)

Improvement within species is only slightly easier to define than choice between species. A crop species is grown because someone wants the product and, if it is sold, someone is prepared to pay enough for it to make it worth growing. It is true that the price will vary according to whether the product is scarce or in surplus but this may be a result of the weather and how many farmers choose to grow the crop: it may have nothing to do with the productivity of the species.

The fact is that crop production is an economic activity and, even when the product is not traded and no money is involved, it is always concerned with the efficient use of resources to produce what is wanted. But it is never concerned with only one resource, even in the relatively simple cases where only one product is involved. For this reason, producers are always concerned with better crop production systems and a better crop species has no meaning for them unless it results (or can result) in a better crop production system.

Crop production systems

It is a cardinal proposition in the study of agricultural systems that no change in a component can be regarded as an improvement unless it leads to an improvement in the system as a whole—in whatever terms the operator chooses to express this. The terms may vary but they will rarely be confined to measures of output only: no one ever wishes to produce more of anything, except per unit of something else. No one can afford to produce more without regard to the cost. Furthermore, *all* the costs have to be taken into account, including labour, rent, interest on borrowed money and cost of machinery bought or hired.

Those who are concerned with technical efficiency, such as output per unit of fertilizer, irrigation water or pesticide, need to assess improvements in these ratios in the context of the wider framework of the whole production system. If we are concerned about national goals, it may be necessary also to go beyond the production system and include service, input and processing industries, markets and transport systems.

Of course, sometimes one resource is scarce, limiting or costly and can usefully be focused on. Support energy is a current example. There is no doubt that developed agricultural systems are now very dependent on support energy and that this now figures prominently in production costs (Table 3). Consider how different the position looks for two major foodstuffs, milk and wheat, in terms of support energy inputs, depending on whether the calculation stops at the farm gate or at the final consumer (Table 4). The fact is that milk can be drunk virtually as it comes from the cow, but no one eats raw wheat.

Efficiency in the use of a resource, measured in technical terms, therefore varies according to where the boundaries are drawn around the production system, and where they are placed depends on the interests of the individual making the calculation. Thus the improvement of components has to be judged not only in terms of the system of which it is a component but also in

TABLE 3 Support energy cost as a proportion of total cost (at January 1981 prices)

System	$\frac{\textit{Support energy cost}}{\textit{Total cost}} \times 100$ *(%)*
Dairying—intensive	77.8
—extensive	69.9
Beef—intensive	87.9
—extensive	74.0
Breeding sows—intensive	79.2
—extensive	70.5
Eggs—intensive	81.4
—extensive	75.4
Broilers—intensive	82.6
Pigmeat—intensive	86.4

Source: Spedding et al (1983)

TABLE 4 Examples of crop and animal production showing effect on efficiency-of-energy-use of inclusion of energy used in processing

	MJ of energy in product per MJ support energy used
Bread—white, sliced, wrapped	0.5
Wheat	3.2
White sugar—refined, from beet	0.6
Sugar beet	5.6
Milk bottled and delivered	0.595
Milk at farm gate	0.65
Beef—to the table	0.0129
—at farm gate	0.0132

Sources: Leach (1976); Spedding & Walsingham (1976); Pimental & Pimental (1979).

relation to two important questions: 'what is the system to be improved?' and 'what constitutes an improvement?'. Unfortunately, even where the aim is limited to achieving greater productivity or profitability for a producer, the production system rarely operates in isolation.

One consequence of 'green revolution' packages, successful in their own terms, was to increase the competitive advantage of the large farmer, who could afford (or obtain credit for) the inputs of fertilizer, water and pesticide required to take full advantage of the 'better' varieties of wheat and rice. Thus the innovation could actually damage some of those it was meant to benefit, simply because it benefited others more. There were also changes in the proportion of cereals to pulses, resulting from the greater profit to be derived from the former and leading to a reduction in the protein available for the local human diet.

Furthermore, landlords and suppliers of inputs can raise rents and prices in the mere *expectation* that land is about to become more productive. In fact, because product prices can fall and input costs increase so quickly, there can be little guarantee that greater productivity will lead to greater profit—and frequently it does not, or only does so for the pioneers.

Some argue that this is the justification for publicly funded research—that its results benefit the consumer, by lowering prices, rather than the farmer. Yet recommendations have to be profitable to the leading farmers or they will not be adopted.

