Chapter 1

INTRODUCTION

With the search for energy and water efficient irrigation methods, it has become increasingly important to understand the spatial variability of irrigation and the evolution of evaporation and soil water content both during and after irrigation. Such knowledge is essential in the effort to maintain high crop yields while using less water and energy, and smaller quantities of chemical amendments.

The present study examined the spatial and temporal variability of some components of the water balance in a field of bare silty clay loam soil under low pressure sprinkler irrigation and developed tools for measuring the irrigation and evaporation components of the water balance. The water balance integrated over a given time period was described by:

$$I + P + Q - D - E - T + S = 0 \qquad [1\text{-}1]$$

where I is water applied by irrigation, P is precipitation, Q is runon (or runoff, if negative), D is drainage out of the profile of interest, E is evaporation, T is transpiration, and S is the change in storage of moisture in the soil. All terms are in units of depth of water based on a specified profile depth and time period. Both precipitation and depth of irrigation are easily measured even though subsequent overland flow may redistribute waters from both sources. In a bare soil field the transpiration component is zero.

Sprinkler Uniformity.

Spatial variability and uniformity of soil moisture under sprinkler irrigation are often assumed to be adequately described on the basis of applied depths measured in catch cans. This assumption is made despite the fact that the processes of evapotranspiration, deep percolation and subsurface redistribution, plus spatial variability of these processes, may all act to change the uniformity and spatial variability of soil water even if no surface redistribution by overland flow takes place during irrigation. Additionally, the geometry and wall material of the cans may adversely affect measurement accuracy (Kohl 1972).

Sprinkler applied water arrives at the soil surface in pulses so that the instantaneous application rate may be much higher than the average rate. Overland flow, causing surface redistribution, will occur if the instantaneous application rate is higher than the infiltration rate. This problem is particularly severe under low pressure sprinklers and consequently the application uniformity, as measured by catch cans under these systems, may be misleading.

Clothier and Heiler (1983) found significant surface redistribution occurring even at an average application rate of 4.1 mm/h for a pasture soil for which the average saturated conductivity was 10.9 mm/h. They showed that transient ponding and overland flow may occur even under sprinkler systems set up to apply an average rate less than the steady infiltration rate.

Hart (1972) studied a simplified 2-dimensional case of redistribution in the soil when application depth at the surface was invariant in one horizontal but varied periodically in the orthogonal horizontal (x) direction. Defining the length modulus as the x-distance over which application depth varied from maximum to minimum, he applied a finite difference solution to the moisture flow equation and found that redistribution over short distances could greatly increase uniformity of soil moisture content if the length modulus was about 1 m or less. Increasing the length modulus from 1 to 3 m caused the increase in uniformity due to redistribution to become smaller. Using actual distributions of application depth, Hart found the increase in uniformity due to redistribution to be small but noted that the length moduli were difficult to evaluate although they appeared to exceed 3 m. He found that the small scale variation in application depth was difficult to analyze since data were usually taken on a grid spacing of 3 by 3 m and variations at a smaller scale could not be deduced. In accordance with his 2-dimensional solution, variations at these smaller scales could have important effects on the degree of redistribution and the consequent changes in the uniformity of soil moisture.

The existence and importance of small scale variations in applied depth were shown by Davis (1966) whose results indicated a decrease in calculated uniformity of sprinkler applied depths as grid spacing of catch cans was reduced from 3 to 0.6 m (maximum decrease in Christiansen's Uniformity Coefficient of 2 percentage points). From these studies it appears that a catch can spacing of no more than 1 m is preferable.

Evaporation Measurement.

Estimation of evaporation from bare soil surfaces in the field is a difficult problem which has recently been approached in two conceptually different ways: 1) models based on the energy balance at the soil surface, and 2) direct measurements by microlysimetry. Ben-Asher et al. (1983, 1984) building on work by Fox (1968), developed a method which used the difference between mid-day maximum soil surface temperatures of a reference dry soil and a drying soil to estimate evaporation from the drying soil. The calculations were based on energy balance considerations and soil surface temperatures were measured with an infrared thermometer. The estimation equation also included wind speed as an independent variable since aerodynamic resistance and thus evaporation rate are dependent on wind speed. In simplified form the equation was:

$$E_d = S(T_{o,max} - T_{d,max}) \quad [1\text{-}2]$$

where E_d was the daily evaporative loss; $T_{o,max}$ and $T_{d,max}$ were the maximum mid-day temperatures of the dry and drying soils, respectively; and S was a positive function of average daytime wind speed and of average daily soil surface temperature. Ben-Asher et al. (1983) tested the equation against actual evaporation from lysimeters but the r^2 value was only 0.61. In addition the equation appeared to underpredict evaporation when $(T_{o,max} - T_{d,max})$ was high (soon after irrigation) and to overpredict evaporation when $(T_{o,max} - T_{d,max})$ was low (several days after irrigation) (Ben-Asher et al. 1983, Fig. 1).

Evaporation from the soil surface can also be estimated using microlysimeters (Boast and Robertson 1982; Salehi 1984). Microlysimeters are tubes inserted into the soil, removed with the soil inside intact, and then stoppered at their bottoms. They are replaced in holes in the soil such that the surface of the soil in the tube, the top of the tube, and the surrounding soil surface are all at the same elevation. They are periodically removed and weighed in order to estimate evaporation.

Various problems have been associated with the use of microlysimeters. Salehi (1984) found that the soil surface temperature in steel microlysimeters was lower than that of adjacent soil and hypothesized that the steel walls conducted heat downward into the soil. Walker (1983) found no such temperature differences using plastic microlysimeters. It has not previously been established if wall material has an important effect on estimates of evaporation. Experiments have shown that length has an important effect on evaporation estimates with shorter lengths causing under-estimation of evaporation (Boast and Robertson 1982; Shawcroft and Gardner 1983). However, when the experiments reported here were started apparently no experiments to date had dealt with lengths longer than 20 cm.

<u>Goals.</u>

The present study was undertaken in the context of a field scale water balance with the following goals:

Evaluate the performance of microlysimeters and of the energy balance method for predicting evaporation, seeking limitations of the methods and making improvements where possible.

Evaluate the spatial and temporal variability of root zone soil moisture and find to what extent the uniformity of soil moisture after irrigation is different from that of sprinkler applied depths as measured by catch cans.

Subsidiary questions included:

How do length and construction material (plastic or steel) affect the performance of microlysimeters?

How do the thermal regimes of plastic and steel microlysimeters compare?

What are the characteristics of the temporal and spatial variability of soil surface temperature and of evaporation as measured by microlysimeters?

Can neutron scattering and the energy balance method, which uses infrared thermometry, be used alone to provide an accurate water balance for bare soil?

In the experiments reported here both an IR based energy balance method due to Ben-Asher et al. (1983) and microlysimeters were used to find the evaporation component and the accuracy and efficiency of these tools were compared. The energy balance model was modified and improved. The change in soil moisture due to irrigation was measured by neutron scattering, giving not only the storage component of the water balance but also a measure of the uniformity of irrigation. Irrigation uniformities obtained via neutron scattering were contrasted with those obtained using the more traditional catch can measurement method. Drainage was assumed to equal the sum of the other components. The minimum spacing of measurements for the present study was set at 1 m. Also, special catch cans were designed and built following some of the suggestions of Kohl (1972).