163 | WORLD POPULATION AND WORLD FOOD SUPPLIES*

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THERE is an old Egyptian saying that whoever has once drunk of the waters of the Nile will want to go back and drink them again. I do not know if that has ever been said of the waters of the Tyne, but it is certainly true that the British Association always welcomes an invitation to Newcastle. This is our fifth visit; to no other city have we been more often.

We came first in 1838 when England was mainly an agricultural country. The 111 years that have elapsed have seen profound changes in our national life, particularly the prodigious advancement of science and of its daughter technology.

Among the many resulting achievements has been a great increase in the certainty and the length of life. The world population has risen more rapidly than ever before; it is now estimated by the Food and Agriculture Organisation at about 2,300 millions, and the increase at about 20 millions a year—an average addition of two every three seconds day and night, year after year, and the two may become three or more as science advances, social services improve, and bodies such as the World Health Organisation become fully operative. Can they all be fed? The problem is complicated by the inequalities in the rate of increase, the less advanced groups multiplying more rapidly than the more advanced, and also by the unequal distribution of population over the earth's surface. Over most of the world the population is so sparse that it can produce its own food; some regions can produce a surplus; but a few regions are so densely crowded that they can themselves produce only a restricted dietary—England, Belgium, Egypt, India and Eastern Asia. England is the most crowded, but its highly developed export industries enable it to import food from the surplus countries, so long as they continue to have surpluses. India and Eastern Asia have fewer possibilities of imports, but their home production can be considerably intensified. Expansion of the world's food supplies depends, therefore, on extension of the food-producing area, more intensive cultivation of the area already used, and the reduction of the present heavy wastes and losses.

Extension of the Food-Producing Area

The world's total land area is 35,700 million acres, but only about 11,000 million are estimated by C. B. Fawcett to be 'climatically suited' to crop growth. Much of this, however, is at present impracticable for cultivation, and the area actually used is some 3,000–4,000 million acres: 7–10 per cent only of the land surface of the world. Some 85 or 90 per cent of this area is used for food production; the rest is for industrial crops. The food-producing area represents a world average of about $1\frac{1}{2}$ acres per head which, at British yields, would give the British pre-war dietary; much less would suffice for a vegetarian dietary. The area 'climatically suited', however, is about 5 acres per head. Can any of those unused $3\frac{1}{2}$ acres per head be brought into cultivation?

* From the Presidential Address delivered at Newcastle upon Tyne on August 31.

Agriculturists have long been engaged in widening the zone of cultivation by converting the marginal regions of their day into farm land and then pushing out into new marginal regions. The pioneers began in the coastal regions of North America, Australia and New Zealand, where conditions resembled our own, using methods that had been very successful in Great Britain. Wheat was their main crop. But in pushing inland they were brought to a standstill by the diminishing rainfall, and in Canada by the early onset of winter; everywhere their crops suffered from pests and diseases. In 1898 Sir William Crookes, in his presidential address to the British Association, startled the world by declaring that the process of expansion was nearly over, and by the 1930's the world would suffer hunger unless yields were raised. He showed how the necessary nitrogenous fertilizers could be prepared synthetically from the nitrogen of the air. Agriculturists did not accept his view. Lawes and Gilbert, old, but full of vigour and Victorian pugnacity, did what many indignant Englishmen have done before and since, wrote to *The Times* about it. But, in fact, the address was one of the most momentous the Association has ever heard; it founded the great nitrogen industry and everywhere stimulated agricultural investigators to fresh efforts.

The wheat problem was solved, but not in the way Crookes expected. Shortly after his address, the new science of plant genetics was founded, and for the first time it became possible systematically to transfer characters from one plant to another and so obtain new varieties possessing certain desirable qualities. Early ripening, shortness of straw and a high ratio of grain to leaf are all required in drought- and frost-resistant varieties, and all are heritable characters, as is resistance to rust and other diseases. World-wide search was made for varieties possessing the desired genes, pure line and other techniques were evolved, and new varieties were in time produced suitable for the marginal regions so that these became productive farm lands. By the 1930's Canada's 1898 wheat acreage of 4 million had risen to 27 million; Australia's 5 million to 16 million, and the Argentine's 7 million to 20 million; the world acreage and output rose far beyond the limits set by Crookes, and there was such a glut that wheat growers everywhere suffered greatly and relief measures became necessary; in the Argentine wheat was burnt in the locomotives instead of coal.

The dreaded catastrophe had not eventuated, but it had been averted by means wholly unexpected; one of agriculture's many illustrations of the ancient truth:

"And the things that we looked for, the gods deign not to fulfil
And the paths undiscerned of our eye, the gods unseal".

Since the 1930's, however, the wheat area of these new countries has not expanded, which has been taken to show that no more new wheat lands are available. The deduction is unjustified. Agricultural development of new lands is very costly, requiring

development of transport, storage and marketing facilities, and it is not undertaken unless a profitable market for the produce is assured. The glut of the 1930's had a restraining effect on development. Even the War has not stimulated much expansion. In 1940 Canada raised her acreage to 28.7 million in response to our urgent appeal; but the difficulties of disposal caused such discouragement that in 1941 the area fell to 21.9 million acres, and even now is only about 24 million acres, this being all that present conditions justify. All the same, Canada was able last year to supply three-quarters of British imports of wheat and flour. We owe a great debt to Canadian cerealists who made this possible—L. H. Newman, C. H. Goulden and their associates—and to the agricultural engineers who excelled themselves in devising implements for cultivating the soil, sowing and harvesting the crop with the minimum of man-power.

