

Control of irrigation based on weather data (*)

by

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The possibility of using weather data in the control of irrigation rests upon the conclusion that the rate of evaporation of water from an area covered by green vegetation cannot pass a well-defined maximum however liberally the vegetation is supplied with water. This maximum evaporation depends almost entirely on the meteorological conditions and scarcely at all on the nature of the vegetation so long as it is green (i. e. in a stage of vegetative growth) and effectively covers the soil.

Before there was much direct experimental evidence to support it, PENMAN and SCHOFIELD (1) had reached this conclusion from an examination of the physics of evaporation in open-air conditions. Their work (see PENMAN 1948) has focussed attention on the fact that the solar radiation incident upon the area is by far the most important source of the latent heat of vaporization. The problem of computing evaporation resolves itself into that of determining the fate of the energy in the incident solar radiation.

In 1943 experiments were set up in the meteorological enclosure at Rothamsted to compare the evaporation from equal areas of grassland, bare soil and open water. This comparison was undertaken as part of a study of the rate at which land dries and becomes trafficable to tanks

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(1) Owing to war-time restrictions the first progress report on this work appeared in the Report of Rothamsted Experimental Station covering the years 1939-1946. Further progress reports have appeared in subsequent Annual Reports of the Station.

and other vehicles. The urgency of the problem dictated the use of equipment that already existed, but was not what would have been designed specially for such experiments. The open water surface and the soil-filled cylindrical tanks, three of which were grassed and three kept bare, were situated around a large brick-lined pit for ready access, but this pit made the exposure abnormal. This was recognised at the outset, and tests were made which showed that the sites were comparable one with another. A measure of the abnormality of the exposure was obtained by installing a well-sighted circular evaporation tank of the same (75 cm.) diameter about 50 metres away from the pit. This tank was sunk in the ground so that its rim projected only 5 cm. above the surrounding soil. Grass, kept short by frequent cutting, grew right up to the edge of the tank, and extended for a considerable distance all around. The surrounding grass was watered when necessary to ensure maximum evaporation from the surrounding area. The interiors of both evaporation tanks were blackened to ensure complete absorption of the solar radiation that entered the water, and wire netting prevented interference by animals.

During sunny periods the evaporation from the tank at the edge of the pit exceeded that from the well-sited tank, but so also did the surface temperature of the water, and a calculation showed no significant difference in the evaporation rate per unit difference in water vapor pressure between water surface and air. This proved that any extra turbulence caused by the proximity of the pit was not a significant factor, and that the principle cause of the greater evaporation from the tank at the edge of the pit was the availability of some solar radiation additional to that which fell directly on the water surface. This was presumably radiation falling on and warming the brickwork of the pit, and it was concluded that about the same amount of additional energy must have been received by the tanks carrying grass and bare soil, so that a comparison was valid.

The tanks around the pit were connected in pairs by pipes entering near the bottom of each — one soil-filled tank being linked to a tank that was initially empty and which was covered by a lid. Water was poured in and maintained within 2.5 cm. of a prearranged level. The evaporation from the grass or bare soil was obtained by determining the precise amount of water that should have been added or removed during the period in question in order to keep the water level exactly constant. This amount of water divided by the land area gave the amount by which evaporation had been greater or less than the rainfall, which was

also measured. In order to avoid errors arising from inequalities in the moisture content of the soil above the water table, calculations of evaporation were only made for periods between rainfalls that caused a distinct rise in the water levels.

No difference was detected in the rate of evaporation from grass according as the water table was held at 30 cm., 45 cm., or 60 cm below the soil surface. It was therefore concluded that, in all three cases, the evaporation had reached the maximum. It was also found that with the water table at 45 cm. an application of fertilizer which produced a three-fold increase in the yield of cut grass (dry matter) did not measurably affect the evaporation rate.

