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WORLD FOOD

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I want to express my gratitude to the previous speaker for pointing to the importance of economics in the food situation. I come to similar conclusions about the importance of the primary input, namely money. However, I disclaim any expertise as an economist.

INTRODUCTION

I have looked at the physical resources for food production only, but our discussion, I hope, will take us further afield to look at the inputs not only in terms of physical things but also in terms of skills, and money, as already mentioned. I have for this presentation diligently perused a three-volume study by the President's Science Advisory Committee (PSAC) "The World Food Problem," issued in May, 1967, by the White House. I think it strikes a realistic middle ground between the alarm of the Paddock brothers' "Famine—1975" and Ehrlich's "Population Bomb" on the one hand, and the optimism of many food specialists on the other. The Paddock brothers and Ehrlich disagree with the United States Department of Agriculture projection that world-wide famine will occur in 1984—they put it ahead to 1975 because they say food production is actually not going up as quickly as the Department of Agriculture predicted, while the population is growing faster.

It is time someone demolished an old Malthusian myth. One hundred and fifty years ago Malthus asserted that food production expands arithmetically and population geometrically. The geometric progression is easily demonstrated for the human population, but it can also be shown to hold for food production. If food did indeed expand linearly, the world must either have been in chronic surplus until now, an economic absurdity, or the population must have been held to *linear* advance through famine, which also is patently false. The conclusion is inevitable that, while food production may experience periods of linear advance or even decline, rapid expansion at times keeps food growth, resembling a step function, near the exponential population curve. There is thus nothing in the record that argues against the possibility of further rapid advances in food production.

George Borgstrom, known to you as the author of "Fish as Food," has also written "The Hungry Planet" published in 1965, in which he is a little more optimistic than the Paddocks or Ehrlich. On the other hand, we have rosier projections by advocates of some detail of food production, particularly protein from petroleum and things of this nature. However, I think that the PSAC Report is a fine penetrating realistic study that leads to many conclusions, some of which I hope to sketch out for you.

I will discuss briefly the global food situation in terms of distribution of food production, and nutritional status of some countries; briefly examine the important inputs such as water, fertilizer, and pesticides, as well as machinery, services, capital, and so on; run down the physical potential of earth for food; and discuss in greater detail the protein picture.

THE GLOBAL SITUATION

Table 1 shows you the distribution of food supplies and population in some of the great regions of Earth. I would like to bring your attention to North America, which with about seven percent of the world population is enjoying a huge supply in total and animal foods, and to the Far East, which is certainly

TABLE 1

Distribution of World's Population and Food Supplies, by Regions (1957–1959)

Regions	*Percent of Population*	*Percent of Food Supplies*		
		Total	*Animal*	*Crops*
Far East (incl. China, mainland)	52.9	27.8	18.5	44.2
Near East	4.4	4.2	2.8	5.5
Africa	7.1	4.3	2.8	6.3
Latin America	6.9	6.4	6.7	6.5
Europe (incl. USSR)	21.6	34.2	38.4	26.2
North America	6.6	21.8	29.2	10.4
Oceania	0.5	1.3	1.6	0.9
World	100.0	100.0	100.0	100.0

From H. A. B. Parpia and N. Subramanian in "World Protein Resources" p. 113, Am. Chem. Soc., Wash., D.C., 1966.

deficient in animal protein and barely makes it in crops. Some regions, like Latin America, seem to get their proper share of food supply in terms of population. Europe is pulling ahead in the food race. As a matter of fact, Europe is now facing a problem of overproduction, making it necessary to take land out of production and perhaps put it into parks and other uses. It is also contrary to the Paddocks' projections that this year we are experiencing a decline in the world trade of food products, which is primarily engendered by the good harvest in India due to the better than average monsoon season.

Maldistribution is also evident in Table 2 dealing with cultivated and potentially arable land. Look for instance at Column (5)—acres of cultivated land per person. In Asia that is 0.7, in Europe 0.9, and other regions exceed this level. Compare these figures with Column (6)—ratio of cultivated to potentially arable land. As one would expect, the continents with the lowest number of acres per person make the most complete use of that land. But there are areas like Africa and particularly South America which do not come close to utilizing their land potential. The PSAC study concludes that potentially arable land in the world is far greater than was originally assumed, namely about 24 percent of the ice-free land area. You see in the bottom row that twice, more than twice the presently cultivated land is available for potential cultivation. Competent cultivation of the tropics alone could contribute two billion acres, the PSAC study estimates.

TABLE 2

Present Population and Cultivated[1] Land on Each Continent, Compared with Potentially Arable Land

Continent	Population in 1965 (millions of persons)	Area in billions of acres			Acres of cultivated[1] land per person	Ratio of cultivated[1] to potentially arable land (percent)
		Total	Potentially arable	Cultivated[1]		
	(1)	(2)	(3)	(4)	(5)	(6)
Africa	310	7.46	1.81	0.39	1.3	22
Asia	1,855	6.76	1.55	1.28	.7	83
Australia and New Zealand	14	2.03	.38	.04	2.9	2
Europe	445	1.18	.43	.38	.9	88
North America	255	5.21	1.15	.59	2.3	51
South America	197	4.33	1.68	.19	1.0	11
U.S.S.R.	234	5.52	.88	.56	2.4	64
Total	3,310	32.49	7.88	3.43	1.0	44

From "The World Food Problem" V. II, p. 434. The White House. U.S. Govt. Printing Office, Wash., D.C., May, 1967.

[1] Our cultivated area is called by FAO "Arable land and land under permanent crops." It includes land under crops, temporary fallow, temporary meadows, for mowing or pasture, market and kitchen gardens, fruit trees, vines, shrubs, and rubber plantations. *Within this definition* there are said to be wide variations among reporting countries. The land actually harvested during any particular year is about one-half to two-thirds of the total cultivated land.

In this context a few figures from Georg Borgstrom [1] on countries' land shortage might be useful. Japan can till only .14 acre per person. The Netherlands is next with .23 ac/person. Then Egypt with .26. In fourth place is the United Kingdom with .34. China, with .40, is in 5th place. That compares with 2.6 ac/person in the USSR and United States, 5–6 in Canada and Australia. Notice that India is not among the most land-shy countries. One is tempted to correlate living standards with land and perhaps other resources. But Japan and England contradict such an attempt. For England the colonial past might provide an explanation. Japan, however, seems to point at work discipline, skill, and organization as better correlants.