A new and very promising attack on the marginal lands is now being made. It is the soil-climate complex, not the climate alone, that determines agricultural use. The climate factor may be beyond our control, but the soils are being improved. Marginal lands are generally used for ranching—often many acres to one animal. Their present use is for low-productive ranching only. The more tractable are being converted into properly managed grazing land. The approach is ecological; the vegetation is surveyed, the types classified, and methods of management and conservation are worked out for each type. In South Africa more than a hundred different types of veld are recognized, each requiring its own system of management. Seeding with better grasses is being widely practised, particularly in the United States; the world is ransacked for suitable types. Canada and the United States took crested wheat grass from Russia; Australia has taken grasses from the Mediterranean countries, Africa, Turkestan and India; they are grown at the experimental stations, and suitable strains are selected and multiplied. Cross-breeding has begun. Good work is in progress at Saskatoon, Swift Current and Kamloops in Western Canada, and by Australia's vigorous Division of Plant Industry and, of course, in the United States. Unfortunately some of the good drought-resisting grasses do not easily form seed under cultivation, though they do so readily in their wild habitat. The cross-breeding of the semi-arid types has scarcely started, though collections such as that of I. B. Pole Evans in South Africa, D. C. Edwards in Kenya and others afford good material. In view of the very great importance of grass for soil conservation in all parts of the British Commonwealth, it is highly desirable that a well-equipped Commonwealth station should be established to study existing semi-arid types and produce new ones. One of the great needs now is for leguminous plants that will do for the semi-arid and tropical regions what subterranean clover and lucerne have done for the moister regions.

Large tracts of land hitherto unfertile are gradually yielding up the secret of their barrenness. Australia has made great progress. In large parts in the south the cause was the lack of trace elements: zinc, copper, molybdenum and others; these being supplied, the soil under proper management became productive. In the attractive Albany region are 300,000 acres to be made into 400-acre farms. For the large parts in the north, however, the secret is not yet discovered, nor has it been for the 300 million acres of peat and muck soils in Canada. But in both

countries scientific workers are studying these problems under the organisation in Australia of Sir David Rivett, and in Canada of Dr. E. S. Archibald, E. S. Hopkins and others. Soil barrenness in New Zealand is ably investigated by Sir Theodore Rigg and his colleagues at the Cawthron Institute.

The wheat belt which once stopped at about the line of 18 in. of annual rainfall now stretches to the 12–15 in. line (dependent on the evaporation), and the utilizable grass belt down to the 8–10 in. line. There are, of course, difficulties in developing regions of erratic rainfall, particularly the old Joseph problem of storing the surpluses of good years for use in bad years; but these should not be insuperable.

The hot regions of the world present special problems because they can never be closely settled by white people. Australia's empty north has vast areas of natural grassland with adequate rainfall for beef production, and bulldozers have revolutionized the making of dams for water storage. The development problems are discussed in an excellent report by W. L. Payne and J. W. Fletcher (1937). They include land and tenure reform, pasture improvement, better living conditions for the resident workers, better abattoir facilities and transport. A chilling process based on the low-temperature research at Cambridge can now replace the old unsatisfactory freezing technique whenever the quality of the beef justifies the cost. The possibilities of arable cultivation have been greatly increased by the development of the disk plough and other implements; the Overseas Food Corporation is proposing to develop 315,000 acres of Northern Queensland, mostly for arable crops, including sorghum varieties suited for mechanized culture.

Africa's problems are fundamentally different. The small native peasant is already in occupation with his own traditional ways of life. Yet he alone can supply some of the products vitally important to us—oil seeds, fibres, tea, coffee and cocoa. The problem is to replace his primitive methods by modern efficient methods without too great disturbance of the best elements in the native life. We may be justly proud of the splendid pioneering work of the British agricultural officers; Great Britain has done more than any other country for the opening up of Africa. The Sudan Plantation Syndicate has for many years been highly successful in combining modern scientific cultivation methods with a way of life acceptable to the native and justifiable before the bar of civilization. In West Africa progress has gone so far that mechanization can now be introduced into the native community farming: this has been discussed in the excellent Clay-Monson report. As in Australia, the bulldozer's remarkable power of scooping out 'water holes' promises greatly to facilitate development. In Central and East Africa scientific workers at Amani and in the Departments have paved the way for the huge scheme of developing 3½ million acres of savannah land, hitherto empty because of the tsetse fly and lack of surface water—troubles now capable of reduction. The unfortunate decision to rush this scheme through has been responsible for much costly disappointment for which, however, the scientific and technical staffs are in no way to blame. Progress would become still more rapid if a good livestock industry could be developed; this would necessitate not only better animal health but also more and better food supplies for the animals. The native problems have been lucidly discussed by Sir Alan Pym in his book "Colonial

Agricultural Production" (1946). The fundamental scientific problems are investigated in Britain under Sir John Simonsen and the Colonial Office Research Council, and in East Africa by a research team under B. A. Keen. Development organised by the Colonial Office is proceeding more rapidly and systematically than ever before.

Difficult human problems are bound to arise, however. The high costs necessitate high output, and the conservation of the soil requires strict control of land use over wide areas. Close supervision by advanced white people will be essential until Africa has its own highly efficient universities, research workers and chemical and engineering industries. African students have been brought to Britain for higher training, but for some their stay has been made unprofitable by inadequate social arrangements, or even by hostile political propaganda.

The wet tropics (50 in. or more rainfall per annum) contain more unused land than any other vegetation region in the world. Sir Harold Tempany has discussed the possibilities of the British portion; the Belgians have done much useful work in the Congo; and the United Nations Educational, Scientific and Cultural Organisation proposes a survey of the vast forest basin of the Amazon. Dr. C. E. Kellog and other American experts are hopeful about the utilization of part of these regions.

At the other end of the temperature-scale lie the cold, leached soils of the northern latitudes, the podzols, naturally under coniferous forest but brought into cultivation as need arises. The Finns—the most northerly farmers of the world—the Canadians and the Russians are all studying the problems involved, while the Swedes, at their incomparable station at Svalof, have produced varieties of arable crops well suited to the conditions.

But we need not go abroad for marginal and waste land; we have plenty at home here in Britain; this also can be reclaimed by conversion first into grassland, then if need be into arable. Sir George Stapledon and his colleagues at Aberystwyth have produced suitable strains of grass and clover; their use is investigated by William Davies at Drayton. R. Ellison has reclaimed much waste hill-land in Montgomeryshire and estimates that 1,000 acres so reclaimed could provide for an additional 250 store cattle. Some half-million new acres were brought into cultivation in the nine years ending June 1947.

