The Relation between Cultivated Area and Population.¹

By SIR DANIEL HALL, K.C.B., F.R.S.

RECENT considerations of the problem of the capacity of the world to continue to feed its growing population appear to have begun with the late Sir William Crookes's address as president of the British Association when he discussed the ultimate curtailment of the wheat supply through exhaustion of the soil nitrogen. Crookes's views attracted little more than academic attention at the time (1898) because the great tide of wheat that was setting in from the newer countries still in the process of exploitation was barely slackening; moreover, Crookes had neglected a factor then imperfectly appreciated—the fact that land under any of the conservative systems of farming adopted in the old settled countries does not become exhausted. Generally speaking, a soil will remain itself indefinitely at a certain level of production. Latterly in Europe that level has been raised by the introduction of extraneous fertilisers. In his review Crookes predicted the development of the synthetic processes of bringing nitrogen into combination which are to-day rendering that prime element of fertility so abundant and so cheap.

Though we no longer fear the exhaustion of soils, of late years certain sociological considerations have revived interest in the old thesis of Malthus. Overpopulation and unemployment have become terrible realities in Great Britain and other countries; many States are finding themselves under pressure to maintain their standard of living against the intrusion of neighbouring races propagating recklessly down to the barest margin of sustenance. Again, various studies of the course of prices of wheat have led to the conclusion that before the War the real price was rising continuously, and that this tendency is manifesting itself again, however much the true sequence of prices has latterly been obscured by fluctuations of currency.

These considerations led Mr. Keynes to envisage the approach of scarcity: his attitude is very much a return to Malthus. On the other hand, Sir William Beveridge, addressing the Economics Section two years ago, dismisses this fear as regards the world at large; whatever may be the troubles in Britain, "the limits of agricultural expansion are indefinitely far." On the whole that seems a very safe proposition; it has been so amply fulfilled for the last hundred and fifty years—during the greatest expansion of population the world has ever known—that it would almost seem to be necessarily true, especially as it can be buttressed by agricultural experiments showing the enormous potentialities of production from the soil.

There is, however, one aspect of the case that appears to have received insufficient attention: the capacity of agriculture to provide food for the people depends upon the extent of land available as well as upon the pitch of cultivation. To what degree can the tuning-up of methods be made to compensate for a non-expanding acreage? The first step towards a more exact consideration of the problem may therefore be an estimate of the amount of cultivated land that is

required to maintain one unit of population—man, woman, and child.

We may make our estimates by either of two methods—abstract or actual. The Food (War) Committee of the Royal Society adopted the figure of 2618 calories as representing the minimal daily energy requirement of one unit of the population, and calculated that the actual United Kingdom consumption in the five years 1909–1913 amounted to 3091 calories per head per day. An average English acre of wheat yielding 32 bushels will produce food, in the shape of wheat, flour, and pig obtained from the offals, of a calorie value of about 2½ millions. As the average consumption was about 1·13 million calories per head per year, we arrive at the conclusion that one acre of wheat would support more than two head, the relationship being more exactly 0·45 acre to feed one unit of population. But this figure is of no service in our more general consideration. The yield of wheat of 32 bushels per acre is far above that of the wheat-producing areas, and is that of only a few selected countries growing but a limited acreage. It is again the produce of land under the plough, and is consumed in the main as a vegetable product.

The great areas of grassland have a lower output of energy than the cultivated land, and the conversion of vegetable into animal food, whether of natural or cultivated fodder crops, is always attended by a great waste of energy. In the most economic production of pig-meat or milk, the energy recovered is only about one-sixth of that consumed, and this represents the machine at the top of its efficiency. The longer period of beef production results in a recovery as beef of only one-eighteenth of the energy consumed, and in practice the actual wastage of fodder and feeding-stuffs doubles or trebles the inevitable losses by conversion. Moreover, just as man is not a vegetarian making the most of the mere sustaining power of the land, so he does not use the land for food alone, but also for drink, for wool and fibre and other industrial materials, and for amenities.

We shall not get far on the theoretical basis, and I have only mentioned it as indicating the order of the superior limit of the maintaining power of land.

THE UNIT OF MEASUREMENT.

We must approach the question in a more empirical fashion and endeavour to ascertain the existing relation between the land in use and the people fed by it. Taking again the estimates of the Royal Society's Committee, it concluded that the United Kingdom production of food for the five pre-War years was 42 per cent. of the food consumed; 46·7 million acres of cultivated land then produced 42 per cent. of the food consumed by a mean population of 45·2 millions, which works out to 2·5 acres to each unit of the population. This figure, however, is somewhat misleading in that it does not do justice to British agriculture, since our farming is to a considerable degree concentrated on the more costly elements of diet like meat or milk rather than upon cereals and sugar. For example,

¹ From the presidential address to Section M (Agriculture) of the British Association, delivered at Oxford on August 9.