To set the distribution of land resources against nutritional experience, let's look at Figure 1. The Group II countries, developed countries all, consume in excess of 3000 kilocalories per person per day. For Peru and India this is as low as 1930. Since Asians generally weigh less than Latin Americans, the Peruvians might actually be suffering more from the low caloric intake. The inside bar shows the protein experience, divided into animal and plant protein. Total protein requirement is about 1 gram daily per kilogram of body weight. Of this 60–70 grams for the average human being at least 20 grams should be animal protein, but you see that some Group I countries, with less than 10 grams, are certainly deficient in animal protein, while Group II countries with two and three times the minimum requirement indulge in luxury consumption of animal protein.

FAO has made projections on nutritional targets. In the short run they hope to achieve in the grossly deficient countries 15 grams of animal protein per person daily, in the long run 21 grams. This takes into account for these countries a better balance of amino acids in their plant proteins by AA fortification and by oilseed meal supplementation.

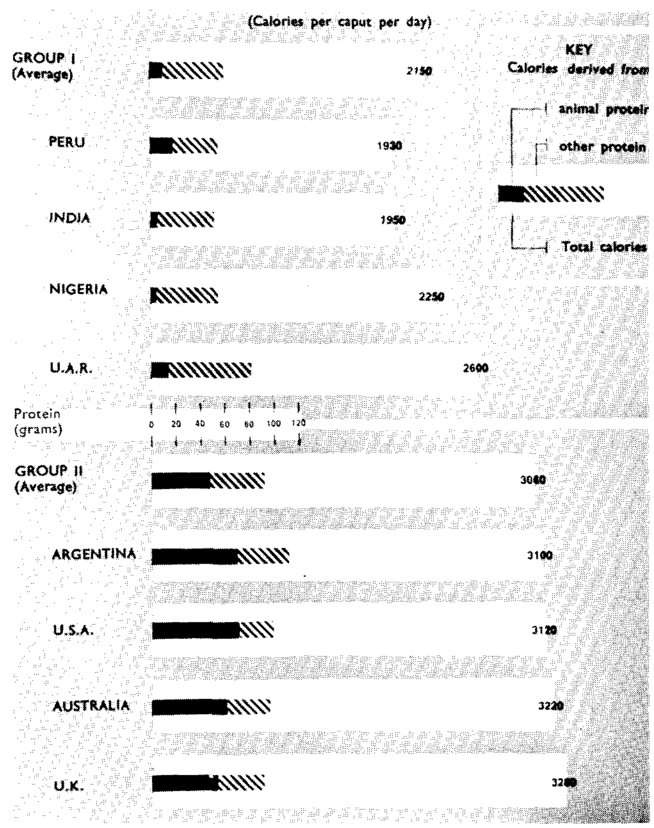

FIGURE 1. Contrast in nutritional status. Group I: Developing Countries, Group II: Developed Countries. *From* Pawley, W. H. 1963. Possibilities of increasing world food production. FAO, Rome. p. 15.

INPUTS, SERVICES, AND CAPITAL

In the next few minutes I would like to discuss some of the important inputs in the production of food—pesticides, fertilizer, equipment, know-how, etc., etc. Pesticide use correlates directly with crop yield. Japan, with the highest yields in the world, applies pesticides at a per acre level seven times greater than the United States. I did not expect this in view of the relative lack of pesticide pollution alarm in that country. Europe is also ahead of the United States in pesticide use but slightly, and in the use of ferti-

[1] The Hungry Planet, p. 5. MacMillan, New York, 1965.

lizer the situation is similar: Japan 1st, Germany 2nd, Europe 3rd, United States 4th.

An interesting picture emerges when we look at the cost of fertilizer in terms of crop value. Take, for instance, rice. A bushel of rice buys a certain quantity of fertilizer in Egypt; let's call it Q. The same bushel of rice produced in India buys 2Q's of fertilizer. In the United States, 4Q's. We are, however, not enjoying the cheapest fertilizer. Pakistani rice affords 4.5Q's—quite extraordinary—and Japan is on top with 5.5Q's.

Time magazine reported a little exotic experiment where in the breeding of seed, or the production of seed, the application of sound—namely music—was beneficial. Under 5–12-kilocycle sound, the resultant seed is tripled in weight and produces four times more potential grain-bearing shoots, possibly due to improved pollination by mechanical shock vibration. Cows also seem to be contented when serenaded and give more milk.

The infrastructure necessary to support an expanding food production requires not only the inputs we have touched on so far, pesticide and fertilizer, and the breeding skills that go into genetic improvement of plants and animals, but also requires a lot of roads and trucks and mechanical power. Figure 2 gives you available power on a per hectare basis, inclusive of animal and human power. You see that Japan is doing much better than the United States, and so is England. Japan's high power rating is mostly due to use of small, below 8 HP tractors in their garden farming, while the United States employs large machinery units servicing thousands of acres. It is quite evident here that developed countries use mechanical power in agri-

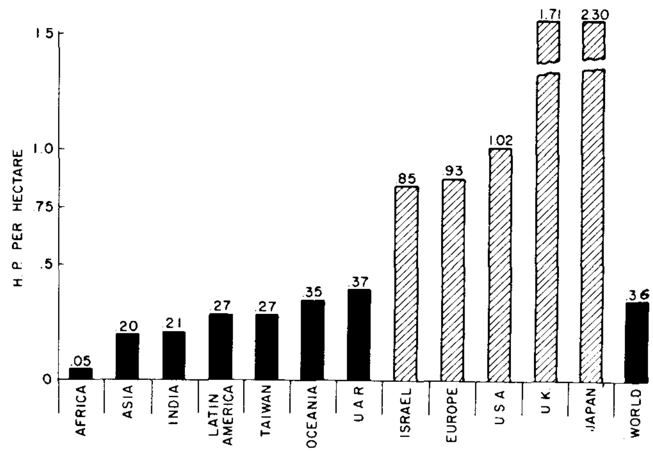

FIGURE 2. Power available for agricultural field production 1964–65. (Arable land and land under permanent crops). *From* The world food problem. V. III, p. 177. The White House. U.S. Govt. Printing Office, Washington, D.C., May 1967.