Even light sands, long abandoned as waste or left to the foresters, are now being put down to suitable grasses or lucerne and used for dairying. Norfolk and Suffolk have some excellent examples of reclamations brought about by enterprising farmers and landowners. *Spartina Townsendii*, shown in 1923 by F. W. Oliver to Lotzy and Verhoeven as a reclainer of mud flats, has proved very successful in Holland and may yet provide much new land there and in Britain also.

In short, wherever cultivation is now practised, there are possibilities of extension, and no one can say how great they may be.

Soil Erosion

Against these potential gains, however, must be set the very serious losses due to soil erosion. This was really an old trouble to the Mediterranean and Eastern peoples; but it was new to the agricultural pioneers who went out from Great Britain and

Western Europe, and they did not realize how greatly the regions to which they were going were liable to it. Unwittingly their practices favoured it: uncontrolled felling of trees in the moister regions led to water erosion, while in the drier regions exclusive grain cropping with finely cultivated fallows to destroy weeds and conserve soil moisture—a false expectation based on the faulty soil physics of the time—broke down the soil crumbs into fine dust which was blown away by the scorching winds of the hot, dry summers.

In Africa great losses have long resulted from uncontrolled burning and over-grazing the grasslands, exposing the bare soil to the beating of the torrential rains characteristic of semi-arid regions, washing it away and often leaving great gullies; and matters were made worse by the success of the health and other departments in increasing the human and animal populations. It was the dust storms of the dry 1930's in the United States, and in particular a terrifying one on May 16, 1934, that made all America aware of the 'Dust Bowl' and the need for drastic action. In the United States some 330 million acres out of 460 million acres of good arable land were estimated to have suffered, as had something like half of the wheat land of Australia, great areas in Africa, Asia and elsewhere. A useful account is given in G. V. Jacks and R. V. Whyte's "Rape of the Earth"; but there has been much sensational writing which may, however, have stimulated action.

The United States was the first to act, and set up very successful soil-conservation services and a superb model: the Tennessee Valley Authority.

It is now recognized that erosion comes about through wrong use of the land, and the remedy is correct utilization, both of land and of water, applied over the whole catchment area. The problems are therefore not exclusively technical but administrative also. A vegetation plan must be drawn up to ensure continuous cover of critical areas—hilltops, slopes, etc.—with trees or grass, and the protection of arable land against soil movements and run-off of water by mechanical devices such as contouring, alternate strip cultivation, etc. For full effectiveness the plan requires the collaboration of the ecologist, the agriculturist, the forester and the plant breeder; the ecologist to ascertain what plant combinations are most appropriate, the agriculturist and forester to select those of most economic value, and the plant breeder to narrow the gap between the ideal plants and those actually available. Grass plays a vitally important part; it not only covers and protects the soil, but also builds up the fine particles into crumbs by processes not yet understood; successful treatment largely depends on the selection of the right grasses, particularly rhizomatous or stoloniferous types. A large amount of successful conservation has been done and much eroded land has been rehabilitated. The United States Conservation Service under H. H. Bennett now operates over some 1,100 million acres—three-quarters of all the farm and ranch lands. The 'Dust Bowl' States—Oklahoma, Kansas and Texas—are now producing much more wheat than they did before the 'Bowl' was heard of. The very sound Canadian prairie rehabilitation programme is in vigorous operation; in all the Australian States affected—especially New South Wales and South Australia—there are active soil conservation departments, and W. Hartley, of the Division of Plant Industry, is studying suitable grasses. Much good work has been done by I. B. Pole Evans in

South Africa, W. S. Martin in East Africa, R. R. Staples in Southern Rhodesia, and by others in the Belgian Congo and elsewhere.

Soil erosion could be dealt with much more easily if the problems were solely technical; unfortunately, the need for recasting the vegetation of a whole catchment area often cuts across all sorts of social or tribal customs, personal or sectional interests, political boundaries, etc., and raises many complex administrative problems. A few recalcitrant objectors could spoil the whole plan; it must be enforceable by law, but voluntary co-operation of all concerned should be the aim. The United States soil conservation laws achieve this admirably and have furnished models to other countries. The farmers and land-owners of the region are invited to meet the Government and State experts, and a plan for proper land utilization is drawn up; any necessary material help is given. The farmers, feeling that the plan is at least in part their own, support it; there is not the automatic opposition given to a plan imposed from above. South Africa also has a comprehensive conservation law. The over-populated and over-grazed areas of Africa present special difficulties where the remedial measures conflict with treaty rights and tribal customs; agitators have not scrupled to stir up trouble, and much interference with useful work has been reported in the native areas of Kenya. Fortunately, the white governments concerned—the British, South African, Rhodesian, French, Belgian and Portuguese—recognizing the truth of General Smuts's dictum that soil erosion in Africa transcends all political problems, have agreed to co-operate and to set up an information office in Paris and a soil research organisation in Africa. The many problems met with in the British Colonial Empire have recently been ably discussed by Sir Harold Tempny.

An elaborate plan has been drawn up for dealing with erosion in the U.S.S.R. In most other affected countries, except perhaps China and parts of South America, the need for control is recognized and the lines of action laid down.

Rehabilitation is necessarily slow, and there are no good figures to show how far it has gone. The estimates currently quoted are those of the early 1930's, when the need was just being recognized and the bias was towards all-inclusion. It is therefore impossible to say whether rehabilitation has yet caught up with erosion. But those engaged in the work are hopeful about the outcome; the control measures are known to be effective. Moreover, erosion is associated much more with extensive and mono-culture systems of agriculture than with the intensive mixed farming systems that will necessarily be more widely adopted as the demand for food increases.