This demonstrates the fallacy of a common belief that increased growth brought about by improved soil fertility must necessarily entail greater use of water. It also shows that the extent of leaf area was without influence on the evaporation per unit of land area. There can be little doubt that these conclusions apply not only to crops that are effectively sub-irrigated, but also to crops given effective irrigation of any kind. They do not, however, apply to crops grown without irrigation when the evaporation from the land area is less than the maximum possible under the existing weather conditions. For such crops greater leaf area could enable the evaporation for a time to come nearer to the maximum and so cause more rapid exhaustion of the soil moisture.

PENMAN found that the ratio, f , of the evaporation from the sub-irrigated grass to the evaporation from the open water surface remained remarkably constant during any particular season, but showed a decided trend with season as shown by the rounded figures given in Table 1.

Months	Mean duration of daylight hours in Lat 52º	Mean factor f
November to February incl	9.5	0.6
March and April	13	0.7
September and October		
May to August incl.	16.5	0.8

SCHOFIELD and PENMAN (1950) have examined the physical processes entailed in the diffusion of water vapor and carbon dioxide they offer very little additional resistance to vapor diffusion unless

wind speeds are unusually high. They attribute the lower evaporation from sub-irrigated grass compared to the water surface partly to greater reflection of solar radiation from grass and partly to the complete closure of the stomata at night.

The direct reflection from green grass is taken from rather scanty data to be of the order 15% to 20% compared with 5% from a clean water surface. The low figure adopted for water takes account of the fact that solar radiation striking a horizontal plane is on an average greatest at midday, and that reflection is least for 90° incidence. The considerable difference in the length of the night between one season and another in latitude 52°, and the consequent variation of the time during which plant stomata are closed is thought to account very largely for the seasonal variation of f . If this interpretation is correct, it should turn out that f varies little from 0.7 in tropical and subtropical regions.

In 1947 G. W. THORNTHWAITTE (1951) installed a set of six soil-filled tanks at the John Hopkins University Climatology Station at Sea-brook, New Jersey. The plants growing in these tanks have always been surrounded by similar plants growing at normal field spacing in the surrounding soil. At a little distance there is below a ground control room where automatic gear controls the depths of the water that must be added or removed.

THORNTHWAITTE uses the term «evapotranspiration» to mean the combined evaporation from plants and soil. Like PENMAN he finds a range over which evapotranspiration is sensible independent of the depth at which the water table is controlled. He finds, however, that the evapotranspiration of sub-irrigated grass is not quite the maximum possible under the existing weather conditions.

This fact was brought to light by applying to the sixth tank each evening enough accurately measured sprinkle irrigation to make good the day's evapotranspiration and give a small surplus of measured drainage. The evaporation from this tank was some 14 % greater than from the rest. It is interesting to speculate how much of this difference came from evaporation of intercepted water hanging on the sprinkle-irrigated herbage while evaporation from the sub-irrigated herbage was checked by closing of the stomata, but it is unlikely to have been the whole cause. THORNTHWAITTE obtained roughly double the growth of grass by sprinkle irrigation compared with sub-irrigation. This shows that sprinkle irrigation more effectively reduced the moisture stress in the grass than did subirrigation. The effect on growth was large and of great practical importance, while the effect on evapotranspiration was slight.

It is generally thought by irrigation engineers that much water is 'lost' by evaporation when crops are irrigated very frequently. There are some grounds for this belief in the case of crops so widely spaced that much of the incident solar radiation falls directly on the soil. The limit set by the supply of latent heat controls the *total* evaporation from the land area. Consequently the more evaporation there is from intercepted water during daylight the less is the transpiration. It is quite wrong to think that a light shower which wets the foliage but does not reach the soil of little or no value. On the contrary it is generally more beneficial to growth than the same amount applied to the soil, and the evaporation from the land area will be substantially the same in both cases.