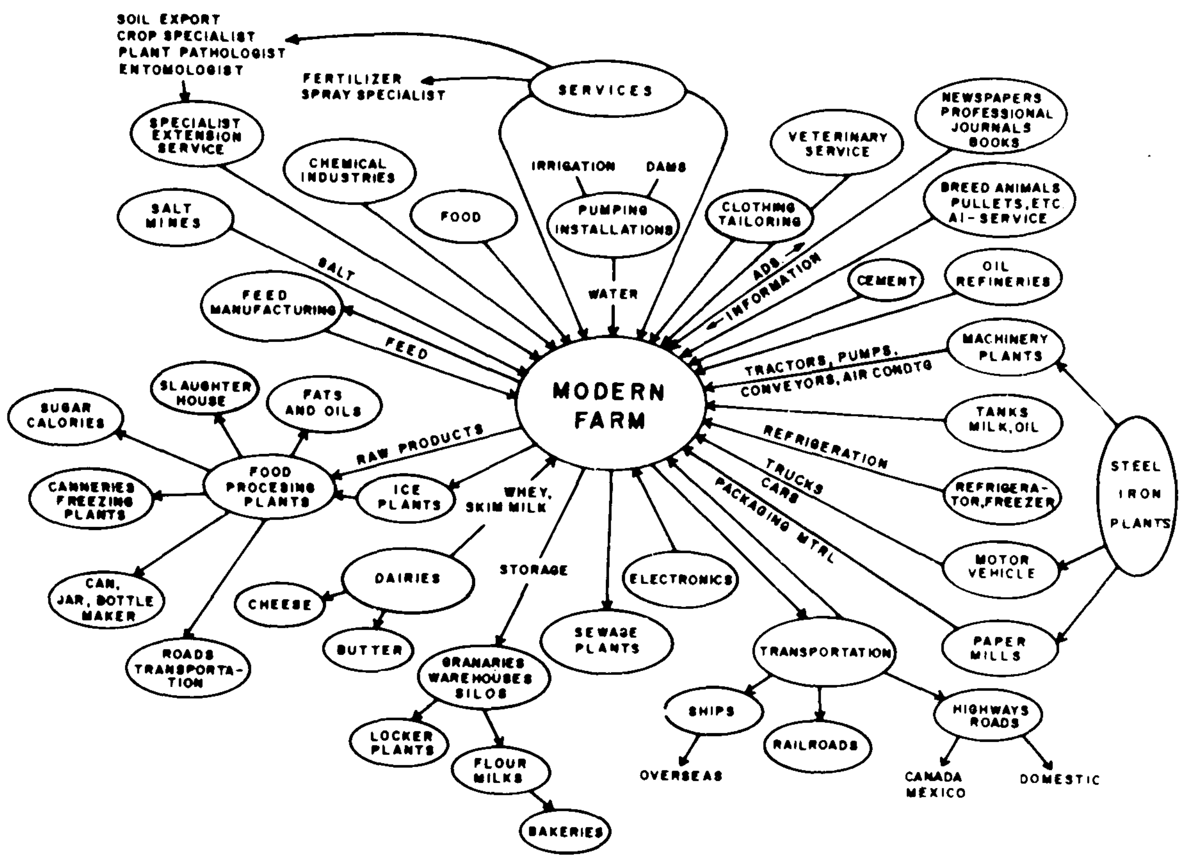

FIGURE 3. The modern farm. A modern farmer leaves all food and feed transportation, most of the storage, and almost all processing to outside enterprises. He brings to his farm most fuel, fertilizers and other chemicals; even a substantial part of his own food is purchased. A modern farmer needs the help of a number of non-farm-employed people in order to be able to produce. Producing food therefore involves far more people than the labor force on the farm. *From* Borgstrom, Georg. The hungry planet. MacMillan Press, N.Y.

culture at many times the rate of underdeveloped countries.

The PSAC report says much about the desirability of enhancing water supplies for irrigation, and while this is a very expensive part of the total improvements for more food, it is a very essential one. I have deduced by indirect means, namely from the potential expansion of hydro-electric power, that the earth's rivers may ultimately irrigate three times as much acreage as they do presently, or about 3×10^6 km ^{2}. Pakistan gives us a fine illustration of the difference between incompetent and competent irrigation. Prior to World War II that country, which practices almost total irrigation agriculture, was a food exporter. Incompetent irrigation led to root fouling and alkalization of the soil on account of high water tables, turning food exports into imports. Invited United States experts, among them Professor Isaacs and Dr. Revelle, recommended that tube wells and drainage canals be installed to permit aeration of the root zone and the flushing of the accumulated salts. This has lead now to a positive export balance again.

In addition to the wells drilled by the Pakistani Government, the farmers have also installed wells at their own cost, from $1500 to $2000 per well. Since these wells paid off in about two years as promised, farmers have been willing to consider and carry out this self-improvement program. This demonstrates, contrary to a widespread notion, the willingness of farmers, even in underprivileged countries, to accept innovations and change when the potential benefits are large enough.

I am only touching on some of the many and complex factors in the whole food improvement picture. Figure 3 puts this all together, perhaps not very clearly. The modern farm, from which the developed countries get their food, makes use of a wide range of inputs—services of many kinds, irrigation systems, fuel and machinery, refrigeration equipment, and so on. It even buys food from retail outlets. The processing of its raw products is done outside. The subsistence farm, on the other hand, has very little outside assistance available to it, and when we compare farm worker productivities we probably should count in all this outside manpower on which the modern farm depends.

In discussing what needs to be done to make subsistence farming and the entire economy more productive, the PSAC study concludes that "The scarcest and most needed resource in the developing countries is the scientific, technical, and managerial skill needed for systematic, orderly decision-making, and implementation." The task to meet even minimum nutritional targets is a large one. This is perhaps best seen from the following comparison: between 1935 and 1962, 21 underdeveloped countries averaged a 0.3 percent annual increase in beef, corn, and rice production. But PSAC suggests that a 4 percent growth rate is necessary over the next twenty years to meet these targets,—an order of magnitude change. The projected capital cost to achieve this for all underdeveloped countries runs to $80 billion over the next 22 years. Of this India requires $30 billion, primarily for irrigation (10), machinery (6.2), trucks (4.5), and fertilizer (3.3 billion dollars).

As Dr. Preston pointed out already, this calls for a 5.5 percent growth rate in these countries' national economies in order to expand the required infrastructure. Dr. Revelle has estimated a $20 billion capital infusion per year, including native capital, to meet this challenge.

EARTH'S FOOD POTENTIAL

Some time ago Professor Isaacs and I looked into the natural capacity of Earth to produce organic matter. The estimates, portrayed in Figure 4, are divided into a marine and terrestrial portion. Despite the land's 1 : 2.5 areal disadvantage, it seems to outproduce the sea. Actual plant and animal harvests are indicated for both realms, and in the sea's case compared with a potential that is equivalent to the productivity at the first carnivore level. It is doubtful that this potential will ever be approached by the fisheries because of the organisms' wide dispersion, unless extensive high-seas cultivation would become feasible in the future.