Intensification of Cropping

The most hopeful way of increasing world food supplies is by more intensive cultivation of the land already in use. It is especially important for Asiatic and African peoples—sixty per cent of the population of the world—for they have no prospect of emigration and very little of food imports from other continents. Their present product is chiefly grain, the yields low and uncertain, the methods inefficient. Experimental farms in India commonly obtain twice the yield of the neighbouring peasants, and there is often no physical reason for the disparity. But the difficulties of levelling-up are enormous; they spring

from the peasants' poverty, their overflowing fecundity and the consequent minute sub-division of the land; these can only slowly be remedied.

Meanwhile, some improvement is possible. Irrigation can still be considerably extended. The projected Nile schemes, if realized, will solve Egypt's problems for a generation, while Asia, which already has some seventy per cent of the irrigated area of the world, mostly in the Himalayan region, can greatly increase the area served by tube wells as developed by Sir William Stampe.

Asia also offers vast scope for fertilizer use. Rice is the crop most affected; it is perhaps the most crucial crop in the world, for it is the main food of Asia, and its shortage is one cause of unrest there. It has been much studied in India, and improved varieties have been raised by pure-line selection; hybridization is scarcely begun. Nothing would more greatly increase its output than wider application of nitrogenous fertilizers. But rice is mainly a swamp crop, and ordinary methods of fertilizer use break down. Nitrate of soda is relatively ineffective; sulphate of ammonia often acts well but sometimes not. These puzzling complexities were resolved from a quite unexpected quarter. Prof. W. H. Pearsall, in studying marsh conditions in Cumberland, found measurable differences in oxidation-reduction potential in the water-logged soils; oxidation took place at the soil-water surface, but reduction lower down. Directly they heard of this, the Japanese experts saw its bearing on the rice problem. Sulphate of ammonia put on the surface of the mud in the usual fashion, at or before transplanting, was quickly oxidized to nitrate, which washed down below and was reduced to gaseous nitrogen. But if the sulphate of ammonia was pushed down through the oxidation zone into the region of reduction, it lay safely until the plant roots took it up. If nitrates, for example, ammonium or sodium nitrate, are added during the period of rapid growth, they can be absorbed quickly before they reach the reducing layer; therefore they may be used as later top dressings. The study of these oxidation and reduction zones showed also how cyanamide and other fertilizers should be applied. It gives for the first time a scientific basis to the manuring of the rice crop; another example of the far-reaching results that may come from a purely academic inquiry well carried out.

The human problems are more difficult. Will Burma under her new management retain her leading position* among rice exporters? And can Siam and Indo-China produce as efficiently as before? How will India fare if they do not?

The millets are specially important as native food in the semi-arid regions of India and Africa. We have done less work on these than we should; but this is to be rectified in the East African research scheme.

The general methods of intensification of food production are the same everywhere. Land tenure and size of holding usually need modifying to encourage higher efficiency; the holding should be of such size that one man can adequately supervise it. More productive systems must be evolved, and bare fallows replaced by tilled crops and by grasses and leguminous plants. Inevitably there comes a development of livestock. In the highest and most productive systems livestock products yield far more income than cash

* Before the War Burma exported almost 3,000,000 tons of rice annually out of a total export of more than 7,000,000 tons from South and East Asia.

crops; before the War livestock accounted for 70 per cent of the value of British farm produce, and according to Leitch and Godden's estimate, consumed on the average about 100 million million calories per annum—just about double the consumption of all our human population, and giving us in return less than ten million million calories. But it is only fair to say that they supply other essential needs; that most of the foodstuffs they consume are useless to humans, coming from grass, straw and various industrial and other residues; and that they greatly enhance the productiveness of the soils.

Intensification is greatly facilitated by the adoption of some form of farmers' association allowing joint and economical use of complex appliances, buying and selling operations, etc. In Denmark co-operation, and in Great Britain a variety of contract and co-operative methods, have been used with great success; in the U.S.S.R. collectivization is adopted. Whatever the method, it must suit the psychology of the farmers and be freely adopted by them if it is to have much chance of success.

Chief among the intensification methods is the improvement of the soil by fertilizers, lime, drainage, etc. Fertilizer requirements are ascertained by chemical analysis and by statistically controlled field trials as used by E. M. Crowther and F. Yates at Rothamsted or by foliar diagnosis and plant analysis, as used by T. Wallace and his colleagues at Long Ashton, and for sugar cane by Pierre Halais in Mauritius. Trace elements are studied by spectroscopic methods developed at the Macaulay Institute, Aberdeen, the Waite Institute and the Division of Soils, Adelaide, and elsewhere, while W. A. Roach at East Malling has ingeniously tackled the problem of supplying them.

Happily the necessary fertilizers are producible in almost unlimited amounts; the nitrogen comes from the air, to which in due course it returns; the known deposits of phosphate are estimated to suffice for some thousands of years at present rates of consumption; those of potash are also abundant. So far, only Western Europe and Great Britain use much fertilizer, between them taking nearly half the world pre-war production*. The War has brought about a great increase in consumption; both in Great Britain and in the United States this has doubled since 1938. World consumption of nitrogen before the War was 2 million tons annually; the present declared need is for about 4 million tons, and the factory capacity is of the same order†. In moist regions nitrogenous fertilizers have more than fulfilled Crookes's expectations; they saved the people of Britain from hunger in the two World Wars, and with clover and lucerne are our best source of the protein equivalent necessary to produce the milk and meat we so greatly need. In drier conditions phosphates are more effective; they have greatly improved the Australian and New Zealand pastures, thus providing large quantities of much-needed lamb and butter. Much more fertilizer could advantageously be used if factory capacity and transport were available. A better fertilizer supply and more leguminous cropping would quickly raise output over large parts of the world.

* The consumption per acre was in the following order: Holland (highest), Belgium, Germany, Denmark and Great Britain, France, and the aggregate was 846,000 tons of nitrogen and nearly 1,500,000 tons of phosphate out of a world consumption of just over 2,000,000 tons of nitrogen and 4,000,000 tons of phosphate.

† Excluding the U.S.S.R., Northern Korea and the Russian zone of Germany, for which no figures can be obtained. The consumption figures (F.A.O.) include technical requirements which, before the War, amounted to about 10 per cent of the total.

