development in the tropics. The indirect effects are so numerous that it is impossible even to attempt an enumeration.

In the first place the rapidity of chemical action associated with heat and moisture extends to organic compounds and leads to rapid deterioration of foodstuffs of all kinds. The problems of storage and preservation loom large and one sees a rapidly increasing role of refrigeration, including quick-freezing, and vacuum packing. In this field the air conditioning stressed above as so important for human beings must play a large part.

In the second place, tropical conditions, especially again heat and moisture, favour the growth and dissemination of a very wide range of pests and diseases of plants, animals and man. Progress in the fight against many of these ills has been spectacular—malaria, yellow fever, yaws, leprosy and others come readily to mind—but the tsetse fly and, from drier regions, the locust, are still two of the real rulers of Africa.

In the third place, what can we say of the indirect effects of tropical climate on the social, including the food, habits of mankind? What made West Africa the White Man's Grave? Was it partly gin?

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Problems in the improvement of output of arable crops in developing countries

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Arable crops are those which are destroyed at harvest so that they have to be sown or planted again each time they are required. They include all the important human foods of the undeveloped countries except sago, bananas, and the coconut and oil palms. The developing countries generally have a farming pattern dominated by subsistence agriculture, dependent almost entirely on human and animal power. They include China, India, the countries of South-east Asia, and most of Africa and tropical America, and they are inhabited by about two-thirds of the human species. Most of them lie wholly or partly within the tropics.

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'The tropics' are both dry and wet, densely and sparsely populated. In the dry tropics evergreen perennials cannot be grown without irrigation; in the wet tropics they can be grown on rainfall alone. The densely populated areas of India, China and South-east Asia, and most of the tropical islands, have 70–300 persons/sq. mile, but most of Africa and South and Central America is thinly populated, with fewer than 30 persons/sq. mile (United Nations, 1960). There is also a vast diversity in soil resources, from the volcanic soils and the heavy alluvial soils of the great deltas and inland flood plains to the ancient, leached soils derived from pre-Cambrian rocks. Each combination of these factors has its own problems of agricultural improvement, but the most important distinction is between the densely populated regions, where the central problem is the improvement of yield/acre, and the sparsely populated areas where there is often the added possiblity of extending the area of arable production.

Current trends in arable output

In what follows, the word 'output' is used for gross production, whereas 'yield' refers to production/acre.

During the past decade, while world population has increased at the rate of 1·7% per year, the total output of the chief cereal crops has increased at an average rate of over 4% per year (Table 1). The combined production of wheat, rice and maize,

Table 1. *Changes in world production of wheat, rice and maize*, 1934–8, 1948–52 *to* 1959, *including estimates for U.S.S.R. and mainland China* (*FAO*, 1960, 1961*a*)

Crop	1934–8 average	1948–52 average	1958	1959
	Output (long tons $\times 10^{-6}$)			
Wheat	164·2	166·8	252·3	245·8
Rice	148·8	161·5	248·9	254·4
Maize	113·0	137·9	199·2	216·1
Total	426·0	466·2	700·5	716·3
	Area (acres $\times 10^{-6}$)			
Wheat	417·4	419·6	512·0	505·6
Rice	212·0	253·5	290·3	290·1
Maize	218·1	225·3	248·4	261·2
Total	847·5	898·4	1050·8	1056·9
	Yield (tons/acre)			
Wheat	0·39	0·40	0·49	0·49
Rice	0·70	0·64	0·86	0·88
Maize	0·52	0·61	0·80	0·83
Mean	0·50	0·52	0·67	0·68

in 1959, had risen by over half compared with 1948–52, from 466 to 716 million tons. The increase was shared roughly equally between the three crops. It arose partly from increases of 14–20% in the area sown but mainly from increases in the yield/acre of 22% in wheat, and 36 and 38% in rice and maize respectively.

These increases in yield/acre represent, in part, a reaction from the static or falling yields of the previous period. Between 1934–8 and 1948–52 the average yield of rice fell, from 0·70 to 0·64 tons/acre, while wheat yields were stationary at around 0·4 tons/acre. Meanwhile population increase continued so that the war increased man's disadvantage in the race with hunger.