In Table 3 are listed a few maximal aquacultural yields under a variety of conditions. The extremely high figure for mussels includes, of course, the weight of their shells. If we compare these yields with the rate of harvesting Peruvian anchovy, which at 350 kg per hectare annually is the most prolific gathering operation in the world, we see that improvements by an order of magnitude may be possible in favorable areas.

The inferior position of the marine plant harvest (Figure 4) is of course due to the generally small size of marine plants and their relative indigestibility for man. In the center of the figure the dietary demand by an eventual world population of 10 billion are sketched in for perspective.

There appears to be ample room for increasing natural productivities since sunlight is inefficiently utilized. For instance, I have elsewhere [2] calculated that after all physical limiting factors save solar radiation would be ameliorated, conventional agriculture has a tenfold potential for product expansion. In this, full pest and disease control would double crops, fertilization also two times, shifting some pasture and technical cropland and using potentially arable land, at least 1.5 times; irrigation competently applied, 1.7 times; and reducing losses in processing, storage, and transportation by half, 1.2 times. In such efforts the principle of synergism should be observed, which says that the combined benefits of these measures are greater when applied simultaneously than when applied separately.

I have left out of this consideration the cultivation of tropical soils, particularly in the rain forests and in the adjacent areas that have some dry season, because its technology is not yet fully mastered. When eventually applied—and this depends perhaps primar-

[2] Schmitt, W. R. 1965. The planetary food potential. Annals, *New York Acad. Sci.* 118(17): 645-718.

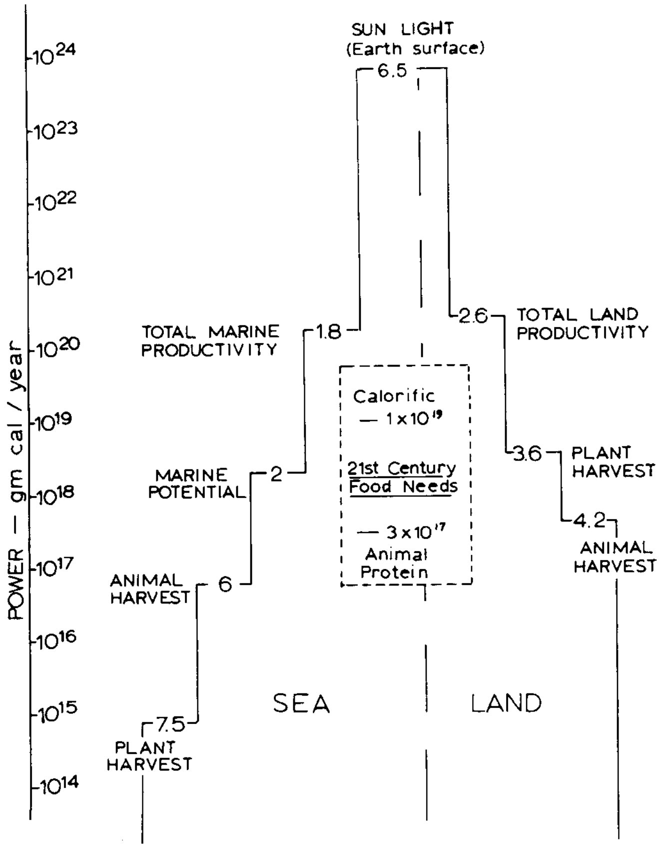

FIGURE 4. Marine and terrestrial food energy.

ily on providing roads and trucks, supplies, comfort and health, etc., through a high degree of infrastructure—these areas alone might double the present world food production.

THE PROTEIN PICTURE

In the last section I would like to examine in some detail what can be done to upgrade protein nutrition where deficient. Lack of a good amino acid balance leads to grossly impaired health with withering limbs and bloated belly, as we see in the picture in Figure 5. On the right is the same child one year later, having received a proper diet including protein from fish. Of course, you can't see what she really looks like under all of this prettifying paraphernalia: smile, clothing, even the tricycle seems to come along with the protein.

The names given to conditions of malnutrition are quite descriptive. *Sugar babies, Annam obesity,* and *weaning damages* speak for themselves. *Kwashiorkor* is an African word meaning red baby. Dr. Alvariño and I reviewed a film made in Guatemala for possible showing tonight that deals with malnutrition in that country. This movie actually did not make a point of animal protein shortage there, but rather charges the incidence of malnutrition to dietary ignorance. Three families are portrayed, a poor one from the country, two from the city, one poor and one middle class. All babies do well until they are weaned. After that the last family is o.k. because it is nutritionally informed. The poor city family also gets by because medical attention eventually arrests incipient trouble. But the

TABLE 3

Selected Ranges of Aquacultural Yields Per Year

(In Kilograms Per Hectare and Dollars Per Hectare, Except as Noted)

Type of cultivation	Location	Yield	Approximate wholesale value of annual crop
Oyster			
Common property resource (public grounds)	United States	9	38
Intensive cultivation, heated hatchery, larval feeding	United States	5,000	21,000
Intensive care, hanging culture	Japan*	20,000	23,100
Mussels			
Intensive care, hanging culture	Spain*	300,000	49,000
Shrimp			
Extensive, no fertilization, no feeding	Southeast Asia	1,000	1,200
Very intensive, complete feeding	Japan	6,000	43,000
Carp			
Fertilized ponds, sewage ponds	Israel	500	600
	Southern Germany	500	
Fertilized ponds, accessory feeding	Israel	2,100	
Sewage streams, fast running	Indonesia*	125,000	
Recirculating water, intensive feeding	Japan	100†	114†
Catfish			
Ponds, no fertilization or feeding	Southern United States	200	70
With fertilization and feeding in slowly flowing water		3,400	2,400
Milkfish			(net profit 300)
Brakish ponds, extensive management	Indonesia	400	
With fertilization and intensive care		2,000	600
Trout			
Cement raceways, intensive feeding, rapid flow	United States	170†	168†

* Values for raft culture and comparable intensive practices based on 25 percent of the area being occupied.
† Per liter per second.
From Bardach, J. E., 1968. Aquaculture. Sci., 161 (3846):1104.