Not long ago people dispaired of getting anything approaching an accurate measure of the total evaporation from a land area, but great strides have been made in the last few years. PENMAN has compared the observed mean annual excess of rainfall over the run-off (river-flow) for 40 catchment areas in the British Isles with the results of calculations which use:

- (1) Total monthly incident radiation estimated from hours of bright sunshine by Angstrom's formula.
- (2) Mean monthly air temperature.
- (3) Mean monthly dew-point temperature.
- (4) Mean wind speed.

to estimate the evaporation from open water and the factors given in Table 1. The agreement was most encouraging. The Agricultural Meteorological Branch of the British Meteorological Office has for the past two summers issued fortnight estimates of maximum evaporation from cropped land as a guide to irrigation using Penman's method of calculation. Field experiments, at first only on sugar beet, but now extended to a full rotation of crops have consistently demonstrated the effectiveness of this approach to the control of supplementary irrigation.

THORNTHWAITE, although he uses a different formula to obtain the maximum evaporation, has also obtained very satisfactory results by controlling supplementary irrigation by computing soil moisture deficit from the excess of calculated evapotranspiration over measured rainfall. BLANEY (1942) has also put forward a method for computing consumptive use of water (total evaporation or evapotranspiration) which depends mainly on mean monthly air temperature and latitude but also uses fac-

tors which differ somewhat from crop to crop. The extent to which his method is used by irrigation engineers in the west of U. S. A. indicates general agreement there that weather largely determines consumptive use of water. Quantitative data are still lacking from which to decide for instance whether, as BLANEY's factors suggest, the maximum evaporation from alfafa is 10% greater than from grass, or whether, as the physical analysis of the problem indicates, there is no difference.

The author believes that the conclusion stated in the opening paragraph is well supported, and will soon command general assent, but it may take longer before all concerned are agreed upon the best method or formula for determining the maximum evaporation from green vegetation effectively covering the soil. Once maximum evaporation is recognized as a fact or even as an approximation which is quite close enough to serve the practical purposes of irrigation, the need becomes clear for a service similar to that set up by the Meteorological Office in Britain to serve all farmers using irrigation, by supplying them regularly with the best estimates of maximum evaporation. Acceptance of the basic principle that, under irrigation, total evaporation remains at or very near to the maximum is essential before such a service can be seen to rest on a secure basis. It is for this reason that the emphasis in this paper has been placed on the examination of this principle and its broad implications.

If, starting from a date when the soil was judged to be at field moisture capacity, a record is kept of rainfall and irrigation and an estimate is available of day-by-day evaporation, simple addition and subtraction gives at any time the deficit of rainfall plus irrigation below evaporation. It is then possible, so to apply the irrigation, that the deficit never exceeds a pre-arranged limit. It will be a matter for experiment to decide how large a deficit it is wise to permit at each stage during the growing season and how much water should be given at each irrigation. While frequent small applications by overhead spray appear to give fastest growth of herbage and enables the minimum quantity required to be evenly spread, this method requires costly equipment and power for pumping. With flood or furrow irrigation it is difficult not to give some areas too much unless others are given too little, but these methods are economical in equipment and labour. In areas where irrigation water is only available at periodic intervals the farmer has only to decide the amount to apply on each occasion, and this he can readily do by aiming at reducing the deficit to the level which experience shows to be desirable.

Thus farmers, even when they are served with estimates of maximum evaporation, will still have to decide many details relating to irrigation in the light of experience and of advice from experiment stations, but the author is convinced that once they have had the opportunity to use this information they will value it as an indispensable service.

Depending on the salt content of the irrigation water it is necessary to have periodic through percolation to a drainage outfall to prevent salt accumulation. Reasonable exact knowledge of the maximum evaporation would enable irrigators to gauge much more accurately than they do at present the amount of water which percolates each year below the root depth. The saving in the water applied per acre would often permit the irrigation of a larger acreage with the available water supply and would reduce the risk from rising water tables. The potential benefit is so great as to be incalculable.

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