49 per cent. of the food production at home, as against only 24 per cent. of the imported food, consisted of animal products.

The importance of this relation between cultivated area and population is so great, and the calculations by which it can be ascertained are so approximate and subject to so many estimates of a speculative kind, that I may be allowed to set out various results obtained by different methods.

We may begin by comparing population and area of cultivated land for all European countries except Russia, to which we add the United States, Canada, Argentine, Australia, and New Zealand, as the white countries which are also the chief exporters of food to Europe. I exclude all oriental countries because in them the mass of the population possesses a different standard of living, and I have excluded the other South American States and the Union of South Africa and other African colonies because they all possess a very large 'native' population and their exports do not bulk large in the food account of Europe. We must recognise, however, that the errors in the calculation will be loaded on to one side, because all the unenumerated countries, Russia and the tropical lands, are to a greater or less degree exporters and not importers of food. However, with this proviso we find that in the States enumerated there are 464.1 million hectares of land under cultivation and a population of 481.5 million persons, or 2.4 acres per head.

In the United States about 356 million acres are in cultivation: from this may be deducted as producing exported materials, for cotton 24, for wheat 16, for maize 2, for meat products 22 million acres, or 65 million acres in all. Other products are exported but may be regarded as balanced by imports, so that we find 291 million acres of cultivated land devoted to supplying a population of approximately 112 millions, or 2.6 acres per unit of population.

France we know is a country that is largely self-supporting; it has a population of 39.3 millions and 36.3 million hectares under cultivation. To this acreage we must add 0.9 million for imported wheat, 0.5 for other cereals, and 1.1 for imported meat; the exports of wine and fruit we may regard as balanced off by other imports. The net result is approximately 1 hectare, or 2.4 acres, for each head of the population.

A similar calculation applied to Spain, a country in the economy of which neither exports nor imports of food play a large part, gives more than 4 cultivated acres per unit of population; but then the so-called 'cultivated' land includes a considerable proportion of mountain pasture of a very low order of productivity. On the other hand, Denmark, with the most highly developed agriculture of all countries, shows a production well above the average. A much closer calculation of production is possible for Denmark than for other countries—the data are set out in Mr. Harald Faber's paper before the Royal Statistical Society in 1924. Denmark is a country exporting agricultural produce chiefly in its most costly form as meat, butter, and eggs, but the means for equating the export against consumption is supplied in Mr. Faber's paper by the reduction of production and imports to food units. Making the necessary corrections for imports, it would appear that for the years 1909–1913 the population of

Denmark was maintained on 63 per cent. of the production of her own land, or 1.82 acres per person.

Putting the various estimates together, we arrive at the conclusion that under the existing conditions of agriculture among the Western peoples, it requires something between 2 and 2½ acres of cultivated land to supply the needs of one unit of population living on the standard of white peoples.

We may confirm this estimate by a consideration of the growth of population during the last century. Between 1800 and 1920 the number of the white peoples increased from about 200 millions to about 700 millions. Data, however, for the land under cultivation in 1800 are very imperfect, and again there was another factor of improved agriculture which came into play in the first half of the nineteenth century. If we take 1870 as our jumping-off point, we may estimate the increase in the white man's numbers up to 1920 as approximately 225 millions. During the same period the addition to the cultivated lands in Europe, United States, Canada, Argentina, Australasia, and South Africa, the countries which have provided the white races with food, has amounted to about 450 million acres. Again we reach a relation between cultivated land and population of between 2 and 2½ acres per head.

This brings me to the central point of my argument, that an increase of population is in the first instance dependent upon an increase in the area of cultivated land. The expansion of the white peoples in the last century was an event unprecedented in the world's history, and was achieved only because of the vast areas of unoccupied land, chiefly in the Americas, which suddenly became available for settlement through the power conferred by the railroad, the steamship, and modern weapons. It will be noticed that the population of Europe previously had become comparatively stable, even as it has become approximately stabilised in France at present—the expansion came with the opening up of the new lands and in proportion to the amount that could be settled.

ENERGY VALUE OF PRODUCE.

Accepting as a basis for further discussion that under the present system of agriculture something more than two acres of new land will have to be brought under cultivation for each unit of increase in the population, we may examine if any means exist of modifying this relationship before considering its consequences.

I have already suggested that a vegetarian diet is the more economical of the resources of the soil, and that meat and all animal products like milk and eggs are produced with an expenditure of energy which may be so low as seven but also so high as twenty times the energy available from them. It is true that to a certain extent the animal will utilise material otherwise of little service to man, like milling offals and low-grade fodder crops—roots, hay, or straw. None the less, if the maximum of population supported by a given area of land is the objective, vegetarianism becomes increasingly necessary, as we see among the crowded populations of India and China. At the same time, the tillage of lands now given up to the grazing of animals becomes possible because of cheapness of labour resulting from a redundant population. Most

of the beef and mutton supply comes from land left untilled because of the costliness of labour relative to products; the meat may represent a very low level of production from the land and yet a high cash return for the labour expended. Hence the apparent paradox of grazing being general in Middlesex because of the proximity of London.