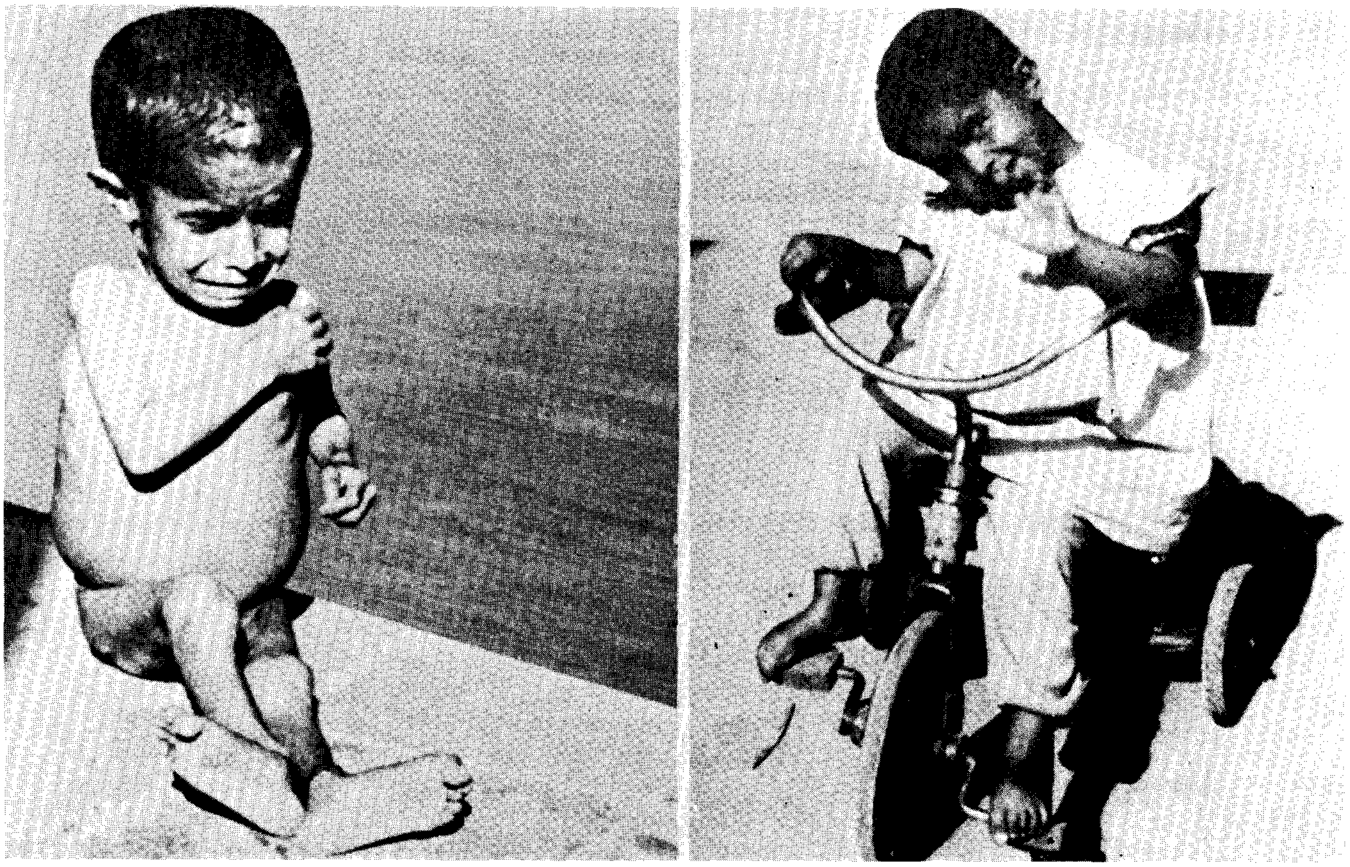

FIGURE 5. One year of proper diet, including protein from fish, separates these two pictures of the same girl in Iran. *From* Jebsen, J. W. 1962. Fish in nutrition. *Ed.* E. Heen and R. Kreuzer. Fishing News (Books), London.

rural family has neither dietary savvy nor help of any kind, and when the weanling develops spotted limbs and diarrhea from its almost purely starchy diet, it is taken off food entirely.

The difference between the protein value of various food stuffs is nicely demonstrated in Table 4 on essential amino acids (AA) contents. The standard used here, egg protein, is pretty ideal though unnecessarily high in methionine and cystine (not shown). If no make-up AA were available during the same meal time, one food's protein would be utilized only to the level of its minimum AA component—beef 70, fish 79, soybean 53, and so on. This then imposes an additional metabolic load to excrete everything above that value which the already malnourished person can ill afford. Unfortunately, this is too often the case. For foodstuffs in combination, the benefits are considerable. You can readily see from this list that fish and rice give a very fine AA balance.

TABLE 4

Percentage of Ideal Concentration of Essential Amino Acids Observed in Typical Proteins [1,2]
(Using Egg as 100 Percent)[3]

Foodstuffs	Histidine	Threonine	Valine	Leucine	Iso-Leucine	Lysine	Methionine	Phenyl-alanine	Tryp-tophan
Beef	157	90	73	87	84	141	84	70	92
Fish muscle	124	96	86	106	105	148	100	79	109
Soybean meal, low fat	138	80	76	89	97	111	53	95	127
Whole rice	81	78	88	91	84	52	106	89	118
Whole wheat	100	67	62	78	64	44	78	91	109
Cottonseed meal	128	61	69	67	64	57	53	107	118
Whole corn	119	76	76	167	103	38	97	89	55
Peanut flour	100	57	66	79	66	57	25	88	72
Dried roast beans	104	79	78	78	89	106	62	89	73
Sesame meal	106	81	67	70	63	38	53	78	93

1 Data mainly taken from Hopper, T. H., Amino acid composition of foodstuffs. *In:* Altschul, A. M. (ed.) Processed plant protein foodstuffs, New York, Academic Press, 1958. 955 p. pp. 877–891.

2 Data mainly taken from Heinz (H.J.) Company. The Heinz handbook of nutrition: a comprehensive treatise on nutrition in health and disease. Rev., 2d ed. New York, McGraw-Hill, 1965. 462 p.

3 *From* "The World Food Problem" V. II, p. 315. The White House. U.S. Govt. Printing Office, Wash., D.C., May, 1967.