The relevance of research

Against this background (and it has only been briefly sketched) it is hard to be sure of the relevance of research, whether planned, current or completed. For some kinds of research, of course, relevance to practice is not an immediate aim but for applied research it must surely be the most important criterion. Yet relevance can only be assessed in relation to specific purposes and to actual or potential production systems.

Some progress can be made by doing sensitivity tests on mathematical models, and greater use should perhaps be made of very simple but realistic models, rather than no use at all or reliance on very elaborate, computerized, simulation models. Commonly, research proceeds by investigating possibilities and then trying them out in practice. Such trial and error can be expensive—unnecessarily so where failure could have been predicted if the importance of other factors (e.g. labour, which is often ignored in biological research) had been more clearly recognized.

One lesson to be learnt from a wider view is that sometimes the targets should be quite different from those normally adopted. For example, sometimes low-input systems may be better than high-output ones, or high output should be expressed per person or per unit of support energy rather than per hectare or per unit of solar radiation. Sometimes, perhaps, the target should be the small-scale farmer rather than the large-scale operator. The majority of the world's farmers are small and even in the UK the proportion farming small areas is considerable (Table 5), even though the major part of agricultural output comes from big farms. Yet the needs of large and small farmers may be very different.

For example, a better crop for a large-scale farmer may be one in which a high proportion is ready for harvest on one day, so that a large machine can make one pass and harvest most of it. On the other hand, for the subsistence farmer who wishes to harvest food every day, a better crop may be one that continues to yield over a long period. There is a danger that plant-breeding

TABLE 5 Numbers of small farmers in UK and the world

UK 1975			*World (80 countries)*	
*SMD**	*No. of holdings* *($\times 10^3$)*	*% of total holdings*	*Size of holdings (hectares)*	*% of total holdings*
<275	115	42	<5	82.7
275–599	65	24	<1	40
600–1199	53	19		
>1200	40	15		

*Standard man days
Sources: MAFF et al (1977); FAO (quoted by Streeter 1975)

will focus on the first rather than the second need because it tends to be associated with large-scale production or the countries that engage in it.

Exactly comparable arguments relate to animal production. In case these appear to be a different subject entirely, let us note that a very large number of crop production systems use animals for traction; that these animals have to be fed, either by growing feed for them or by giving them by-products of crop production; that their dung is often a major product of the system as a whole (for fuel especially); and that the crops grown have to suit the forms of animal power available. Animals cannot therefore simply be ignored in determining what is a 'better' crop.

The problems of assessing a research 'breakthrough' are clearly substantial. A breakthrough in one of the underlying sciences may be clear enough but whether it represents a breakthrough or even an advance in *agricultural* research is very hard to judge.

If 'better' cannot be predicted, can it be sought? Applied research is obliged to try to do this and the argument here is about understanding the context within which the search has to be undertaken. This raises some organizational problems, since not all research workers in agriculture can be expected to understand the practical systems within which their results will be applied.

There are some topics to which most research workers seem willing to accord priority, on the grounds that it is essential to understand a process as important as photosynthesis, for example, or to know how to do something such as increase disease-resistance or pest-resistance in plants. This discussion suggests that because of the wide range of practical contexts, it may be useful to know several ways of doing something, because it is hard to know in advance what will prove economic.

In world terms, the range of research aims may have to be widened to include, for example, growing crops with less fertilizer; breeding crops for small-scale production and storage, for local transport and local forms of processing; selecting species that need less processing; and providing crops that yield a great deal of biomass that can be partitioned for food, animal feed, fuel and industrial use. This last point is mentioned because it may be neglected in a discussion that focuses on food crops.

World hunger

Finally, 'better' crops must be considered in relation to world hunger, not because hunger is particularly relevant but because it is widely thought to be so.

Probably most people concerned with agriculture like to believe that they are in some way contributing to solving the problem of world hunger, and it would be absurd to argue either that there is no connection or that such contributions cannot be made. There are, however, a number of unpleasant facts that also need to be borne in mind. As is widely recognized, the hungry are so because they are poor. Apart from disasters, people who have money are not hungry, and if the poor had money to buy food, it would be produced. There really is not a shortage of food or of capacity to produce it: indeed, in many areas, including the European Community, there is significant overproduction. Nor is it always, or simply, a problem of distribution or even of social justice, though there are certainly enormous problems of these kinds.

