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Climatic limitations to development in the tropics

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Introduction

A large proportion of the lands which are commonly regarded as 'underdeveloped' lie on the earth's surface between the Tropic of Cancer in the north and the Tropic of Capricorn in the south. Also it is true to say that a very large proportion of all land so situated can be described as underdeveloped. Though many countries in the tropics are developing and developing rapidly, it is still hard to name any one which has yet reached levels of economic development to be found in many, if not most, mid-latitude countries. It is accordingly difficult to avoid the conclusion that in some way the tropical climates have had, to date, a retarding effect. When, however, one comes to substantiate such a conclusion it immediately becomes very difficult to separate what may be called the direct effects of climate, as on the production of crops, from the innumerable indirect effects through influence on human physiology and energy, through the many aspects of pests and diseases of plants, animals and man, or even through the climate–soil relationship. In this paper an attempt will be made to separate some of these direct and indirect effects, though the net result will frequently be to show how little we really know at present.

The characteristics of tropical climates

Encircling the earth, broadly though certainly not exactly, in the neighbourhood of the equator is a belt which used to be described as the Belt of Equatorial Calms, or Doldrums, but now in terms of air-mass meteorology as the Inter-Tropical Convergence Zone (ITCZ). It is a belt where moisture-laden air masses from the north-east and south-west meet and tend to rise; the ascending air currents which are caused become cooled and abundant rain results. A similar effect is produced by local convection currents of heated air saturated with moisture derived from local evaporation. Although the zone tends to move a few degrees northwards with the northern summer and similarly a few degrees southwards with the southern summer, there

is to be found encircling the earth in the neighbourhood of the equator a belt of constant heat and moisture—the Equatorial Climate. Ideally the central part has a double rainfall maximum; towards the margins the maxima tend to coalesce so that the year is divided into a wet season and a wetter, it being characteristic that no month can be described as 'dry'. Monotony is the keynote of the Equatorial Climate with mean monthly temperatures ranging from 2 or 3 degrees above 80°F to 2 or 3 degrees below, with day temperatures rarely above 90°F and nights rarely below 70°F, relative humidity always high, yearly rainfall averaging a typical 80 in.

On its northern and southern margins the Equatorial Climate fades gradually into the Tropical Climate properly speaking—in the trade wind belts—or the Tropical Monsoon Climate where wind direction is reversed for half the year. Instead of the monotony of the equatorial belt the seasons are marked and become more so with increasing distance from the equator. It is usual to distinguish three seasons (a) a cool dry (roughly November–February in the northern hemisphere, May–August in the southern), which passes gradually into the (b) hot dry (March–May or September –November) before the coming of the (c) hot rainy season (June–September or December–March). A fourth season is sometimes separated when the rains are drying up. In the Tropical Monsoon Climate the 'rains' break suddenly with reversal of winds. There are several features of special importance to note in these tropical climates. The first is that frost and snow are unknown and temperatures rarely drop below the crucial 42 or 43°F growing temperature. On the other hand, temperatures in the dry season may rise well over 100°F and in the hottest months may in fact average over 90°F. In the rainy season the conditions with temperatures averaging about 80°F closely resemble the equatorial climate. The second outstanding factor is the enormous variation in rainfall. In mountainous areas there are sharp contrasts between windward and leeward sides and the highest rainfalls in the world are found on windward coasts. Contrasts such as 200 in. on the Arakan coast of Burma to 20 in. only 80 miles away across the mountains are common; even in quite small islands such as Oahu (Hawaii) rainfall may vary from 100 to less than 25 in. within a few miles. On the other hand, where physical barriers are absent and there is nothing to obstruct the air masses the position of 'fronts' and consequent rainfall may vary widely from year to year. This is the curse of tropical Africa: the coming of the rains may be delayed, with disastrous results, and the total fall may vary greatly in amount. This is especially true of the drier margins, hence the existence of famine zones. In broad general terms the regions of Tropical and Tropical Monsoon Climates fall into three zones: (a) the wet zone with more than 80 in. of rain a year and where conditions resemble those of the equatorial belt except that there is a definite dry season; (b) the intermediate zone with 40–80 in. of rain; (c) the dry zone with 20–40 in. of rain and where irregularity is the curse.

With less than 20 in. of rain a year the Tropical Arid Zone may be said to begin. In its Arid Zone studies UNESCO has used a criterion of 'aridity' which is less than 500 mm of rain a year.