TABLE 5

Major Oilseeds Used as Food

Species	Botanical Name	Protein Content (Av.), %	Oil Content (Av.), %	World Production, 1000 Metric Tons	Major Producing Countries	Problems in Processing as Food
Soybean	*Glycine max.*	42	20	35,000[a]	U. S., China	Antitrypsin factors Hemagglutinin factor
Peanut	*Arachis hypogea*	27	48	14,800[b]	India, Senegal, Nigeria	Aflatoxin
Cottonseed	*Gossypium*	30	30	20,600[b]	U.S., India, USSR, Mexico, UAR, Brazil, Pakistan	Gossypol, malvalic acid, aflatoxin
Sesame	*Sesamum indicum*	25	50	1,500[b]	China, India, Sudan, Mexico	Fiber, oxalate
Sunflower	*Helianthus annus*	30	40	6,840[b]	USSR, Argentina, Uruguay, South Africa, Turkey	Fiber
Coconut	*Cocus nucifera*	8[c]	65[c]	3,200[b,c]	Philippines, Indonesia, Ceylon, India, Malaysia	Fiber

[a] Estimated for 1965.
[b] *(6)*.
[c] Dried meats (copra).
From Milner, Max, 1966. World Protein Resources. Am. Chem. Soc., Wash., D.C., p. 54.

Supplementing the three staples shown here with oilseed meals is moderately beneficial. This is, of course, the basis of a truly vegetarian diet, but I suspect that many vegetarians are kidding themselves and us in that they accept such animal products as eggs, milk, and its derivatives, even sea food. The use of oilseed for food is quite a big business, as is evident in Table 5. Some 80 million tons, containing 24 million tons of protein, or about one quarter of the total protein demand, are globally produced for this purpose. The oilseed products are sold for 12–40 cents per pound of protein, not exactly cheap. Some also contain toxins in troublesome concentrations, requiring costly extraction and posing problems of food adulteration if fortification levels are high. Despite such drawbacks, they have won wide acceptance. An estimated 10 percent of the Japanese' protein intake is supplied by various soybean meal products named Tofu, Miso, Shoyu, and Natto. Perhaps one-tenth of the Indonesians eat 100 grams per day of Tempeh, also made from soybeans. A similar portion of Guatemalans use Incaparina, a protein meal made from cottonseed under United Nations auspices, either occasionally or regularly. And in Hong Kong, a soft drink, Vita soy, with 6 grams protein to the bottle and vitamin enriched, has captured 25 percent of the soft drink market even though it tastes like liquid library paste.

We in fish research are, of course, partial to another high grade protein supplement, namely MPC, or FPC as it is more widely known. The objectives of MPC are twofold: first, to supply an inexpensive high grade protein of wide versatility to malnourished people, and secondly, to utilize for food marine species not in great dietary demand. Although MPC is not yet in commercial production, it is clear that it will not be competitive with other protein products, as from oilseeds, for instance. It is also facing resistance on culinary grounds. MPC would, however, extend fishing pressure to presently unwanted species and thus achieve a desirable ecological balance that would be requisite if the marine potential in Figure 4 were to be approached. Already, severe dislocations among many exploited fish stocks are apparent, as we will hear from Dr. Chapman.

Referring back to Figure 5, we see lysine particularly deficient despite methionine's negative bias. Lysine is now being produced by fermentation with select microorganisms on substrates of molasses and corn steep liquor. This process has replaced a purely synthetic chemical approach. However, some of the other AA are chemically synthesized. Total world production figures are unavailable; in the United States in 1964 about 3000 tons of AA were manufactured. They are selectively added to certain foods and feeds staples. AA fortification not only allows exact tayloring of proteins, but may well be cheaper than supplementation with MPC or SBP (soybean protein). The PSAC people report that at 25 cents per pound MPC, 15 cents per pound SBP, and $1, $1.5, and $2 per pound of lysine, threonine, and tryptophan, selective AA fortification of rice, wheat, and corn is 30 percent cheaper than MPC supplementation and ten percent cheaper than that with SBP. There is, moreover, impairment of the staple's flavor and functional quality if MPC exceeds six percent and SBP two percent.

By far the most exciting development with respect to AA balance has been the breeding of two corn varieties—Opaque 2 and Floury 2—that are double in lysine and 1.65 times in tryptophan. Children, fed a diet with Opaque 2 corn as sole source of protein at 2 grams protein per kilogram of body weight daily, retained nitrogen as well as a control group using skim milk for protein. I think that such genetic enhancement of AA balance is at least as potentially beneficial as the recently developed dwarf varieties of wheat (in Mexico) and rice (in the Philippines) for high yield and sturdiness.

There are a few other ways to expand the protein supply that I want to mention briefly. For one, we have what collectively can be called Single Cell Protein, that is yeast, bacteria, or fungi cultures utilizing all manner of organic and inorganic substrates. Laboratory work with cultures has made us aware of their enormous capacity for growth, but in practice we encounter unsolved problems of production, processing, and nutritional quality. Also, at 20 to 40 cents per pound of protein, these proteins are not competitive with more palatable preparations. More expensive yet are algal proteins, as that from chlorella at 70 cents per pound when cultured pure, and even then questions remain with respect to digestibility, palatability, and toxicity. Sewage has been considered as substrate of algal cultures and would bring down the cost sharply, but such products would not be suitable for direct human consumption. Rather, we could envision algae as an intermediary link in a double symbiotic system such as shown in Figure 6. Here the output is in conventional products, at the same time that the primary objectives, sewage treatment, water re-use, and recycling of nutrients, become achievable.

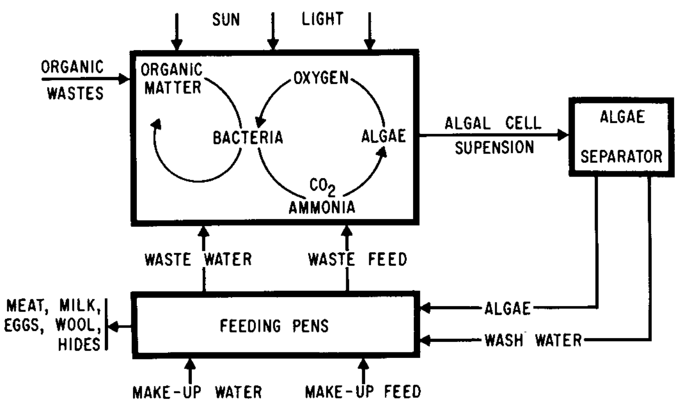

FIGURE 6. Algal culture linked with livestock feeding pens. *From* Schmitt, W. R. 1965. The planatary food potential. *Annals New York Acad. Sci.* 118:696.

Some research is now being directed toward the extraction of leaf protein through pulping and pressing. The cost seems to be quite reasonable at around ten cents per pound of protein; however, their acceptability is not well known.

