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Irrigation Systems and Management to Meet Future Food/Fiber Needs and to Enhance Water Use Efficiency

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The world's population reached six billion on 12 Oct. 1999 and is currently increasing by about 80 to 85 million people per year. The United Nations projects that the world's population in 2050 could be 7.3 to 10.7 billion if reproduction fertility declines and as much as 14.4 billion if the world's population expands at its current rate. This is a projected increase of ~3.7 billion (65%) by 2050 (Wallace, 2000), taking a conservative view. We recognize that past irrigation expansion has been a critical factor responsible for the world's ability to meet its current food needs (Howell, 2001), but that irrigation expansion can no longer keep pace with population growth. The importance of enhanced crop productivity from our currently irrigated lands and the drylands and rain-fed lands (Renault and Wallender, 2000) will only increase in the future. Therefore, enhancing water use efficiency has never been more critical than in the next 25-30 years when the world's population is expected to double.

Irrigated land in the world was approximately 274 million ha in 1999 (FAOSTAT, 1999) with 22.4 million ha in the USA, 6.5 million ha in Mexico, and 0.7 million ha in Canada. Hence, North American irrigated lands barely exceed 10% of the world's irrigated lands. Irrigated land in the U.S., barely 15% of its cropland, produces in excess of 50% of its economic value from crops (USDC, 1999) (Fig. 1).

Water Needs to Meet These Population Levels

Currently, 7% of the world's population lives in areas where water is scarce. By 2050, this is expected to rise to over 67% (Wallace, 2000). Greater productivity will be required from our irrigated lands and the dryland and rain-fed lands. Economic plants use only 10 to 30% of the global fresh water supply in transpiration. In arid environments without irrigation, transpiration uses less than 5% of the available water (rainfall, soil, and/or ground water). Wallace and Batchelor (1997) suggested great potential exists to improve water use efficiency in both dryland/rain-fed and irrigated agriculture. Falkenmark (1997) estimated about 50% of the future demand to meet the per capita food requirement might come from irrigation with about 1,600 m^3 per person per year. This differs appreciably from the FAO (Food and Agriculture Organization of the United Nations) forecast that about 84% of the world's agriculture would be rain-fed (including

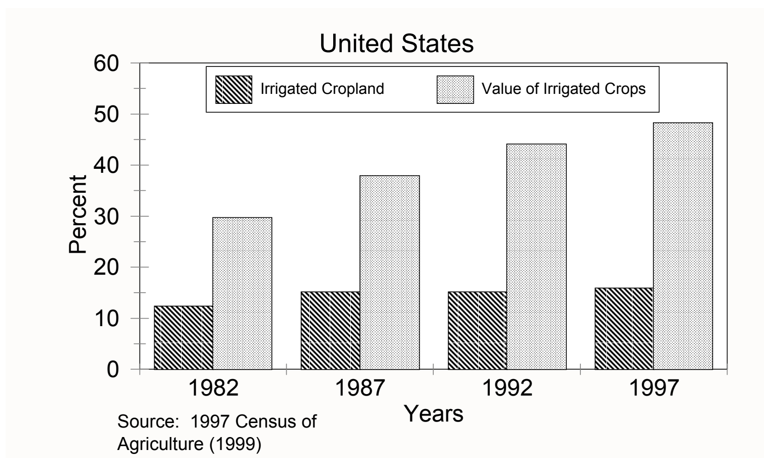

Figure 1. Percent of U.S. cropland that is irrigated and its economic value percentage.

dryland) by the year 2000 and producing two thirds of the world's production. Gleick (2000) estimated annual per capita water consumption for a "North American" diet as 1,800 m^3 and only 630 m^3 for a sub-Saharan diet. Renault and Wallender (2000) derived a basic U.S. diet requirement of 1,970 m^3/yr and estimated water requirements for lower protein diets as low as 365 m^3/yr per capita (1.0 m^3 d^{-1} p^{-1}) for a survival diet. They indicated diet changes are occurring as developing countries experience economic growth. Even in developed countries poultry consumption, with its lower water requirement, has gained substantially as a diet protein source.

Improving Water Use Efficiency

Water use efficiency (WUE) can be presented as

$$WUE_b = \frac{\left(\frac{k_b}{VPD}\right)}{\left[1 + \frac{E}{\left(P + I_r + SW - Q - D - L_c - E\right)}\right]} \qquad \ldots[1]$$

where WUE_b is based on biomass production (W in g m^{-2}), k_b is a physiological characteristic for a species (in kPa kg m^{-3}), VPD is ambient vapor pressure deficit (kPa), E is soil water evaporation (mm), P is rainfall (mm), I_r is irrigation (mm), SW is soil water deficit (mm), Q is runoff (mm), D is percolation below the root zone (some D is required for salinity management), and L_c is any irrigation conveyance loss (mm) following Howell (2001) and Gregory et al. (1997). The transpiration ratio is usually given as T/W in m^3 kg^{-1}; where T is transpiration (mm). The value k_b/VPD represents the transpiration efficiency (T/W). Equation 1 illustrates that WUE can be increased by decreasing the transpiration ratio or increasing the transpiration efficiency and by increasing water available for transpiration through reducing/eliminating losses (D, Q, or L_c) and enhancing use of supplied water (P, I_r, and SW).