When discussing the problems of tropical climates some writers restrict themselves to the 'humid tropics', but it is obviously important to consider the whole range and

to include the arid zone of the tropics. It will become clear in subsequent sections of my paper that the outstanding problem in tropical development is control of water. In most parts of the tropics there is either too much or too little, or too much at one season and not enough at another, too much in one year, not enough in another.

The International Geographical Union in 1955 set up a Humid Tropics Commission to supply data to the Humid Tropics division of UNESCO. It has given attention to the definition of the Humid Tropics and to what is now being called 'humid tropicality'. B. J. Garnier, who coined the term, communicated the following definition used in the *Glossary of Geographical Terms* (Stamp, 1961): 'The climatic condition relative to a standard period of time (*e.g.* a month) in which relative humidity exceeds 65 per cent, pressure 20 mb, mean temperature exceeds 68°F (20°C). To this may be added rainfall exceeding or equalling evaporation for the period in question approximating to 3 inches or 75 mm per month.' Defined in this way a station may enjoy 'humid tropicality' for varying periods of the year but to be included in the 'humid tropics' must have conditions of 'humid tropicality' for a minimum of 9 months of the year. The concept has been elaborated and world maps have been published by Fosberg, Garnier & Küchler (1961) but further studies are needed. The important points which arise are that stations in the heart of the wettest parts of the tropics may have periods when they cease to enjoy 'humid tropicality' and when provision may have to be made for irrigation. The criterion is the relationship between available moisture and potential evapotranspiration. However, the correlation between the 'humid tropics' as now defined and vegetation is not as close as might have been expected. Proximity to the sea seems to produce climatic figures indicating 'humid tropicality' in regions commonly regarded as completely arid, e.g. the Aden coast.

Climate and soil in the tropics

Speaking generally, chemical reactions are speeded up by the application of heat in the presence of moisture. We need go no further than the test tube and the Bunsen burner for evidence of the general truth of this statement. In climatic regions of constant heat and moisture—the equatorial regions—chemical weathering of rocks tends to be rapid and to take place to great, if irregular, depths. The geologist often despairs of finding an exposure of the underlying rocks, so thick is the mantle of weathered material. There are several important results of this deep weathering *in situ*. The weathered rock is soil-forming material rather than soil but where the parent rock is rich in plant nutrients, as with basic lava flows, the weathered rock is also at the same time a fertile soil, which is apparent on many volcanic rocks in the wet tropics. On the other hand because of the irregular depth of weathering there is usually no clearly marked water table and in the wet tropics there may be virtual saturation right to the surface. Unfortunately chemical processes do not stop with the weathering of parent rock. The combination of heat and moisture at the surface produces rapid oxidation of organic compounds: fallen leaves do not decay to a valuable humus but are dissipated into the atmosphere as CO_2 and other gases. At the same time there is constant downward leaching and soon nutrient salts are carried

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down below the reach of the roots of crops. At these lower levels in the soil the roots of trees are able to find nutriment. Herein lies the explanation of the luxuriant rain forest of great trees and the poverty of the soil when cleared for crops and the fact that all the goodness can be 'ploughed out' of the soil in a couple of ploughings. Soil and land management often become the reverse of what is good practice in mid-latitudes: a soil protected with weeds is better than a clean farm, though a fodder or leguminous crop useful in itself is better than weeds. It is doubtful whether a plough should ever be used in the humid tropics—it has the additional disadvantage of starting soil erosion. The once despised shifting cultivation, better termed land rotation with slash-and-burn (plant nutrients for use at the surface) and bush-fallowing (tree roots bringing up nutrients from lower levels) is probably the best scientific answer to the land-management problem known at present.

Over vast areas of Africa, which has been a continental mass of ancient metamorphic rocks for millions of years, the soils are entirely of sedentary origin as opposed to the more normal transported soils of mid-latitudes. Because they have not been transported by water and rounded, the rock fragments in the soil are angular. All but the lightest mechanical cultivation will tend to compact these fragments into a hard surface after the principle of the Macadam road: the hoe wielded by the hand of a bare-footed African is the right implement; a caterpillar tractor is not.

As soon as one passes from the humid tropics to those regions where there are marked seasons the process of rock weathering is slowed down but follows a cycle geared to the climatic régime. In the wet season there is rapid chemical weathering and downward leaching of dissolved salts. With the onset of the dry season evaporation and upward movement of soil water exceed rainfall and downward leaching. As the soil moisture evaporates, its content of salts is deposited—as a hard pan below the surface or at the surface and as saline crusts. Even when the hard pan, such as the *carapace latéritique* of the French, is formed below the surface, overlying material is easily washed away and the crust exposed as a surface layer. But this layer and the hard pan below the surface may be so ironlike in character as to make impossible the penetration of plant roots. A very arid semi-desert may result, even in regions with a good rainfall. To prevent the formation of hard pan, to break it up where it occurs and to enable plant roots to pass freely through the horizon where it occurs are the great soil-management problems of the moderately wet tropics and persist in varying degree into more arid margins.