Most of the protein supply measures I have discussed thus far involve human intervention in varying degree. There are situations in which the opposite approach can be more fruitful. In the tropical lands of Africa, for instance, the husbandry of temperate zone livestock is often plagued with animal diseases (e.g., rinderpest) to which the imported animals are more susceptible than the native game. Returning the range to the latter, especially ungulates, while exercising a modicum of range management, can not only increase the yield despite the game's generally smaller size, but also be quite profitable. A 50-square mile area in Rhodesia was harvested of 60 tons of game at a £3200 profit. The same area's cattle potential is estimated at 50 tons at £500 profit.[3] In this way the high losses to disease (30 to 40 percent) could well be halved for a 25 percent increase in animal protein, possessing higher meat quality and traditional acceptance. And most of the work with urea-fed cattle should be equally applicable since most of the game species of interest are ruminants. Africans, incidentally, make the most efficient use of these animals' protein by milking and bleeding them. For the world, milk is the single largest source of animal protein and accounts in part for the toleration of the Indian cattle.

How successful novel approaches toward better protein nutrition will be depends on many factors. Supply is not enough. In the underdeveloped countries, which all lie in tropical or subtropical climates, better systems of cultivation, harvesting, processing, distribution, storage, and marketing must evolve. If I were to single out the, to my mind, most promising way to combat malnutrition speedily, it would be AA fortification of cereals and/or genetic breeding for AA balance. The malnourished, largely vegetarian peoples would, I think, readily accept such an improvement and might even remain unaware of it culinarily.

CONCLUSIONS

Perhaps some alarm about the world food situation stems from an underestimate of our globe's tremendous physical potential for food. I have indicated this to be at least ten times the present utilization. With the exception of rainforest and high seas cultivation, the technology for food expansion is well in hand. Also, historically, food production has kept pace with population advance, by and large. However, the latter is now so rapid that only the economies of developed countries can meet the necessary rate of expansion. Since populations in the underdeveloped countries grow faster yet, and at the same time lack a sound economic base, they are doubly penalized. We are thus faced with a distribution problem, not so much in physical resources as in capital, skills, attitudes, infrastructure, and so on. The attainment of these under adversely high and still accelerating population growth rates is the world's principal dilemma and is not likely to succeed without drastic birth rate limitation. What the underdeveloped countries must do in the agricultural and economic sectors, Roger Revelle, now Director of Population Studies at Harvard, sums up in this way:[4]

"If the people of the poor countries are going to get enough to eat, they must practice market-oriented agriculture; and there must be overall economic development. They cannot concentrate, as they have always done in the past, on the relatively simple problem of improving subsistence agriculture. They must urbanize, industrialize, develop their entire economies. At the same time they must create the research and teaching institutions, the transportation and communica-

[3] The World Food Problem, V. II, p. 269. The White House, May, 1967.

[4] Revelle, R. R. 1968. International Cooperation in Food and Population, International Organization, 23(1): 366.

tions systems, the incentives for farmers, and the social conditions required for modern, scientifically-based agriculture.

"These are not problems that can be solved in a year or ten years. The solution will take at least two generations. They must be approached not as in the past with short-term, quick payout programs or with gimmicks of various kinds, but with realistic, long-continued, large-scale action. Any review of these problems shows that they cannot be solved without very great contributions from the developed countries."

In all this nothing has been said about pollution or environmental degradation. In its global aspects this is a fairly recent concern. An expanding world agriculture, employing fertilizer and pesticides as intensely as Japan or Germany do, and the pollution peril from the accompanying industrialization, will certainly multiply the present dangers to the world's ecology. The mode of attack that R. Revelle inveighs above in the interest of viable peoples and economies will need to incorporate strong environmental safeguards in order to maintain a viable planet.

DISCUSSION: Walter R. Schmitt—WORLD FOOD

Discussant: Professor John D. Isaacs

Isaacs: In listening to Walter's excellent presentation and in relating it to the remarks of the first speaker, Dr. Preston, I have been attempting to put in mind just what is the position of the scientist in these problems. It is very much, I think, as we have found in the research on the fish of this coast. We can show what is scientifically possible, the engineer and technologist can show how to do it, and then whether it is done results from a different set of inputs and a different set of people involving economic, political, social relations, and a whole bevy of other matters. In this case that Walter has discussed, the scientist can show what is the potential of a planet to support people. The engineer, that is the agricultural technologist, food technologist, etc., can show how it can be done. Whether or not it is done is quite outside of the control of the scientist or technologist.

The scientist and technologist produce a degree of assurance that there are openings and potentials. The better the scientist documents the potential, the more pressure there develops for these things truly to be done. The more there are mistakes of advice the more uncertainty and reluctance is generated in the undertaking of new developments.

So, I think that the major scientific input into resource utilization is overall assurance and guidance. Of course there are also the many scientific aspects involved in the individual steps of putting developments into operation. The scientific product is thus assurance, and this assurance for obvious reasons should be as strong, meaningful, and unequivocal as possible. Where the scientific input is not, humanity is done a disservice. One way that a disservice is done is to be proven demonstrably wrong by lay people. As members of an advanced western society, U.S. society, scientists often tend to take a "holier than thou" attitude, as though lay people really don't know anything about their own problems. I am impressed by the occasions when simple people have shown surprising insight. As an example, there are a number of cases where they have not continued to accept and cultivate hybrid corn for the very good reason that the groups of hybrid corn that were introduced mainly increased the yield of starch rather than protein and hence were precisely what was not needed. These people recognized this deficiency though perhaps through not very sophisticated scientific tests—the flour didn't hang together to make good tortillas or something of this nature—so they went back to their own native seed. We have seen here today that the starch component of some of these hybrid corns has principally been increased, not the protein, and we should be impressed that these native people recognized that before we did.

There is abundant evidence that the customs of natives may be of very profound significance. A friend of mine who spent some years in Egypt tells a remarkable story of dead donkeys there. I will briefly relate it. He became curious that he never saw a dead donkey in Egypt, as there were plenty of donkeys, and they surely were not eaten. With much difficulty he broke through the communication barriers, which exist to the scientist in all these countries in talking to the man in the field. It slowly and finally developed that there was a great tradition about dead donkeys, and he discovered that these people clearly knew much about trace element chemistry. There was a ritual in which the rib cage was put under the plants that obviously suffered from conditions now known as resulting from phosphate deficiencies; the liver was put under the plants that showed the symptoms of copper deficiencies; the flesh was put under those with nitrogen needs, and so on even to the genitals for the plants that suffered sulphur deficiency. So for more than 2000 years these people in Egypt have practiced trace element chemistry in their agriculture.

When I look at these lists of foods and their amino acid contents, I wonder if perhaps some of the simple processing of foods broadens the amino acid spectrum.