For the world as a whole, the recent increases in food production have outstripped population growth. The relevant indices, referred to a prewar base of 100, are about 155 for food and 130 for population. These figures are the resultant of considerable advances in Europe, the U.S.S.R., North America and the Near East, on the one hand, and of less favourable or effectively static situations elsewhere. In the Far East, as a result of remarkable increases in crop production, the output per head has at last returned to the prewar level (FAO, 1961*b*).

In Table 2 the data for rice and maize are broken down to show what has been happening in different countries, and similar figures are given for four other tropical and subtropical crops—groundnuts, soya bean, sorghum and millets combined, and cottonseed, which is of course an important though sometimes neglected source of edible oil. Table 2 shows that the output of these crops has increased generally, both by increases of area and by improvements in the yield/acre. We may summarize Table 2 by saying that a world increase of over one-half in total output of the six crops was produced by a 10% increase in area and a 37% increase in yield. Though t is true that a considerable part of the total increase has been produced in economically more developed countries a good deal of the increase in mean yields has been recorded in developing countries, particularly the Far East.

The development in China, if the official figures are to be relied on, is particularly important, in spite of the recent setbacks. In 1948–52 Chinese yields of maize (0·59), soya (0·32) and cottonseed (0·16 tons/acre) were well below those of the United States (0·98, 0·57 and 0·22 tons/acre respectively), and the Chinese rice yield (0·86 tons/acre), which was around 1·01 tons/acre in 1934–8, was well below the Japanese (1·59 tons/acre). By 1959, in spite of difficulties with weather and harvesting, Chinese yields of these crops are said to have risen by 50–100%, to levels approaching those of the United States and Japan, even though these had also improved considerably. Similar striking improvements have been obtained with rice in Formosa. The Chinese increases in yield, which represent in part a recovery of the prewar level, and the increases in acreage and output associated with them, are among the most potent geopolitical factors of our time. It would be unwise to regard the disastrous Chinese harvest of 1960 as anything more than a temporary setback in the agricultural progress of that able, industrious and patient nation.

Another important feature is the consistently very low level of yield of all the crops in India, where increases in output have been produced mainly by increases in area, with smaller absolute increases in yield/acre than are recorded in other underdeveloped countries. There are no agronomic obstacles to considerable improvement of Indian crop yields. Other noteworthy aspects are the relatively small increases in yield/acre in groundnuts and in the marginal, dryland sorghums and millets in countries other than the United States.

Clearly crop yields/acre have been increasing in many underdeveloped areas, but they still lag far behind the levels of yield which are achieved in more advanced countries.

Table 2. *Changes in production of six tropical and subtropical crops*, 1934–8, 1948–52 *and* 1959 (*FAO*, 1960, 1961*a*)