Some of the hungry are small farmers and their families who do not have enough to eat in poor seasons. Some are the rural poor who depend on the health and wealth of local agriculture. More could be done for these small farmers by relevant research. The mass of the urban poor, however, represent a much more intractable problem for agricultural research. Better crops to the urban poor are crops that produce very cheap food but, for the very poor, it can never be cheap enough.

These are very complex matters and it is dangerous to oversimplify them. But it is also a considerable oversimplification to imagine that crops are produced mainly to feed hungry people, even though without crop production the world would clearly starve.

The fact is that simply producing better crops does not reduce the number of people who are hungry. Yet, surely, there are ways in which it could help. It is with this in mind that I end with a question: 'What is a better crop to a hungry person?'.

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DISCUSSION

Bell: In deciding whether the production of meat is an economic proposition we must consider whether the plants that animals eat could themselves be consumed by human populations. The production of beef from grass, for example, is surely an economic process whereas perhaps the production of beef from maize is not.

Spedding: It is of course generally claimed that there is a vast part of the world which is grassland and therefore must be converted into animals. In fact there is no part of the world that cannot grow crops for direct human consumption if enough labour is put into it. You can see that in a place like Thailand where the mountains are terraced.

Secondly, one of the things I was arguing was that animal production and crop production are very much integrated. If the animal is needed to help you to grow the food, then it makes sense to eat some of the animal products as well: the animal is not going to live for ever so you might as well kill it and eat it just before it would have died.

Thirdly, if you do have to sustain animals then a better crop may be one that produces some food directly for you and also some by-products on which you can feed your animals.

Holmes: About 20 years ago the vegetable protein industry produced vegetable protein products as meat substitutes. These appeared to have great potential but in practice they have not sold well. I would have expected the price of meat to rise in real terms over the last 20 years, indicating that vegetable protein manufacturers would be able to sell their product, but instead the price of meat has gone up only in line with inflation. Twenty years ago we would have said exactly what has been said this morning about the need for more food. So is the food shortage you are talking about really imminent? Is it going to happen at all?

Spedding: Whether there is a crisis depends on where you are standing. The developed world will pay for meat because it wants it and irrespective of whether it is using barley, for example, to produce it. If the barley did not go into producing the meat animal it wouldn't go to the hungry people: next year it would not be produced at all. For people who are hungry this argument is irrelevant. They haven't the money to buy either the meat or the other crops.

Holmes: The prediction in the 1960s was that the standard of living in developing countries would increase, and it is increasing in many countries. India is becoming prosperous compared to what it was 20 years ago. One expected then that there would be an increased demand for meat, because people like eating meat. This would put pressure on world food resources and force the price up. But that doesn't seem to be happening. The standard arguments used over the last 20 years do not tie up with events.

Boulter: Several new elements have affected the prediction that vegetable protein would be a viable commercial substitute for meat. One is the cheap production of chickens by the broiler industry; a similar situation occurred with pigs so that meat prices rose less steeply than anticipated.

Another reason for the failure of textured protein was that most of the effort was put into simulating beefsteak instead of introducing other forms of vegetable proteins to the food industry. Technically it was much more difficult to produce knitted beefsteak than had been anticipated. Another problem was that it was mainly launched as a substitute for meat and cheaper than meat, so people thought it was second class. The Inner London Education Authority launched vegetable protein more effectively with an educational programme saying that it was a more healthy form of food.

Rudd-Jones: It will be interesting to see whether Rank-Hovis MacDougall's mycoprotein takes off. The prospects for leaf protein looked very good years ago but most novel protein sources have been resisted as foods for humans. When a small fish called *Haplochromis* was converted into fish meal in East Africa it was resisted very strongly because it was rumoured to make people sterile. Another fish with a snout like a pig (*Mormyrus*) was rejected on religious grounds. This is a digression from our real discussion but the point is that what people choose to eat in developing or developed countries may be determined by social *mores* or habits over which there is no rational control. If people in developed countries want to eat fresh tomatoes they will pay for them even though they may be very energy-expensive to produce locally or to import from more southerly latitudes.

Nair: Not every area where grass grows now can be made to grow crops for direct human consumption, Professor Spedding, because of the cost involved. Terraces, for example, are good for soil conservation, but they take too many resources, both for their construction and their maintenance.