Along with more fertilizer goes the need for better seeds and better varieties; here the British farmer is particularly fortunate.

But all improvements fail unless weeds—arch enemies of mankind—are adequately controlled. Their destruction is one of the chief tasks of arable farming; chemical methods are coming in, but cultivation is the standard method; this and the preparation of a seed bed are usually its main purposes. Research on implements is done at the Farm Machinery Institute at Silsoe under W. H. Cashmore, and on field effects by E. W. Russell at Oxford.

Among the most significant changes in modern farming have been the increasing mechanization and the alacrity with which the younger farmers have accepted it. Tractors are displacing working horses—perhaps too rapidly.

Before the War about 60,000 tractors and 650,000 horses were used for agriculture in Great Britain. In 1948 there were more than 260,000 tractors, mostly ranging from 12 to 40 h.p.*, a gain of more than 200,000; in the same period horses were reduced by 192,000. Assuming with the Oxford Agricultural Economics Research Institute that the effective working power of one tractor is, on the average, the equivalent of four horses, British farms had in 1948 1½ million 'horse equivalents' compared with the pre-war 889,000, a gain of 68 per cent. During the War the quantum of output per man-year rose about 10–15 per cent; but the evidence available for the past five years suggests that, despite additional power and machinery, annual output has been below the war-time peak, while the total labour force on farms, allowing for changes in composition, has remained well up to war-time strength. Clearly there is room for more economical use of farm power.

It is impossible to forecast what the tractors of the future will be like; the United States already has some of 140 h.p. The limit is likely to be set by the amount of oil fuel available; the French foresee a shortage and are starting experiments on the production of methane by fermentation of straw. Tractors require their own special implements, which must be generalized and mass-produced to keep down their cost; they can no longer be made by local craftsmen to suit local requirements, like the old types; their manufacture is shifting to the industrial regions of the Midlands and Yorkshire—Canadian and American firms are recognizing the possibilities.

These engineering developments are enabling farmers to cope with the ancient difficulty that Nature's production of food is by jerks, while consumption is fairly steady. Storage is therefore necessary; usually it has to be done on the farm, and it is often attended by considerable loss. Grain crops may suffer from rats and mice, and these are estimated to destroy 2 million tons of food annually in England and Wales alone; a single rat is said to consume 50 lb. of grain a year and to spoil an additional 1½ cwt. Grass, a most important and for long most neglected crop, when made into hay commonly loses 30 per cent or more of its valuable protein equivalent, according to S. J. Watson's estimate; but, in any event, haying is inapplicable for modern intensively managed leys or lucerne that give three heavy cuts of highly nutritious material a year. Artificial drying preserves the nutrients intact; it requires 10–15 cwt. of coke per ton of product; 3 tons of dried grass per acre can be obtained—three

* The tractor statistics include market garden types of lower h.p.

time the old average yield of hay. Ensilage is cheaper, but involves loss of 20–30 per cent of the nutrients; lack of driers makes it at present the more practicable alternative.

Increased intensification necessitates strict measures against pests and diseases which now travel widely and are favoured by the greater crowding of crops. Resistance is fairly frequently a heritable character, and once the genes are found, resistant varieties can be produced, such as the rust-resistant wheats of North America and Australia, and the potatoes bred at Cambridge and at Corstorphine. The pathogen may exist in several strains, necessitating the introduction of several genes. The work is never-ending, for a relatively harmless organism may suddenly change, like the *Verticillium* which, having long lived an almost blameless life in the Kentish hop gardens, about twenty years ago suddenly produced a virulent mutation which has since done much damage there.

Measures for protecting plant and animal health are being steadily improved; they are the subject of important international conferences; if in spite of all precautions the attack still comes, counter-measures can often be taken. Plant virus diseases still defeat us, but the able and persistent efforts of F. C. Bawden, N. W. Pirie, Kenneth Smith and others cannot fail to bear fruit. Against insects the new chlor- and phosphorus-insecticides are very potent, and methods of spraying have greatly improved; even wireworms, long invincible, have succumbed to hexachlorbenzene. But there are always risks in interfering with Nature; the D.D.T. which was so effective against codling moth in orchards also killed the insect that had kept in check the red spider, and this not being affected by the D.D.T. became in its turn a pest.

Animal diseases—to which we in Britain are very liable because of our large imports of animal carcasses—are steadily being brought under control. The old method was instant slaughter to avoid spread; it was effective but costly. The modern method is to apply diagnostic tests so as to catch the disease early, then to segregate and give the appropriate treatment. Vaccines are used for a number of diseases, and immunization by the appropriate serum is growingly practised. Estimates of loss are always rather speculative, but before the War the loss of milk due to disease in England and Wales was estimated at 200 million gallons per annum. More definite is the fact that the present life of a cow in the milking herd averages about $3\frac{1}{2}$ lactations only; it should be 6 or 7.

Most countries could increase their food production considerably by applying known methods of improvement and raising the average performance to the level of the best. The yield of wheat in Great Britain used to be about 8 or 10 cwt. per acre; it now averages 20, and the best farmers get 30 or 40; but the world average is only about 7. A pedigree breeder may export a bull for £3,000; a scrub bull may be dear at £30. The average milk yield of England and Wales is about 550 gallons; recorded herds average about 700, and yields of 1,000–1,200 gallons a cow for a whole herd are not uncommon. Trained advisers, recently considerably augmented in number, have long been trying to reduce these gaps.

The old agriculture could be carried on by appliances made by local craftsmen. Modern intensified agriculture cannot; it demands high-grade machines, chemicals, sources of energy that only a highly

developed industry can supply and, of course, corresponding standards of education among the farmers. A food producer on the old system can feed about 4 to 5 persons—this is still a very common number; on modern systems he can feed about 15 or 20, provided some of these supply him with the necessary appliances. In the self-sufficient countries of Western and Central Europe, about 20–30 per cent of the population is agricultural; in Eastern Europe and in Asia the proportion is 60–70 per cent or more, and the standards of living are much lower. They can still be raised, but marked improvement can be obtained only by taking some of these redundant people off the land and setting them to make the appliances for a better agriculture, and providing the necessary transport and buildings.