Country	Output (long tons $\times 10^{-6}$)			Area (acres $\times 10^{-6}$)			Yield (tons/acre)		
	1934–8	1948–52	1959	1934–8	1948–52	1959	1934–8	1948–52	1959
				Maize (excluding U.S.S.R.)					
U.S.A.	52·2	80·7	109·0	93·5	82·8	84·6	0·56	0·98	1·29
China	8·4	13·8	27·5	14·9	23·6	23·7	0·56	0·59	1·16
India	2·2	2·1	3·6	7·6	8·3	10·5	0·29	0·26	0·35
Other	50·3	41·2	76·0	102·1	110·6	142·4	0·49	0·37	0·53
World	113·0	137·9	216·1	218·1	225·3	261·2	0·52	0·61	0·83
				Rice					
Japan	11·3	11·8	15·4	7·8	7·4	8·1	1·45	1·59	1·89
China	49·7	57·3	112·2	49·4	66·3	77·1	1·01	0·86	1·46
India	33·6	32·9	44·0	62·2	74·4	81·3	0·54	0·44	0·54
Pakistan	11·0	12·2	14·2	18·7	22·2	24·1	0·59	0·55	0·59
Other	43·2	47·4	68·6	73·9	83·2	99·4	0·58	0·57	0·69
World	148·8	161·5	254·4	212·0	253·5	290·1	0·70	0·64	0·88
				Groundnuts (in shell)					
U.S.A.	0·5	0·8	0·7	1·6	2·3	1·5	0·34	0·37	0·49
China	2·7	2·0	2·2	3·8	3·8	4·9	0·72	0·54	0·45
India	3·1	3·1	3·9	8·0	10·8	14·9	0·39	0·29	0·27
Senegal	0·7*	0·5	0·9	3·2*	1·7	2·3	0·22*	0·33	0·38
Other	1·7	2·8	4·4	5·9	8·7	12·4	0·28	0·32	0·36
World	8·8	9·3	12·1	22·5	27·2	35·8	0·39	0·34	0·34
				Soya beans					
U.S.A.	1·1	7·2	14·4	2·5	12·6	22·4	0·46	0·57	0·64
China	9·8	7·2	11·2	21·4	22·2	24·0	0·46	0·32	0·47
Other	1·1	1·3	1·9	3·8	4·3	5·7	0·30	0·31	0·33
World	12·1	15·6	27·6	27·7	39·0	52·1	0·44	0·40	0·53
				Sorghum and millets					
U.S.A.	1·2	3·8	14·5	3·9	7·6	15·6	0·31	0·50	0·93
China	21·9	13·8	19·6	43·6	68·4	68·5	0·50	0·20	0·29
India	12·6	11·9	15·2	73·6	80·3	86·9	0·17	0·15	0·18
Other	12·1	15·8	17·7	55·2	68·3	60·4	0·22	0·23	0·29
World	47·8	45·3	67·0	176·2	224·6	231·3	0·27	0·20	0·29
				Cottonseed					
U.S.A.	4·8	5·2	5·3	28·4	24·2	15·1	0·17	0·22	0·36
China	1·5	1·7	4·7	7·4	10·9	14·8	0·20	0·16	0·32
India	} 2·3	0·9	1·3	} 24·7	13·9	19·3	} 0·09	0·07	0·07
Pakistan		0·5	0·6		3·1	3·4		0·16	0·17
Brazil	0·8	0·7	0·9	5·2	6·4	6·8	0·15	0·12	0·13
Other	3·3	4·6	7·2	16·3	20·3	24·2	0·20	0·23	0·30
World	12·6	13·7	20·1	82·0	78·8	83·5	0·15	0·18	0·24

*French West Africa.

The possibilities of further improvement in yield/acre

Comparisons between modern and primitive farming in countries like Rhodesia and East Africa suggest that nothing inherent in the tropical climate opposes the improvement of arable output. Though the days are shorter than those of the temperate summer, the light is more intense, so that the total radiation per day and per year is often greater (Black, 1956). Consequently it is not surprising that the highest known level of agricultural dry-matter production is in sugar-cane in Hawaii, where around 30 tons of dry matter can be produced per acre in a year (Burr, Hartt, Brodie, Tanimoto, Kortschak, Takahashi, Ashton & Coleman, 1957). A heavy wheat crop in this country may consist of 2 tons of grain and 2 tons of straw/acre, mostly produced in about 6 months between February and August; but sorghum in the Sudan can give 6 tons of dry matter/acre, of which 2 are grain, in 4 months. The banana crop in Central America and the Canary Islands can produce an annual starch yield as high as that given by the potato crop in the United States (Simmonds, 1946). Certainly some tropical soils are poor in plant nutrients, and (especially on some of the ancient leached red earths of basement complex regions) an effective fertilizer technology is not everywhere available, particularly for phosphate, but the solution of these problems is only a matter of time. Though the attacks by pests and diseases (Padwick, 1956) can often be catastrophic, control methods are steadily developing. The risks of crop production in arid regions can be offset by dry-farming methods based on various systems of moisture conservation. The present poor yields of grain and pulses in India must be compared, not with modern temperate farm production but with the yields of 6–8 cwt of grain and 3–4 cwt of beans which were normal in Britain up to the time of the great agricultural improvements of the 17th and 18th centuries.