Secondly, when you consider the systems approach to cropping, why not go one step further and consider the whole farming system as one unit?

Spedding: What I said was that any grassland area can produce human food directly if there is enough labour. You are right that the cost would frequently be exorbitant. That emphasizes again that the choices are really economic ones.

I entirely agree that one has to view a wider and wider system to make adequate judgements. I would go further and say that forestry must be considered as well as crop and animal production systems.

Scowcroft: How do you arrive at the figures for efficiency-of-energy-use in Table 4? There was very little loss with milk, yet with flour or bread there was a 6 or 7:1 conversion. The transport costs for milk and wheat must be much the same.

Holmes: Baking ovens are very inefficient but energy is too cheap for there to be any major economic incentive to improve their efficiency.

Scowcroft: But that is not true for other crops. Professor Spedding also gave the figures for sugar beet but the ratio for cane sugar is much better because the whole crop is utilized, part of which provides energy.

Spedding: That is true, but by the time cane sugar has been brought to the UK and refined the figure is not very different from that for sugar beet. It is mainly the processing that uses a lot of energy, not the transport. The calculations are all based on the energy content of the food, that is on the output. You can criticize that in terms of whether it is digestible, balanced and so forth. The inputs include not only the fuel used on the farm but also the energy cost of making the tractor and the fertilizer, and all other inputs apart from solar radiation.

Karikari: I still haven't got a picture of what a better crop is. Is it soybeans or cassava or what?

Spedding: That means I have done a good job! There will be circumstances when cassava is a better crop than something else, whether because more of it grows or because it is what people want, or is less susceptible to losses, or consumes fewer resources, or has a high yield per unit area of land or per worker or per unit of energy. But there will be other circumstances when 'better' will mean many different things. What I tried to say was that what one means by 'better' will depend on the purpose and the circumstances. These are going to vary enormously across the world and they are going to vary unpredictably in the future, which is where R & D is directed. The question then is, if we can't predict what is a better crop can we seek it?

Cooper: Looking at scenarios for low input systems may be particularly relevant where there is overproduction of many commodities, for instance in the European Community. As you know, there has been discussion about this in terms of grassland production. Fertilizer nitrogen has high support energy costs and high financial costs so should one use grass plus fertilizer or a grass-legume which fixes its own nitrogen, but which is less predictable and probably gives a lower output? In plant-breeding operations there has always been a tendency to say that what we want is higher and higher yields, provided we get the necessary quality. Perhaps we should instead ask whether we can produce the same yields with lower inputs.

Spedding: I agree, but we ought to beware of suggesting that we ought to turn to lower-input systems of research and away from something else. My point is that we need to widen the range of purposes for which we carry out R & D. In developed countries we have, perhaps unwisely, been concentrating recently on high output systems, disregarding the fact that they are also high input systems. We ought to use low input systems as well.

I also want to give a warning about our tendency to talk of going for a higher yield without saying to what unit the yield applies. In crop circles there is a tendency for yield to mean yield per unit area. That is not so for apple trees or for cows, where yield for individual organisms may well be meant. It is not a question of turning away from higher-yield crops but simply of altering the dimensions: yield per unit of what? It could be yield per unit of labour, or support energy or any of the important resources, and not just land.

Flavell: I support your view that one has to appreciate all components of the system. Clearly, the information gathered by people looking at the systems has to be transmitted to the people working on the component parts. Have you some examples or advice on how that information transfer should take place?

Spedding: It is difficult to answer that without sounding as though I wished to displace the Almighty. An occupational hazard for systems people is that when they try to answer a question like that, they sound as if they are telling everybody else what to do. In other words, a systems expert tends to sound as though only he or she has a picture of the whole system, and if you are working on only one component of that system the expert can tell you what kind of changes in that component would benefit the whole system. What is required of course is a dialogue between the two, and that can only be done when a basis of trust has been established. If someone is working on a component in an applied context, a systems expert could describe that system in such a way that the other person could see where the component fits in and what the effect of changes in it would be on the whole. That would have to be done by a mathematical model and that is now possible with the use of computers. That can give rise to a host of misunderstandings.