But this raises new problems; it involves segregation, as seen very clearly in England where the difference in outlook between town and country is sharply marked, and knowledge of the countryside is often curiously lacking. So we hear exhortations to more food production, but at the same time the land on which alone this can be done and the money necessary to do it are steadily taken away for other purposes. Some land reclamation, it is true, has been done; in the nine years 1939–47 the area of rough grazings in England and Wales fell by 1.4 million acres, much being brought into cultivation. But a larger area, often of better land, went out of cultivation, and the total land under crops and grass shrank by 316,000 acres, according to the official statistics*. It is hard to find a countryman with a good word to say for planning. In the end, common sense has a way of prevailing, and we may still look for further intensification of production even in our highly cultivated lands, still more in the less developed regions elsewhere. From the present small and shrinking allocation of land in Britain we may yet raise half our food, besides improving the quality of both meat and milk. And the less developed countries can feed their people better than they now do.

New Uses of Science in Food Production

Pure science is continuously opening up new possibilities for use in agriculture. The starting point is commonly some purely academic problem of no apparent practical interest whatsoever. R. A. Fisher's investigations on the theoretical foundations of statistics, ably developed by F. Yates, have revolutionized agricultural experimentation by enabling investigators to make valid estimates of the significance of their results. Frequently the physiologist has started the chain of inquiries, followed by the biochemist and the organic chemist, and finally the technological chemist.

One of the most fruitful series of investigations began with the old inquiry: Why do plants turn their leaves towards the light? Went and Kögel at Utrecht showed that the response was due to minute amounts of an organic compound which operated by causing growth of the tissue where it happened to be. Several of these growth-promoters were found; they are called auxins and have a fairly simple chemical pattern—a straight-chain acid group combined with a benzene, naphthalene or indolyl group; indole-3-acetic acid is one of the commonest.

* Prof. L. Dudley Stamp puts the net loss at 438,954 acres, after allowing for some 500,000 acres of reclamation. The difference largely turns on the definition of 'cultivation'. In the official figures for 1948 the ten-year fall is given as 270,000 acres.

These and similar substances were soon prepared on a large scale and were shown to promote root formation in cuttings: Zimmerman and Hitchcock at the Boyce Thompson Institute investigated the action in detail, and horticulturists used it in practice; these and other effects are being followed up at East Malling under F. G. Gregory. Later it was found that these auxins induced the setting of fruits of the tomato and cucumber family without the intervention of pollen from the male organ; workers at Wisley, Long Ashton and Wye have all been active here. A spray of β -naphthoxyacetic acid, 40 parts per million of water, has been used considerably by commercial growers; the fruits are normal in appearance but not yet in quality, and they are seedless. Some fifty substances of this type have been tried by R. L. Wain and Daphne Osborne at Wye, and L. C. Luckwill at Long Ashton; each has some effect on the habit of growth of the plant or the character of the fruit—not always desirable—but a considerable range of control is possible.

So far no substances have been found effective for large fruit trees except some varieties of pear.

Another important action of the auxins was discovered by W. G. Templeman, E. H. Slade and W. A. Sexton at Jealott's Hill, and somewhat later, but quite independently, by P. S. Nutman and J. H. Quastel in following up some of H. G. Thornton's work at Rothamsted. It was naturally expected that auxins might increase seedling growth; but they did not—they even killed some but not others. Cereals were much less injured than some of their common weeds, and selective weed-killing became a possibility. Chlorine atoms were introduced to give sufficient stability and greater toxicity. 2:4 dichlorophenoxyacetic acid (called for short 2:4 D) is very effective and now widely used, especially in North America; some 5–10 million acres of grain were expected to be treated in Canada last year. G. E. Blackman at Oxford with a team of workers is developing this chemical control, and important practical results may be confidently expected.

Others of these compounds are used for checking growth: preventing potatoes from sprouting in storage; staggering pineapple harvests in Hawaii to fit the canning facilities; preventing the pre-harvest fall of apples, etc. Other substances change vegetative shoots into flowering shoots. No one can see the end; and, I repeat, it all started with the purely academic inquiry: Why do plants turn their leaves to the light?

Another investigation that may have far-reaching effects is being done jointly by a team of workers under R. Brown of Leeds and A. R. Todd at Cambridge. Brown and M. Edwards had shown that the seeds of *Striga*, a plant parasitic on sorghums and millets and the cause of much loss in Africa and India, germinate only when stimulated by a substance excreted from their roots. Todd found it to be apparently a sugar: D-xyloketose acted well. If the different varieties of sorghum should differ in their ability to prepare and excrete this stimulant, a chemical test might be devised that would greatly assist plant breeders searching for resistant strains.

It is possible that other parasitic fungi can live only on varieties of plants capable of producing the necessary stimulant.

The cysts of the destructive potato eelworm hatch out only when stimulated by a substance excreted by the roots of potatoes, tomatoes and other Solanaceae; this also is being studied by A. R. Todd.

When this is identified and prepared on a large scale, it might be applied to the land while fallow, so that the emerging larvæ could perish of inanition before the potatoes were planted.

Various soil organisms are known to produce antibiotic substances, analogous to penicillin, highly destructive to certain other organisms. Thaysen and others have found in tropical soils bacteria with high powers of inhibiting the growth of fungi. In the absence of a good soil fungicide, it is possible that soil-borne fungal diseases such as 'take-all' disease of wheat and Panama disease of bananas might be successfully controlled by introducing or encouraging organisms producing the appropriate antibiotic. Bacteriophages, destructive to various bacteria, are also known to exist in soils, though they have as yet found no application in agriculture. Add to this list the large number of Protozoa, Acrasieae and giant Rhizopods found in soil by B. N. Singh and other Rothamsted workers, and shown to feed on bacteria and other soil organisms, and it is clear that life within the soil is as full of risks as life on the surface. Some degree of control of this vast soil population so vitally important to soil fertility has long been sought, and the older method of partial sterilization may in due course be supplemented by newer agencies.