The principal technical means for improving yield/acre in the tropics fall into three groups—improved protoplasm, improved methods of production, and improved crop protection. Improved crop varieties offer the simplest means of increasing yield, quality and disease resistance. There are innumerable examples of this. In the Sudan, the Empire Cotton Growing Corporation has co-operated with the Sudan Ministry of Agriculture to produce cotton varieties of high yield and consistent quality which are resistant to blackarm disease (Knight, 1954), and forms resistant also to jassid attack are in an advanced stage of development. In India, scientists of the Rockefeller Foundation, co-operating with the Indian Council of Agricultural Research, have produced in 4 years (1956–1960) superior hybrid maize varieties adapted to the main maize-growing regions (Rockefeller Foundation, 1960). In the Sudan rainlands 4 years of selection produced, from local material, sorghum varieties adapted to combine harvesting and capable of yielding over 3000 lb of grain/acre (Walton, 1959), against the yields of 1000 lb or so which were formerly acceptable. The current increases in yields in China must owe a great deal to improved varieties, since it has probably not been possible in one decade to provide adequate supplies of nitrogen and other fertilizers or to make much change in farming methods which were already quite highly developed.

The principal points at which production methods are defective are in respect of rotations, control of soil erosion of various kinds, timeliness and density of sowing and fertilizer practice. In the thinly populated areas, the bush fallowing system of shifting cultivation provides a slow, laborious, wasteful and not very effective method of conserving plant nutrients (Nye & Greenland, 1960). Shifting cultivation can be organized, as in the *couloir* system of the Congo forests, but it cannot safely be abandoned in favour of a stable system unless ecological land-use planning, including reform of land-tenure arrangements if necessary, soil conservation methods, improved rotations, and, if possible, fertilizer practice and weed control also, are introduced simultaneously. Much of this was done in one operation during the Mau

Mau emergency in Kikuyuland: a countryside was replanned into a new and more efficient form in a few years. An essential component of such improvements is a reliable cash crop, or several: modernized agriculture must rest on a modernized economy.

As population increases, shifting cultivation becomes less and less possible, and so the dense populations of the tropics are largely dependent on rich, low-lying alluvial soils where annual deposits of river silt and the absence of leaching permit continuous crop production. In these situations improvements in fertility must depend on fertilizers (Richardson, 1961). In China, average responses to 54 lb fertilizer nitrogen/acre have been reported as 500–600 lb of paddy (Richardson, quoted by de Geus, 1954); in India 20 lb of fertilizer nitrogen will give nearly 300 lb of paddy (Yates, Finney & Panse, 1953). The Japanese consumption of fertilizers is the highest in the world outside Europe. In Japan, the consumption of fertilizer nitrogen in 1959–60 was nearly 600 000 tons/year, or about 15 lb/head of population. In India it was 180 000 tons/year or $1\frac{1}{4}$ lb/head. In both China and India, the additional use of phosphatic fertilizer will give further increases. Here and there, as in temperate countries, trace-element shortages may restrict yields.

Timely planting at sufficient density is often impossible for the hand cultivator who has a great deal of hard work to do in a short time at the opening of the crop season. It is difficult to sow by hand at the close spacing which is essential for high yields of groundnuts, and this can only be overcome by mechanization. Simple hand drills have an important part to play in densely populated areas where the introduction of tractors is not possible. Very often officially organized schemes for mechanical ploughing, as in the Rufiji valley of Tanganyika, will allow village people to sow and tend areas of crops, especially on heavy soils, which they could never have prepared for sowing by hand. Ancillary forms of mechanization—pumping, milling of grain, cutting of timber, haulage—will liberate man- and woman-hours for the care of crops. Such methods are no more than a beginning: the tractor is in the under-developed countries to stay, as anyone will agree who has seen the development, during the last 8 years, of over 1 million acres of partly mechanized sorghum production in the Eastern Sudan. The tractor in the tropics can be a powerful agent for destruction, but when tamed by land use and soil conservation legislation it becomes an essential tool of farming progress, and eliminates the wasteful food consumption of draught animals.

In the field of crop protection the cheapness and effectiveness of modern agricultural chemicals are leading to their widespread use on cash crops. DDT (dichlorophenyltrichloroethane) spraying of irrigated cotton is standard practice in the Sudan: the Ghana cocoa farmer uses an official fungicide spraying service. MCPA (chlorophenoxyacetic acid) could abolish the witchweed of cereals (*Striga* sp.) in tropical Africa, and simazine (2-chloro-4, 6-bisethylamino-s-triazine) can give total weed control in maize, the only plant species known which is not sensitive to it. Seed dressings can be effective against seed bed and other soil pests and diseases, against seed-borne troubles, and, in the groundnut, can delay the multiplication in the crop of aphid vectors and so reduce the severity of rosette disease. In the Sudan rainlands, a seed dressing of 2 g γ-BHC (γ-benzenehexachloride)/acre, for sorghum, often makes the difference between a thin stand leading to a crop failure, and a dense stand yielding over a ton to the acre.