As you know, herbivorous animals convert the vegetable protein into the full range of amino acids that we have been discussing as "animal protein," but they do not do this solely by themselves. The principal synthesis is carried out by symbiotic microorganisms in their digestive tract. These and other microorganisms are quite capable of manufacturing "animal protein."

Perhaps the human race, in developing foods that have been acted upon by microorganisms, such as fish sauce, poi, leavened bread, etc. have partly compensated outside of their bodies for their poverty of inner symbionts. We perhaps should look at these as sorts of symbionts external to the human digestive system which aid in protein conversion. I see little evidence that we have considered it possible that people developed these fermented foods for the very real purpose of improving their amino acid intake, and I believe that most of the analyses of diet are of the input food material rather than of the finished products. Perhaps the primitive chefs are better than we think, and the introduction of baking powder has been sinful.

Of course, finally looking at the examples of how we should not develop a "holier than thou" approach, we have our own nutritional illogic and problems, as everybody knows, while we eat our eggs, drink our milk, and put ourselves into early graves with our own American sacred chickens and cows and our own sacred dairy industry. The picture of the healthy American person is a rosy-cheeked individual with high blood pressure, atherosclerosis, and a big glass of enriched milk in his hand. Clearly we would be more sensible and much better off, and anybody from India or any other country whom we advise could argue this, that the sensible thing to do would be to catheterize our cows and drink blood rather than the milk. The dairy industry could be changed over instantaneously to deliver bottles of warm blood each morning for breakfast. I believe that regardless of the logical case that could be made for us, say by some of the nations *we* are advising, it is quite possible that we wouldn't like that. We have our own "sacred cows." Looking at these other countries then, we must realize that there are things that they don't like even though they are logical. We die prematurely and illogically well-fed, while others die prematurely and illogically ill-fed. I am, of course, not arguing against helping where we can. We should consider such help of extreme importance, but I *am* arguing that we should enter such advice with a consciousness that the food customs may have more meaning than is immediately apparent, and that much more enters into these matters than logic. We are not in a strong position when it comes to logic, ourselves.

Chapman: I was caught by the modern farm and all the things around it. I think this points out a lesson that we don't always abide by, that when you take the modern farm and transplant it into a society where all the little gimcracks are not available, it doesn't work worth a darn and this applies to a modern fishing boat and applies to a lot of other modern things. Take it out of context in which it is developed and used very efficiently and put it into another social context, it doesn't work well at all.

Isaacs: Walter pointed that out. It is an important factor that you have emphasized. I wonder if there is a kind of biogenetic law in these developments also, that in the ontogeny the phylogeny must be recapitulated. As you try to introduce modern developments into Pakistan, for example, it is clear that you just can't superimpose them on the country—there has to be some sort of a shorthand repetition of the kind of development our forefathers went through.

Longhurst: This is being brought out by people like Duboise looking at the African agricultural economy where they maintain that what they require first is buffalo rather than tractors. Walter, in your tabulation of power available for agriculture in these various places, has anybody taken into consideration animal power in agriculture?

Schmitt: Yes, the PSAC Study gives such a breakdown. Of the world average of .36 hp/ha, 12% is animal power and 7% is human power, while in Asia it is 50% and 25% respectively. These range from practically nil/nil in the United States to 23% and 42% in Taiwan and 69% and 27% in India, respectively.

Isaacs: In regard to the totality of the development being the difficulty, in Pakistan it isn't adequate just to throw some fertilizer on the ground, you must apply more water. As soon as these are done, you get weeds, and the native crops are incapable of competing with weeds. Now with all the weeds, you have to cultivate intensively. To do this, crops must be in rows. Thus you can't hand broadcast the seed, so you must have seeders, and improved seed, then herbicides and insecticides, and on it goes. Everything really, as we have developed it in our society, has to go together. You can't start out with one single part effectively.

Mackett: You mentioned it would take an investment of $80 billion to modernize subsistence agriculture. Was this annually?

Schmitt: No, this was a 22-year total. It would require about $300 million a year initially, rising to $4 billion a year at the end of this phase. This is in an attempt to meet the minimum nutritional targets over this period. It also allows for population growth and infrastructure development in the underdeveloped countries.

Chapman: This sort of a figure has no meaning to business people. For instance, what is the pay out? What are you likely to get in return for the capital? You can quite easily take $25 million and build a good size fishery and have your $25 million back at the end of 10-12 years.

Schmitt: I don't think that we can apply in an aid program the usual profit yardstick. A viable world cannot be maintained on gross disparities of living standard, especially not at a time of instant communication. The rich countries are still exploiting the poor through adverse trade, and the gap is widening. While per capita income expressed in dollars is not a good measure of living standards on account of artificial exchange rates, I think we are agreed on the need for full money market economies in place of subsistence economies, and this requires massive infusion of low-profit capital. Perhaps this can only be accomplished with a world currency or full currency convertibility.

Ahlstrom: I was wondering about some of the projections you made for the future, the rapid drive of urbanization that is picking up land for freeways and for peoples' cultures. Has this been projected? This is going to take an awful lot of good land.

Schmitt: No, I don't think this has been accounted for. But perhaps with the increase in soil knowledge, one can reclaim or put to use some of the marginal lands that have so far not been included in the potentially arable land category.

Chapman: I would like to see some of the data that backed up this business of withdrawal of land versus desirability of urbanization. As an example, the whole Los Angeles area was worth nothing—it was made fruitful and then urbanized, but you certainly can't feel that Los Angeles was hurt very much agriculturally.

The area in the northeast corridor, very poor land covered with scrub forest, is being scraped and made into suburb, and I am not sure the suburb won't be a better use for it.

Schmitt: I think Benny Schaefer, in a discussion, made a good point with respect to land use. As long as an outside supply of food is available, the best land use is industrialization. The profits generated by such an operation can buy more food than can be grown on any particular piece of land.

Isaacs: I have been astonished by two cases:

(1) Everybody shouted how disastrous it was to mine the water around the region of Phoenix and after what actually happened it became clear that this was what they should have done. Now Phoenix is there and they have an industrial city which draws in water from other and more expensive sources.

(2) In the case of Pakistan the British knew perfectly well a hundred years ago that they had to put in an adequate drainage system, otherwise if agriculture continued they would develop water logging and salination. Economically you could not put in these drainage systems at the outset. It was not profitable. Pakistan did not become an industrial nation.

How do you predict all of this? One case should have carried on despite this apparent disruptive disastrous approach, and in the other one, a disaster actually developed. We are in a quandary; we can't be overly conservative in these matters but we also must! I have no answers.

Thank you very much, Walter.