The rhythm of life in the tropics

Since the problem of dealing with frost, snow and ice does not arise and the temperature rarely drops below the temperature at which vegetative growth is active, the rhythm of life in the tropics reflects essentially moisture conditions. In the equatorial belt with its essential monotony throughout the year an individual species appears free to select its own resting period. The rain forest is never leafless, but a given species may have a definite cycle of leaf fall. There is a year-round sequence of food crops for man and, under cultivation, two, three and more crops are possible.

Fleure's old phrase, 'the equatorial climate is a good servant but a bad master' sums up the position well. The rubber of Malaya and the intensive agricultural development of Java are examples of man's using the climate as his servant. The change from primitive man relying on what he can gather or produce by primitive means to economic development is marked always by control of water. Terracing, as for rice, control of erosion after forest clearing, prevention of flooding are all important.

Even in the wettest parts of the tropical climate it is coming to be recognized that there may be 1, 2 or 3 months when supplemental irrigation is needed in place of the drainage so essential at other seasons, such is the position in the Bengal delta. But it is in the vast areas of the tropics of Africa, America and Monsoon Asia that the rhythm of life is so closely attuned to the climatic régime and nowhere is this more so than over the heart of Africa. At the end of the dry season, the land is parched and brown, and animals and man alike are ill-nourished and exhausted. The vegetation, especially the trees of the savanna, seems to anticipate the coming of the rains by a flowering period. With the advent of the rains there is a quick vegetative growth of grass and herbs and a period when food for herbivores is superabundant. The first of a succession of crop harvests soon follows—unless the rains have been deficient or delayed or man has been too exhausted by the privations of the previous season to have the energy to prepare the land. Towards the height of the rainy season there may be dangers of flooding, affecting man, his domestic animals and wild life, and gradually as the cool dry season sets in and merges into the hot dry season food becomes scarcer. The well-known 'hungry season' for man and beast coincides with the heat of the hot season: it is then that famine and disease are most rampant and may take such a toll as to leave man and animals quite unfitted for the labours to follow. Clearly what is everywhere needed is water control—storage of supplies from the rainy season to last the year. This has long been understood in India and has been steadily developed into the great irrigation works of the present day, but is still insufficiently appreciated in tropical Africa. It is most vital where average annual rainfall is between 20 and 40 in. a year, where a rainfall below average may spell disaster. With lower rainfall, irrigation is always essential and the danger is less.

But from the desert to the rain forest, the need of the tropics is water control.

Climate and man

Remarkably little is yet known of the direct effect of tropical climate on the physical and mental activity of man himself. With the passing of time one 'hunch' or fashion has given place to another in a way which, viewed in retrospect, approaches the ridiculous. It is perhaps important to distinguish between the natives of tropical climates and the sojourner, probably white, in the tropics. Considering the white sojourner in the tropics first, the undoubtedly disastrous effects of tropical conditions on white troops engaged in warfare were attributed primarily to sun rather than to heat on a body fantastically over-clothed. The idea grew up that the sun struck through the spine and the skull, hence the red flannel spine-pad worn to protect the spine and the solar topee to protect the head. When I first went to the tropics of Burma and India in the early twenties the spine-pad was dead but the

solar topee was so much *de rigueur* that one did not venture the few yards from one building to another without having the head thus protected; one might swim in the nude in a jungle pool, but only so long as a sun helmet was worn. Young employees of commercial firms faced being sent home if they disobeyed the rules and it was the usual belief that 'a touch of the sun' ruined a man's career in the tropics. The protection of the eyes by sun glasses followed particularly the demonstrations of Sir William Crookes, and harmful rays were eliminated by 'Crookes' lenses', though regarded as less important than protection of the skull. By the nineteen-thirties medical men were arguing that 'sun-stroke' did not exist, though heat apoplexy was real enough. In fact it took the Second World War with the campaigns in Burma and elsewhere to sweep away the old shibboleths and to prove that what mattered was the free dissipation of heat from the body surface with the loosest and lightest of clothing compatible with decency.