In cotton and hybrid maize, control of seed stocks can be used to ensure efficient seed dressing as well as varietal improvement. Seed schemes could be devised for many other crops, based on free issues of dressed seed of improved varieties produced on official seed farms. The cost/acre of such a service would be relatively small and it would also insure against shortage of seed at sowing time, which is common after a poor harvest because hunger has driven the cultivator to eat his seed stock. No doubt safe but unpalatable seed dressings would ensure that the official seed supply was not eaten also.

Finally chemical protection, and improved varieties and storage methods, can do much to control the immense losses (often up to one-quarter of the produce) caused by insect attacks on stored produce.

All these methods require efficient research and extension services. One way of providing them is outlined in the first report of the Rockefeller Agricultural Program (Rockefeller Foundation, 1960), published last year, which should be compulsory reading for all who are interested in the war on hunger in developing countries. They also require finance and economic organization. But to the agricultural scientist they present no insuperable difficulties. We know how to do the job.

The development of new agricultural areas

Whether or not we accept Salter's estimate (in de Turk, 1948) that there are 700 million acres of unused land in the tropics suitable for arable development, there can be no doubt that considerable extensions of farming on new land are possible. In the U.S.S.R., Iran, Iraq, Pakistan and North East Africa large irrigation schemes are being surveyed or constructed in areas which are at present useless or of low productivity. In the Asiatic U.S.S.R. the so-called virgin lands scheme, in spite of its tribulations, will probably succeed in opening at least 50 million new acres. In the central Sudan at least 50 million acres of good soil with adequate rainfall are at present unused for lack of perennial water supplies, which could be provided relatively easily by modern techniques. The failure of the groundnuts scheme in East Africa damped British enthusiasm for projects of this kind, but given good initial selection and assessment, and the proper preliminary sequence of ecological land-use survey, research, pilot development, and logistic planning (Bunting, 1952, 1955) they can certainly be successful. Ecological land-use survey and planning techniques, largely based on aerial photography, are now available commercially, and a considerable body of experience of their use has accumulated in the last 15 years.

One of the lessons of this sort of work is that existing land use is no guide to the potentialities of modern technique. The Central Rainland Research Station in the Sudan was started in a region used only by nomad graziers, yet with the guidance of research its potential for mechanized arable farming was excellent (Bunting, 1956). Another very important lesson is that when land is cleared mechanically on a large scale in wet regions the reduction in transpiration may produce unmanageable waterlogging and swamp conditions in previously well-drained country, and leaching and erosion may severely damage the soil. Enthusiasm must be balanced by accurate and imaginative survey, and by dispassionate research and pilot development. A third lesson teaches the folly of preconceived ideas: in a new development crops and farming methods must be tested anew. The fourth, and most difficult, lesson is that natural forces are not amenable to administrative instruction.

Some generalities

Throughout this review the very important human, social and economic aspects of the problem have been largely avoided. Yet they represent the most difficult part of the problem. We have or can find technical means to do most of what we want to do, but they will be ineffective without capital, industrial backing, education, and extension services, marketing systems, wise economic management and so on. In overcrowded areas, it is essential to reduce the human and animal pressure on the land. India and Pakistan cannot hope to progress so long as they harbour uneconomically one-quarter of the world's cattle population. Conversely, technical developments of this sort affect man and society. They produce the new men, the operatives, scientists, teachers, organizers and leaders who help to carry the national development on to its next stage.

Finally in the long run all of this will be negated unless mankind is able to use the breathing space given by rapid increases in output to advance cultural and living standards and stabilize the size of populations. Though it is far off, there is a technical limit to the potential increase of food supplies, but long before it is reached I hope mankind will rebel against the sheer pressure of numbers and regulate them to ensure the dignity and worthiness of human life.

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