Some of the algae and fungi, especially the yeasts, have remarkable power of synthesizing fats and proteins. Only limited use has so far been made of this property, but the possibilities are considerable. H. A. Spoehr and his colleagues at the Plant Biological Institute at Stanford, California, showed that the composition of the dry matter of *Chlorella* could be varied widely by suitably modifying the environment; the fat could be raised to 50 per cent or the protein to 75 per cent.

Moreover, there still remain unknown possibilities in the oceans, for they carry much more vegetation than the land. Prof. Lily Newton is dealing with this matter in her presidential address to the Botany Section.

Genetical science can still do much more to help crop production. To give only one instance: wide crosses often produce sterile offspring. But treatment with colchicine in some cases doubles the chromosome number and makes the offspring fertile. New types can thus be synthesized which can be used for producing new economic forms.

Ecology is also coming in to help. The old idea that science would enable the farmer to go anywhere and produce anything has given place to the more realistic principle that every acre of land should, as far as possible, be used in the way to which it is best adapted. Extensions of the cultivated area, treatment of eroded land and improvement of wild pasture are already seen as ecological problems, but the range is much wider and the possibilities great.

Many of the vital processes in animals are, like those of plants, determined by chemical substances, and some degree of control has already been attained. H. D. Kay at the National Institute for Research in Dairying, Shinfield, has shown that thyroxin injected subcutaneously, or iodinated protein (casein) fed by mouth, increased the fat content of the milk and also raised the yield up to 20 per cent after the peak of lactation was passed. Even more dramatic was the use of a synthetic oestrogen, diethylstilboestrol, introduced in tablets under the skin, for inducing lactation in virgin heifers or barren cows—the first stage in making the male redundant.

Artificial insemination is already widely used, and is rapidly spreading, especially for dairy cattle, as milking capacity is largely inherited from the sire. Much successful upgrading has been done in Denmark; some half-million cows were inseminated in 1946, but this is only a beginning. J. Edwards estimates that by suitable dilutions the number of cows inseminated per bull could rise to 10,000 or even 15,000 per annum. We may yet live to see bulls, other than a small select aristocracy, become unwanted anachronisms. But that is not all. A cow normally produces only one ovum at each oestrus. When pregnant mare serum hormone is injected, however, she produces a number, as shown by J. Hammond, jun., and Bhattacharya at Cambridge. Attempts are now being made to transplant these into other cows—one into each—then to fertilize them by artificial insemination, and so get a dozen or so offspring from the chosen mother in place of a solitary calf. Scrub cows, otherwise of little use, could thus become incubators of the eggs of high-grade cows, the method would be particularly valuable for beef cattle. Already the transplanting has been successfully done with rabbits. No end is in sight: one cow could potentially produce some 75,000 ova during her lifetime. Nevertheless, there is always the lurking suspicion that Nature may resent being uncereemoniously bundled out in this way; we can only wait and see.

For it is a fact that attempts to control natural processes without adequate knowledge are always risky and may be dangerous. So agricultural scientists have long aimed at knowledge rather than control, certain that if their knowledge is sound their control will be secure. In the great agricultural research institutions to-day ideas and equipment are freely borrowed from the pure sciences; in studying soils, plants, animals and their relations one to the other, use is made of modern biochemical methods, of physical methods, of X-ray photography, of the electron microscope, of tracer elements to follow the processes of plant nutrition and so on. There is inevitably a time-lag between the gaining of new knowledge and its possible use; for engineering Sir Richard Southwell puts it at fifty years. For agriculture it is less, and the Agricultural Improvement Council has been recently set up to keep it to a minimum. The Royal Agricultural Society has long been working to the same end.

I shall attempt no forecast as to how much food the earth could be made to yield. The limit at any time is set by the efficiency of the plant as a transformer of radiant energy; at present this does not exceed 5 per cent, and, reckoned on the basis of the amount of food produced, it is much less. Whether this can ever be raised, whether we can ever do more than increase the proportion of assimilation products useful as food, cannot be said. But the present limitations to food production: utilization of 7-10 per cent only of the surface of the earth; conversion by the animal of 10-25 per cent only of its food into human food; and fixation by the plant of no more than 5 per cent of the radiant energy it receives; these are all challenges to agricultural science—which its workers are vigorously taking up.

No limits can be set to the possibilities of science, but it does not follow that the present rate of advance will continue. Great scientific discovery is possibly only for the gifted few, and only in an atmosphere of complete intellectual freedom: subordination to political or any other dogma is utterly destructive.

Nor can we praise the growing tendency to take good men of science out of the laboratory and put them into committee rooms, or to load them up with so much administrative and other detail—nowadays housework as well—that they lack the leisure for “reaping rich harvest from the mellow soil of quiet thought, mother of great deeds”, to quote the noble words of Æschylus. Then there is the ever-growing specialization against which Sir Richard Livingstone and others are tirelessly warning us. The individual suffers: Whitehead reminds us that a man may know all about the laws of light and yet miss the radiance of the sunset and the glory of the morning sky. And the loss to science may be greater: the breadth of culture of some of our pioneers—D’Arcy Thompson, Percy Frankland, J. B. Farmer and others—had much to do with their breadth of scientific vision.

Nevertheless, remarkable success is attained by teams of highly trained specialists working under an inspiring leader—even when the team includes men who, by themselves, would easily become

“lost in a gloom of uninspired research”,

as Wordsworth put it.

The possibilities of food production are, however, only part of the story. Food producers will labour to obtain a surplus for the outside world only on condition that they are provided with adequate appliances and incentives; and the replacement of craftsmanship by mechanization is inducing in agriculture, as in industry, a flight from labour. In many cases now the problem is not so much to increase output as to maintain markets and reduce hours of work. Happily, in spite of modern tendencies, a strong sense of individual responsibility in regard to hungry peoples still survives among food producers. This is, indeed, the basis on which Lord Boyd Orr built up the Food and Agriculture Organisation, now doing such useful work. But it would be entirely wrong to think of the world as a welfare State where food will be produced simply out of a sense of duty. If more food is needed, more work must be done to earn it.