Willey: Particularly in the developing world, the farmer will certainly not accept an improvement in an individual crop unless it also leads to a net improvement in the whole system. Thus we must be aware how much a suggested improvement is likely to disturb a system. If we improve, say, the nutritional quality of a crop without altering the agronomic aspects this might be very readily accepted, provided of course the farmer considers he is getting some benefit out of it. But with new crops we have to be particularly careful: if a new crop replaces a similar crop it may be relatively easy; but if it requires different inputs, or if the farmer has to put in additional work, it may be a considerable disturbance to the system. To go one step further, the greater the disturbance to the system, the greater the rewards have to be for the farmer.

Epstein: Even with something rational like larger yields there are often emotional and irrational considerations. Someone who works for the Agricultural Extension Service in Iowa told me that he tried to get farmers to grow somewhat smaller crops because the additional input of fertilizers needed to get the extra bit of yield was not worthwhile. But in Iowa they pride themselves on getting the largest possible crop, however much they spend on fertilizer.

Spedding: There is no shortage of irrationality. Certain tribes in Africa, and in North America, will go for the biggest cattle whether they are more productive or not.

Zadoks: The systems analysts always work on one's conscience, as Professor Spedding has done with his two major questions: what is the system to be improved and what constitutes an improvement? The systems people, of whom I am one, have substituted mathematics for prayer but their effectiveness is not yet very different. In the Netherlands the major shortage is always land so the question about its most effective use came first. When industrialization set in, productivity per person became a priority. Now we are talking about yield per unit of energy input.

Another measure being promoted now is the return in financial terms. But we don't need to go to Africa to find examples of people who want big yields whatever the input costs: Dutch farmers want these too. A fourth approach being used now is to segment the market. There is a small but strong market for products with a low input of energy (including agrichemicals), and as long as the demand is great enough the economics are acceptable. Many different approaches are possible and there is apparently a gradual change with time.

Day: Professor Spedding did not mention the time lag in plant breeding. Even with inbreeding plants like cereals, up to 12 or 13 years go by between a breeder making a cross and the farmer growing a new variety.

Another important damping element in the system is the way varieties are selected by the national testing system. In the UK, varieties are recommended on the basis of yield, quality and resistance to pests and diseases. Changing the standards is difficult.

British farmers are competitive too. Some want to be in the Guinness Book of Records. Others have computers to monitor their cost-effectiveness. Most farmers try to produce as much as possible per unit of land, because land is in short supply.

Spedding: Professor Cooper earlier illustrated a low-input system not by the same kind of plant with lower inputs but by the substitution of, say, clover for fertilizer nitrogen in a grass–clover mixture. There one could make a rather different prediction about the need for putting breeding effort into clover, not on the grounds that one might predict that this would be useful but because we don't have the choice unless that work is done.

Nutritional aspects of improvements in legume seed crops

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Abstract. In developing countries where protein–energy malnutrition is common the limiting factor is energy, not protein, except where roots and tubers or bananas are the staples, when primary insufficiency of protein may exist. Increased and stabilized yields of legumes are the priority and nutritional improvement of legume seed composition is of secondary importance. Improvements must be related to the diet as a whole and often there is inadequate information available on diets for breeding objectives to be devised efficiently. In developed countries where diets are based mainly on animal products the desirability of replacing animal by plant proteins rests on arguments based on conservation and on health. However, the market for plant protein products has developed more slowly than expected, for several reasons. Improved nutritional education is needed urgently in both developed and developing countries.

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There are about a dozen major legume crops, each of which is used in a variety of different diets (Boulter & Crocomo 1979). This paper outlines important general considerations for the improvement of nutritional aspects of legume crops but does not attempt to survey in detail specific improvements in named crops.

Dietary considerations

Nutritional improvement of a legume only has meaning if related to the diet in which that legume is used. Improving the quality of a legume protein in a western European diet, in which ample good quality protein is provided from other sources such as meat, is not significant. However, in other diets such as those with staples of root or tuber crops, improvement may be another matter.