Now the pendulum has swung in the opposite direction; tropical beaches in Hawaii and the West Indies as well even as in once dreaded Burma and tropical Africa are now littered with white bodies seeking a quick tan. Only recently has come the suggestion that increase in skin and blood cancer may not be unconnected with the new cult of sun-worship. As recently as the nineteen-twenties after a visit to Malaya, Noel Coward could write 'Mad dogs and Englishmen go out in the noonday sun', while all sensible residents in the tropics indulged in a mid-day siesta; now the tendency seems to be to ignore the possibility of harmful effects from the midday sun.

Many of the native peoples of the tropics have developed protective devices against tropical conditions. Skin pigmentation is one; the close woolly crop of the negro with rare baldness may be another, freedom of sweating is undoubtedly a third. Though lethargy under tropical heat is frequently found to be connected with some chronic disease rather than directly with climate, it would be absurd to pretend that high temperatures, especially when combined with high humidity, have no effect on mental and bodily activity.

As a young man I carried out certain experiments on myself when working as a field geologist in the Dry Belt of Burma. For my first season I found, with a considerable amount of determination, that I could carry out broadly a day's programme as in Britain. It proved far more difficult in my second season and I gave up the attempt in my third. This is the reverse of what is commonly understood by acclimatization. The personal reaction came when, each afternoon, the thermometer climbed above blood temperature to about 104 or 105°F. I did not sleep, but my mind refused to function normally.

The questions arise: what are the best conditions for active functioning of mind and body, and second, how far can these be provided by modern air conditioning? The first question is so often answered by some such phrase as 'it depends on the individual'. Yet every day and in every part of the tropics more use is being made of air conditioning, and at least some principles can be stated. It is almost unbelievable that as recently as 5 years ago D. H. K. Lee (1957), Professor of Physiological Climatology at Johns Hopkins University, could write, when editing *Climate and*

Economic Development in the Tropics, 'the desire for air-conditioning is not based upon scientific proof of its value, but rather upon the simple idea of comfort' (p. 116). Since elsewhere in the book it is admitted that climatic conditions in the tropics have direct physiological effects which impair efficiency—though 'complete acclimatization' may follow (p. 96)—this is indeed a strange attitude.

Since air conditioning is now becoming so general and there is plenty of evidence of the increase in efficiency in offices, warehouses, schools and colleges that results, it may be of some interest to give details of the principles followed in a specific instance. I am greatly indebted to Mr Wilfred Wong of the American Engineering Corporation, Hong Kong, for freely giving me the results of his wide experience there. What may be called 'Western standards' derived from the United States (United States Department of Agriculture, 1941) put 70°F and 50% (or less) relative humidity as standards. This suggests a tendency in America to overdo the cooling, since indoor temperatures in winter are commonly 75–80°F and it seems incongruous to set an indoor temperature 10° lower for summer than for winter. Certainly these levels are regarded as too low in Hong Kong. With summer temperatures (June–September inclusive) there of 78–80°F, but liable to go up to a maximum of 92°F, and humidity 70–90% it is found that the thermostatic control should be set at 76°F; *i.e.* at that temperature the system functions and reduces the indoor temperature to 75°F with r.h. 55. In winter a desirable indoor climate is regarded as 70°F with r.h. 55 when outside temperatures average 58°F (February). The new University Library at Hong Kong has been air-conditioned to these standards. Though it is obviously difficult to measure increase in efficiency due to air conditioning, experience in offices, student-use of libraries, etc. set it at 30% at least. Since Hong Kong is not untypical of large areas of the damper tropics, experience suggests that human efficiency is well served by a temperature of 70–75°F and a r.h. of 55 and that such 'climatic control' is rapidly becoming as normal as central heating in colder lands. Although any direct measurement of increase in human efficiency may be mainly a matter of intelligent guesswork, it is safe to say that the development of air conditioning in buildings has, for two simple reasons, completely altered the possibilities of industrialization in the tropics. The first reason is the elimination of human sweat with its deleterious effect on many delicate fabrics and other materials which can now be handled, e.g. in the manufacture of garments, as in any mid-latitude. The second is that it is now possible to use materials easily affected before by heat and humidity. Hong Kong now has a large business in high-quality printing (since the paper no longer need be affected by humidity changes) and book binding (it is now possible to use glue), and prints millions of books for the English market. Formerly articles in which glue had been used grew moulds even in a single 24 h period and fell to pieces after a few days.

The indirect effects of climate

It has seemed to me most useful in this introductory paper to stress certain of the current lines of thought regarding the direct effects of climate in limiting

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.