The increased food production that may confidently be expected is more than ample for population increases at Western rates. But it could easily be outstripped locally where Eastern rates of increase prevail. A physiologically adequate dietary might still be attainable, but if Western standards of living are desired, Western restraints must be adopted.

These, however, are human problems, and, great as are the powers of science, it is of only limited help here. It can do much to overcome material difficulties and, better still, to satisfy man’s thirst for knowledge of the universe in which he lives; and it can insist continuously on our high duty to seek out the truth fearlessly and honestly, and having found what we believe to be the truth, to proclaim it—but in all humility and recognizing that we may be wrong. Apart from that, science can give little guidance in those great moral and spiritual problems which lie at the root of our most serious troubles to-day. It opens up many possible ways of life, but gives no help in choosing which to follow; it deals with the facts of existence but not with the values of existence. It gives some light to them that sit in darkness, but it has little consolation for those in the shadow of death, and it does not guide our feet into the way of peace. Even if science should make large-scale fighting wars impossible, it can do little against the more subtle wars by infiltration. It offers us great

possessions, but as the old aristocracy knew, great possessions imply a sound sense of values and great personal responsibilities. Democracies still have this to learn. That is one of our greatest problems to-day.

But there is no need for pessimism. Looking back to the time of the first meeting of the British Association at Newcastle, one can find much ground for hope. Those, too, were days of terrible anxiety and strain, and yet there were then born

many movements and activities which, scarcely noticed at first, blossomed later into full vigour, and greatly enriched our national life. How many important centenaries have been celebrated in the past few years. It may be that, unperceived by us, new movements are now starting into life, equally full of momentous possibilities for the future. Science can help us best if we have a sustaining faith, a high purpose in life and unflinching courage to pursue it.

SUMMARIES OF ADDRESSES OF PRESIDENTS OF SECTIONS

SOME DEVELOPMENTS IN ASTRONOMICAL INSTRUMENTS

SIR HAROLD SPENCER JONES opens his presidential address to Section A (Mathematics and Physics) by pointing out that, until far into the eighteenth century, astronomical observations were concerned almost entirely with the determination of the positions and movements of the heavenly bodies. In the seventeenth century the transit instrument became the standard instrument for the determination of right ascensions, while the mural circle was generally used for the measurement of declinations. Eventually the two instruments were combined to form the transit circle, which, with improvements in detail, has continued up to the present day to be used for the fundamental determination of positions. As requirements for precision have increased, its limitations have become more apparent. The errors of adjustment, continually changing with the ambient temperature conditions, are difficult to control accurately; complicated flexure effects, the error of figure of the pivots, and minute mechanical displacements in a telescope which is swung into different positions, introduce errors which are partly of a systematic nature and limit the accuracy with which a fundamental reference system of star places can be provided. Consideration is, therefore, being given to other designs of meridian instrument, likely to be less affected by systematic errors. In one of these the position of the instrument for each observation is determined by optical methods; in another the moving parts are reduced to a mirror, which can be turned to reflect light into one or other of two horizontal telescopes in the meridian, to the north and south of the mirror. For the determination of time, the development of the principle of Airy's reflex zenith tube to permit of photographic observations provides a much higher accuracy than is attainable with the transit circle.

The developments in physical astronomy have caused meridian instruments to be superseded almost entirely by equatorial telescopes in most observatories except the principal national observatories. The refracting and reflecting types of telescope have alternated in favour. In the seventeenth century the large aberrations of the primitive simple lenses necessitated telescopes being made so long that they fell into disfavour. Newton devised the form of reflector which bears his name, but the first satisfactory reflecting telescope of this type was made by Hadley in 1720, who took the essential step of parabolizing the mirror. Dolland's patent of the achromatic objective in 1758 brought the refractor back into favour, but the size was limited by the

poor quality of the optical glass. William Herschel's success in making larger mirrors of speculum metal, and the excellent quality of his telescopes made the reflector more popular. But the need for frequent repolishing of the speculum mirrors, the inconvenience of the altazimuth mounting, and the better refractors that became possible through Guinand's improvements in the making of optical glass and through his collaboration with Fraunhofer caused an almost complete reversion to the refractor. The equatorial mounting was developed by Sisson, Ramsden and Fraunhofer, among others. There was a rapid increase in aperture of the refracting telescope from Fraunhofer's $9\frac{1}{2}$ -in. Dorpat refractor of 1824 to Alvan Clark's 40-in. Yerkes refractor of 1897. It had then reached the practicable limit in size, and it is unlikely that a larger aperture for a refractor will ever be attempted.

Liebig's discovery of a simple chemical process for depositing a film of silver on glass, together with Foucault's improvements in the methods of figuring and testing glass disks, caused attention to revert again to the reflector. The developments in technique due to Draper, Common and Ritchey made the modern large reflector possible. Its light grasp, its achromatism, and the ease with which it can be used at different equivalent focal lengths make it a much more general-purpose instrument than the refractor, the main purpose of which is now in precise measurements. The use of an aluminium film, deposited by vacuum distillation, has enabled spectrographic observations with the reflector to be extended to the limit of atmospheric transparency.

'Pyrex' glass, because it has a lower coefficient of expansion and a higher thermal diffusivity than plate-glass, is now generally used for mirror disks. The thinner the disk the more rapidly it will reach a state of temperature equilibrium; but then also the more flexible it is, the more elaborate the support system must be. Sagging of the disk under its own weight can be counteracted by a properly designed support system. Couder has derived criteria, based partly on dimensional considerations and partly on experimental results, from which the number of supports required for a disk of specified diameter and thickness can be estimated.

The principal defect of the paraboloidal reflector is the small angular field which is free from coma, seriously limiting its use for direct photography. It can be overcome by the use of a spherical primary mirror in conjunction with an aspherical plate in the plane of its centre of curvature, figured to correct for the spherical aberration of the primary. This arrangement, generally called the Schmidt camera after its designer, has effective radial symmetry and