Another item of waste which would have to be eliminated in case of stern necessity is the conversion of potential food into alcoholic drink. Great Britain ferments the equivalent of one and a half million acres of barley. France devotes 4,000,000 acres, nearly 4·5 per cent. of her cultivated area, to vineyards. Without going so far as to say that beer or wine possesses no food value, it is certainly not half of that which could have been grown from the land thus used for the production of drink. In such matters it is vain to prophesy, but I cannot help feeling that the race (not individuals) which cuts out meat and alcohol in order to multiply is of the permanent slave type destined to function like worker bees in the ultimate community.

INTENSIFICATION OF PRODUCTION.

The second question that merits very careful consideration is whether the current agriculture cannot be intensified so as to bring about a great increase of production from the existing area of cultivated land. A cursory examination of the average yields of our chief crops in different countries shows what an immense potential increase of production is here open. The average yield of wheat (1921 to 1924) for all the countries of the world collecting statistics was 13·2 bushels per acre; the average yield in Denmark for the same period was 41·4 bushels per acre—more than three times as much. Of course the area devoted to wheat in Denmark is about 200,000 acres in all, or 3 per cent. of her arable land, whereas the wheat acreage of the world amounts to about 250 million acres. The mass production of wheat in the world is from countries of low yield; more than half is grown in countries in which the average yield is less than 13 bushels per acre.

It is from these countries with the low yield per acre that wheat is exported, and their production determines the world market, with the consequence that wheat production has been increasing in these and similar countries, while it has been shrinking in the European countries with a higher yield per acre.

The dominating factor has been cost of labour; speaking broadly, it may be said that increased yields per acre are associated with higher expenditure per bushel for labour, and the great wheat-producing countries with a low yield per acre are the countries with a correspondingly high yield per man employed. It may be estimated that in England a man's labour produces about 960 bushels of wheat, in Australia 1500 bushels. A more exact comparison shows that in England the labour cost amounts to 1s. per bushel of wheat, against 8d. in Canada; this with an average wage rate of 30s. to 36s. a week in England as compared with 60s. in Canada.

All this goes to show that intensification is only to be purchased at the cost of labour, and that in the past, extending the cultivated area has been a cheaper way

of getting the wheat required by the world than higher farming.

This general statement, however, does not tell the whole story; particularly it disguises the intensification of yield that may be obtained without a commensurate increase of labour. For example, the introduction of more heavily cropping varieties, originated by the skill of the plant breeder, may add greatly to the production from a given area without increasing costs other than those of harvesting and marketing.

One must not, however, expect too much of the plant breeder. Over the greater part of the cultivated land of the world the gross amount of production is limited by external factors such as water supply, temperature, available fertility of the soil, etc. For example, the wheats and barleys grown in England had long been subjected to selection and improvement before the scientific methods of plant breeding were evolved, and the further steps in improvement are going to be neither big nor easily won, depending as they do upon altering what Dr. Beaven has called the migration ratio, whereby the plant will convert more of the material obtained from the air into useful grain and leave less as straw. The chief opportunities, in fact, lie in the elimination of susceptibility to disease or destruction by frost, or general tenderness of constitution, by which means the range of the high-yielding cereals, or even of cereal growth at all, may be enormously extended.

ARTIFICIAL FERTILISERS.

The general enhancement of production by processes which induce improvements of the water supply or the temperature, as by irrigation and drainage, soil amelioration, cultivations, etc., suffers from the disadvantage of calling for labour, until it may prove far more costly than the increased produce can repay. Fertilisers appear to offer more promise. It may be recalled that the general level of production from English land was raised by nearly 50 per cent. between 1840 and 1870. At the beginning of the period the average yield of wheat was of the order of 20 bushels per acre, this being the crop the land was capable of maintaining under a conservative rotation with no extraneous source of fertility. But between 1840 and 1870 artificial fertilisers were introduced and became a generally accepted part of British farming, with the result that the yield of wheat had risen to about 30 bushels per acre, though no other marked change in the routine of cultivation had been adopted during the period. The employment of fertilisers still lags far behind the opportunities of employing them to profit.

