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CROPS AND CLIMATE

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Dr. Penman, Head of the Physics Department, Rothamsted Experimental Station, U.K., spoke about the effectiveness - or perhaps the relative ineffectiveness - of utilization of solar energy in plant growth. He showed how the analogous processes of outward transfer of water vapour (evaporation) and inward transfer of carbon dioxide (assimilation) were subject to the effects of several distinguishable flow resistances. Two of these were common to both transfers, namely the diffusion resistances of the external air layer adjacent to the plants, r_a, and of the internal air paths through the leaf pores or stomata, r_s. But a third, r_m, arose in the assimilation pathway only, from the need for CO_2 to diffuse in solution through the mesophyll tissue of the leaf, from the initial regions of uptake at the stomata to the fixing points in the chloroplasts inside the leaf. Here, light of certain wavelengths is absorbed by chlorophyll and the energy used to activate reactions converting $CO_2 + H_2O$ into units of carbohydrate CH_2O, with the release of O_2. At the same time the reverse reaction also takes place, the actual growth rate depending on the net balance between assimilation and respiration.

Little is known as yet about factors governing r_m, although in many circumstances it may be the dominant resistance of the three. This raises the possibility of useful modification of one of the other more accessible resistances, for example, increasing r_s by chemical treatment of leaves to induce stomatal closure. In this way we should often be able to produce a significant rise in the total resistance affecting water vapour loss ($r_a + r_s$), thereby conserving water, while at the same time only slightly affecting the overall resistance governing CO_2 uptake ($r_a + r_s + r_m$) and hence only slightly reducing growth rate. An increasing amount of work is going on all around the world on methods of achieving this, with some apparent success, but the economic value of such treatments still remains to be seen.

In any case, the overall process of light utilization can be assigned a theoretical maximum possible efficiency, based on the minimum amount of active light required per mole of converted CO_2, as a fraction of the total light incident on the crop. For the usual wavelength distribution in sunlight and typical values of leaf reflectivity, etc., it can be shown that with no other factors limiting growth, plants should be capable of utilizing overall (i.e. in total dry matter produced) about 8 percent of the incident solar radiation.

In actual practice (as illustrated in Table 1), this theoretical efficiency limit is rarely approached, even for short periods under ideal controlled conditions, while typical figures for commercial production, and even more so for subsistence farming, lie far below what should be possible under near optimum growth conditions. For instance, in English and Australian field trials to date, even the best long-term light utilization achieved so far has been about 4 percent at the peak of a growth season, for sugar beet at Rothamsted and bulrush millet at Katherine (under much stronger insolation), respectively.

Data from irrigation and fertilizer experiments were also presented to show the effects on pasture and potato growth of two of the more obvious limiting factors, namely reduced availability of water and of nitrogen. Another important check, about which not nearly enough is yet known, lies in the effects of plant diseases and pests.

Table 1. Range of achievement and possibilities

System or Source		Efficiency %	
Subsistence farming	Average Probable best	0.04 - 0.1 0.08 - 0.2	Most of the hungry nations
Ranch farming	Average Probable best	0.1 - 0.2 0.2 - 0.4	Satisfied: adequate output with minimum effort
Intensive farming	Average Probable best	0.25 - 0.35 0.6 -14	Industrialized: seeking maximum return for large capital investment
Experiments (season)		0.8 - 1.5	
Experiments (few weeks within season)		1.5	
Experiments (few days within season)		2 - 4	
Experiments (in very feeble light)		4 - 7	
Theoretical upper limit		8 -10	

Dr. Penman remarked that the great efficiency gap revealed by the above figures suggested that the potential benefits of greater food production could be just as great as those claimed for population control - if we could only find out how to overcome at least the main checks on growth rate. He suspected that many of these checks were social or political rather than agricultural or economic. In conclusion, he made the plea that in future agricultural experiments more attention should be given to the reasons why some plots gave better yields than others nominally the same, instead of merely averaging out variations in plot yield for each given treatment.

I.C.M.