The optimum protein mixtures between *Zea mays* (maize) and *Phaseolus vulgaris* (beans) in a rat feeding trial are shown in Fig. 1. Cereals and legumes form the main part of the diet in many developing countries and Fig. 1 illustrates that cereal protein can nutritionally complement legume protein in a diet. It also demonstrates that different ratios of cereals to legumes can determine whether a diet is lacking in lysine or in methionine, the limiting

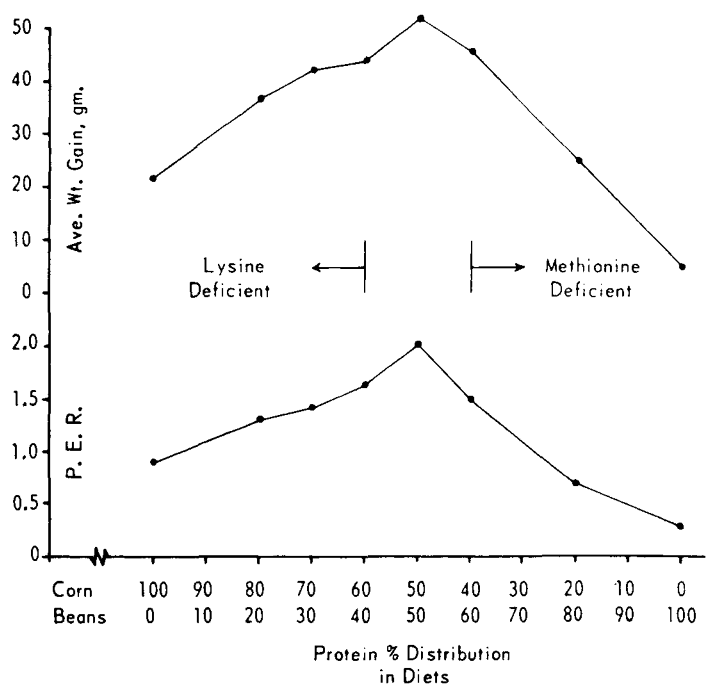

FIG. 1. Optimum protein quality mixtures between maize and *Phaseolus vulgaris*. P.E.R., protein-efficiency ratio.

amino acids, respectively, of these crops. Thus, increasing the content of methionine in beans or lysine in maize would be irrelevant at inappropriate ratios. When we consider improving nutrition in relation to diet, two world situations exist, broadly speaking—one in the developing countries, where the diet is based mainly on plant products, and the other in developed countries, where the diet is based mainly on animal products.

Developing countries

Nutritionally inadequate diets cause deficiency diseases in several developing countries. Protein–energy malnutrition (PEM) is the most important of these and is found mainly in young children of the poor. If PEM is severe, death can result; less severe forms of PEM lead to impairments, not only in childhood but also in later life (Srikantia 1982). Generally the primary limiting factor in such inadequate diets is energy, not protein, although in diets where roots and tubers or bananas are the staples, primary insufficiency of protein may occur. Kwashiorkor and marasmus, the extreme forms of PEM, have different clinical symptoms but probably not separate dietary causes, both being due primarily to caloric inadequacy and secondarily to protein deficiency. The symptoms exhibited depend on the response of the individual to the nutritional stress (Srikantia 1982).

More food is a prerequisite for correction of PEM but clearly many factors, including poor living conditions, lack of public health care and ignorance, are involved. The additional food must fit into the social pattern with regard to price and acceptability. Higher yields per hectare, which reduce the cost of the product while maintaining the return to the producer, are clearly important, and different legume crops are not necessarily equally acceptable in different places. Apart from such obvious characteristics as the colour and texture of cooked grains, less obvious factors such as short cooking times are of crucial importance when fuel is in short supply or where the social *mores* dictate that the women should not spend long periods cooking. The diet must also be attractive or the total amount of food consumed may fall short of nutritional requirements; legumes have been shown to improve the palatability of nutritionally adequate diets and thereby encourage consumption of a sufficient amount. Children, with their small stomachs, are a special case in this respect and it is essential that the vitamin and protein content of their food intake should be considerably higher than the norms for adults. Young children, especially in areas where urbanization has led to changed breast-feeding habits, are one of several especially vulnerable groups in the population; others are the chronically sick and the aged, who also require special attention.

Grain legumes are primarily important as high protein crops but they are also sources of energy and contain both oil and carbohydrate in varying proportions. Although relatively poor in some vitamins, such as retinol, riboflavin and ascorbic acid, legumes have reasonable amounts of thiamin and nicotinic acid. The nutritionally important minerals, calcium and iron, are also present, as well as fibre. Legume fibre consists of polysaccharides and lignins that resist hydrolysis by human digestive enzymes and form viscous solutions or gels with water. This fibre is of particular importance