The various processes of bringing atmospheric nitrogen into combination, to which the War gave such a stimulus, are now being developed on a vast scale in all civilised countries, and will result in an almost unlimited increase in the amount of nitrogenous fertiliser available at low prices compared with the prices of agricultural produce. Here at least is the opportunity for another step up in production from our cultivated lands comparable with the progress that was made between 1840 and 1870. It is not all

plain sailing; the farmer has to study carefully where an increased supply of the cheapened nitrogen can be most suitably applied to his land and what changes in his system of cropping are demanded. The plant-breeders' art is needed; on most of our land any great enhancement of growth of cereals brought about by the use of nitrogenous fertilisers is attended with the danger of lodging. Few of our cereals possess stiff enough straw to remain standing on a soil enriched to the degree even that is reasonably practicable to-day. Thus the more immediate outlet for the new fertilisers would appear to be the fodder crops which are convertible into meat and milk.

In the solution of the main problem under discussion—the possibility of intensification of production from the existing farmed land to meet the needs of a growing population—the development of the synthetic nitrogen fertilisers must play a dominant part. Crookes's prophecy is coming true.

THE ECONOMICS OF PRESENT-DAY AGRICULTURE.

The present annual increment in the white population may be estimated at about five millions. This, taken alone, would necessitate the taking into cultivation of twelve million acres of new land every year. No process of the kind is going on; indeed, for many crops there has been an actual shrinkage in the acreage since the War. The shrinkage is doubtless no more than a temporary matter, the back-water of the wild fluctuations of prices and values brought about by the War, but it does not promise well for that continued expansion of the cultivated area which the still growing population demands. Indeed, we may detect a new influence at work, the growing disinclination of the civilised peoples to continue in agriculture because of its small and uncertain returns as compared with those of other occupations.

The flight from the land is manifest equally among the wage-earners of large-scale agriculture and among the peasants or family farmers in whose hands resides the greater part of the cultivation, whether in the old settled countries of Europe or the newer exploitations of America. Again and again it must be urged that the determining cause is economic; for the last half-century, save for the abnormal War years, farming has not paid a return on the capital and labour expended comparable with that obtainable elsewhere. It has been said that even the American farmers of the Middle West, who cut prices for all the world, made no profits during the last half-century except those derived from the accretion of land values; and the peasant farmer, who counts neither the capital he has in the business nor the hours of labour he gives to his land, who in Europe is held to the land by secular tradition, finds agriculture unattractive so soon as the growth of industries and the spread of communications render an escape possible. If not the peasant himself, at least the sons look for an easier and less exacting mode of life.

At this stage it would be impossible to begin to diagnose the causes of the comparative unprofitableness of agriculture. Fundamentally it is due to the weakness of the farmer as a commercial unit; the smaller the farmer the more ruthlessly does he compete

with his neighbours and reduce prices to a bare level of sustenance for his long hours of labour. Even the large farmers who can put into practice some of the economies of an ordered industry are helpless against the large commercial organisations which pass on their produce to the customers. Always there is the peasant farmer to cut prices.

I cannot, however, pursue this issue. I return to my original text: that if we are to continue to feed the growing population of the world on the present methods a continued expansion of the cultivated area is required; new land is called for year after year. I cannot see where this new land of the necessary quality is to be found in quantities commensurate with the immediate demand. Doubtless the white races will insist on maintaining their rising standard of living and will apply deliberate checks to their fertility, a process we already see in action. But the restriction of increase will not take effect all at once even under economic pressure, and the danger lies in the period preceding the comparative stabilisation.

As it cannot be supposed that the development of the civilised races can be allowed permanently to be checked by lack of food when food is obtainable, it follows that resort must be had to the intensification of production from the area already under cultivation. The means for that intensification are already in sight, more will be supplied with the advancement of research. Intensification, however, is in the main attended by a higher cost of production, and movement in that direction is likely to be slow until it is stimulated by a rise of prices. Organisation will have to be introduced into the industry, and it may be expected that organisation will take one or other of three forms. The farmer may be left as the producing unit, but his methods will be strictly controlled and standardised by the great selling corporations that handle his produce, and these corporations may be either commercial ventures or co-operative associations of the farmers themselves. The co-operative venture appears to imply an even more rigid discipline of the individual than that imposed by the capitalist firm. Alternatively, the capitalist may venture upon the direct exploitation of large areas of land and industrialise farming as he has industrialised other producing businesses. But capital will only be tempted back to farming, whether for the organisation of the business or even to enable the individual to take advantage of the possibilities of intensification, if prices rise to a definitely remunerative level.

I hope I have given reasons for supposing that prices must rise, because the surge in population set up by the unprecedented extension of the cultivated area last century cannot all at once be checked, whereas the new land still available is either inadequate in amount or unsuited to cheap production by the old methods. How close at hand the period of pressure may be it is unsafe to prophesy, but it may be agreed that pressure is sooner or later inevitable and that one of the biggest problems before the world at present is to prevent the pressure developing suddenly or becoming unbearable. The intensification of production is the only remedy, and, again, the only means of rendering intensification practicable is the continued pursuit of scientific research.