EXECUTIVE SUMMARY

1. RATIONALE

Total evaporation from cropped lands comprises components for evaporation from the vegetation and the bare soil surface. Any analysis of crop total evaporation, whether it be for purposes of either simulation, or problem solving, must consider both components separately. This applies to both rainfed and irrigated situations.

Any water evaporated through the soil surface is wasted because it does not contribute to producing crop biomass. Hence, for the management of scarce water resources, an accurate mathematical simulation of plant and soil evaporation is required.

In the past, experimental difficulties have been encountered with the measurement of soil evaporation separately. This has hindered the simulation of soil and plant evaporation. hence the present project sought to develop a new method of executing such measurements as well as to develop a new model for simulation of these variables.

In pursuit of these goals, the main objective of the study was the measurement of sunlit and shaded foliage and sunlit and shaded soil surface temperatures and evaporation from the vegetation and soil components of crops. Various new methods of observation were investigated. For evaporation, these included micro-meteorological techniques and the utilization of lysimeters. Data for the different weather elements were measured routinely by an automatic weather station because the eventual practical application of any new model developed would depend on the continuous provision of such input data.

The maize and wheat crops were studied and modelling of vegetation and soil surface temperatures and evaporation attempted using the latest scientific theories.

2. OBJECTIVES

While the overall objective of the study was to produce an accurate model for estimating plant and soil evaporation from cropped lands, the specific objectives addressed in this study were:

- develop and test the accuracy of an iterative model for simulating foliage and soil surface temperatures;
- measure or estimate various values needed for the complete characterisation of evaporation from cropped lands (reference crop evaporation; crop total evaporation and its two components, plant and soil evaporation) using various lysimetric techniques as well as data

collected by means of automatic weather stations and micrometeorological instrumentation; and

- refine two models (Shuttleworth and Gurney; PUTU) for simulation of plant and soil evaporation.

3. METHODOLOGY

3.1 Measuring evaporation rates

Crop total evaporation was measured using two 2 m x 2 m x 1 m drainage lysimeters, while crop plant evaporation was measured by covering the soil surface of a large (3 m x 3 m x 2 m) weighing lysimeter with a plastic sheet to suppress soil evaporation. Soil evaporation was then simply obtained from the difference between measured crop total and plant evaporation. The weighing lysimeter has a resolution of 0,04 mm of water. Two additional drainage lysimeters were also used to measure plant evaporation, soil evaporation again being prevented with a plastic-sheet cover. The plastic sheet was in turn covered by a shallow (10 mm) layer of soil which ensured that plant micro-climate (soil and air) remained representative of surrounding field conditions.

Numerous micro-lysimeters (10 cm diameter x 20 cm deep) were also used in an attempt to measure soil evaporation directly, both from a bare soil surface and from between crop rows.

Micro-meteorological techniques of estimating crop total evaporation in this study included:

- direct measurement using the eddy correlation method,
- derivation from surface energy budget measurements and eddy correlation measurements of sensible heat flux density, and
- determination from energy budget and Bowen ratio measurements.

3.2 Mathematical simulation

The reliability of two mathematical models for estimating plant and soil evaporation separately was tested with a view to developing an improved simulation procedure.

The one, here termed the SG-iteration model, is based upon a model developed by Shuttleworth & Gurney (1990). It requires surface temperature as an input. Originally Shuttleworth and Gurney suggested that foliage temperature might be measured by infra-red thermometry. This was not permissible here in view of the objective of the project, which was to produce a technique for simulating plant evaporation solely from routine data provided by an automatic weather station. Hence, the development of a computerised numerical iteration procedure for achieving reliable estimates of soil and leaf temperatures was the first matter studied. The values so obtained were then substituted in appropriate equations in order to obtain estimates of plant and soil evaporation.

The second mathematical approach entailed re-investigation of the existing PUTU-model, which utilizes the products of evaporation coefficients (one of each for plant and soil evaporation) and reference crop (short grass) evaporation.

Refinements for accommodating the so-called second phase evaporation by means of evaporation coefficients were examined. Second phase evaporation from the soil surface commences approximately six days following a wetting event.

4. RESULTS

Major results of the research included:

Micro-meteorological methods of determining crop total evaporation were found to underestimate plant evaporation as measured in the large weighing lysimeter. This could have been a real effect caused by the altered surface energy balance due to suppression of soil evaporation. In effect it meant that soil evaporation could not be determined satisfactorily by a difference method.

- micro-lysimeter determinations of soil evaporation overestimated weighing lysimeter values for bare soil conditions by a factor of nearly 3. This could have been due to restricted drainage from the micro-lysimeters which caused excessively wet conditions to persist.
- Agreement between drainage and weighing lysimeter values of plant evaporation was sometimes good, but not consistently so.
- For a bare soil surface, evaporation values from the drainage lysimeter overestimated weighing lysimeter values by a factor of 1,5.
- The dry-down model of the soil evaporation coefficient as used in the PUTU-model reliably estimated soil evaporation measured on bare soil. A reliable mathematical adjustment for second phase evaporation was developed.
- Foliage temperature obtained from an iteration technique in a modified SG-model compared fairly well with the mean of sunlit and shaded leaf temperatures as measured by infra-red thermometer.
- A good relationship was evident between sunlit and shaded soil surface temperatures, both measured using the infra-red thermometer.
- Plant evaporation simulated by both the PUTU and SG-models compared well with the weighing lysimeter values on both hourly and daily basis.
- PUTU and SG-model daytime values of soil evaporation compared reasonably well with weighing lysimeter values of soil evaporation.
- Possibly due to the drainage procedures adopted, the values of bare soil evaporation, as measured by the micro-lysimeters, greatly overestimated soil evaporation computed by both models.

- Suggested improvements to existing albedo (i.e. surface reflectivity to solar radiation) functions and formulae for estimating net radiation appear to offer minimal benefit at this stage.

5. DEGREE OF ACHIEVEMENT OF OBJECTIVES

The plastic covered, large lysimeter measured plant evaporation accurately in cases of a dry soil surface and a closed canopy. This made possible successful, practicable improvements to the sub-models for estimating plant evaporation. In respect of plant evaporation then, the objectives of this project have been achieved for both maize and potato crops. The PUTU- and SG-models as here modified may be recommended for use in the future.

Because of the rapid dry-down of wet soil surfaces and the fact that crop canopies shield the soil surface from incoming solar radiation, growing season soil surface evaporation in cropped lands is less than plant evaporation. Errors in the estimation of soil evaporation thus have smaller practical significance than do errors in plant evaporation estimates. For this reason the overall objectives of this research have, to a large extent been achieved.

The measurement and modelling of soil temperature and soil evaporation, however proved unsuccessful in this study. This was possibly due to the inherent problems experienced with the particular experimental techniques employing eddy correlation measurements, drainage lysimeters and micro-lysimeters.

6. FUTURE RESEARCH

The results obtained, show that the models as developed here have probably reached a level of sophistication and refinement which is sufficient for practical irrigation scheduling, mathematical modelling, or other problem solving. Limited further development is thus foreseen at this point in time.

The measurement and modelling of soil evaporation from a partially vegetated surface is difficult and was not satisfactorily solved by this study. Future work could pursue the improvement of techniques to achieve this goal. Such work includes application of the empirical relationship here developed for estimating shaded soil surface temperatures in terms of sunlit soil surface temperatures.