Increasing the transpiration ratio. Although, the transpiration ratio is relatively conservative for a species type, C_4 species have about twice the transpiration efficiency (one—half if expressed as transpiration ratio) compared with C_3 species. Transpiration efficiency can be altered by microclimatic effects that change reduce VPD (either seasonal shifts or physical changes that alter VPD) or breeding or genetic changes to increase k_b. Often subtle changes, i.e., no-till with standing crop residues or narrow rows, can dramatically reduce the VPD environment, especially when plants are developing compared with just bare soil that can be quite warm in semi-arid and arid environments.

Increasing transpiration partitioning, WUE, and irrigation efficiency. Many techniques from agronomy, soil science, or engineering can be used to enhance WUE. The new five year project of the Water Management Research Unit (WMRU) under the National Program 201 (Water Quality and Management) is focused on improving WUE by utilizing efficient cropping systems, irrigation management alternatives, and measuring the water use of crops over time and space scales. These objectives aim to improve crop productivity, avoid unnecessary application losses, and enhance the use of rainfall and soil water while avoiding excessive percolation, reducing/eliminating runoff, and reducing/eliminating conveyance losses.

Sprinkler and microirrigation. Research focuses on developing efficient sprinkler technologies ranging from low-pressure spray to low-energy, precision application (LEPA) technologies either in a bubble mode or drag socks with furrow diking. Previous research has identified that with full soil water replenishment, spray application technologies were effective, especially when used in combination with conservation tillage. Microirrigation research hasn't demonstrated a yield benefit from subsurface drip irrigation (SDI). Also, SDI can have excessive percolation beneath the crop root zone at higher irrigation rates and can have problems consistently establishing a crop. But SDI can deliver nutrients and water precisely into the root zone.

Irrigation automation. Canopy temperature measured with small, inexpensive infrared thermometers (IRTs) has been effective in controlling microirrigation systems for five years (Evett et al., 2001). For both corn and soybean, the automatic, canopy temperature based irrigation system was consistently able to produce yields as large as or larger than those from a more traditional weekly irrigation scheduling system that employed soil water measurements to determine the amount of water needed to bring the soil profile back to field capacity. However, only for corn was the automatic system clearly more capable of maintaining high yields while using rainfall efficiently and delivering large irrigation water use efficiency (IWUE) values in years with good rainfall (Fig. 2).

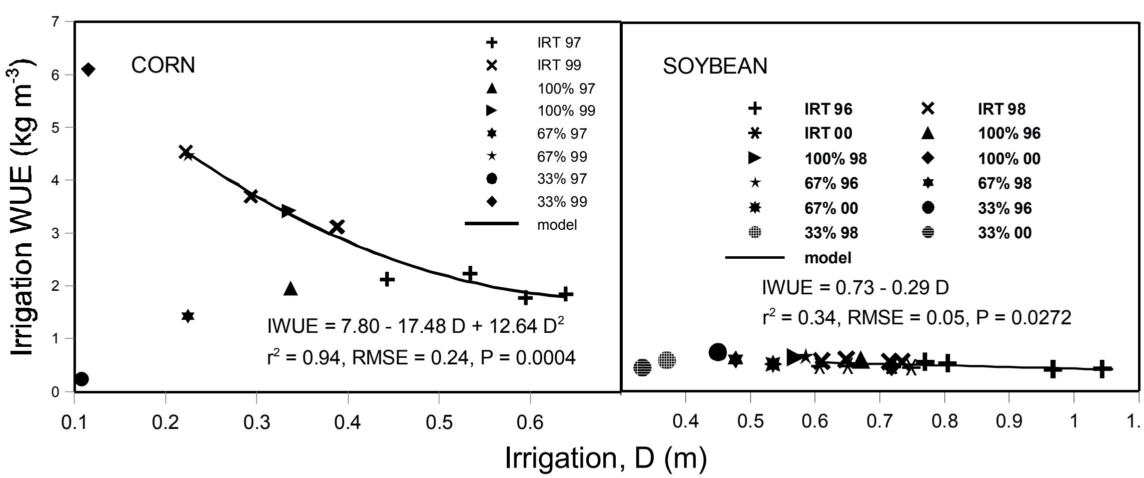

Figure 2. Soybean (right) and corn (left) irrigation water use efficiencies (IWUE, kg m^{-3}) vs. irrigation depth (D, m) for automatic and manual drip irrigation treatments. Models are fit to data from automatic treatments.

Irrigated cropping systems. Cotton-sorghum rotation systems under both graded furrow and sprinkler irrigation are being evaluated as well as dryland systems in differing row geometries. These studies are designed to evaluate synergistic rotation effects on the differing crops that follow as well as weed control techniques and conservation tillage methods that can effectively store soil water.

Irrigation management techniques to increase WUE. The WMRU project focuses strongly on measuring crop water use with weighing lysimeters, Bowen ratio energy balance, eddy correlation, and soil water balance methods. Irrigation scheduling requires accurate ET information and reliable soil water measurement techniques. Figure 3 (Tolk and Howell, 2001) illustrates the increased WUE (Eq. 1) as ET increases, but that IWUE is 'optimized' at an irrigation level below maximum ET. IWUE is usually maximized at a WUE lower than its maximum (Howell, 2001).

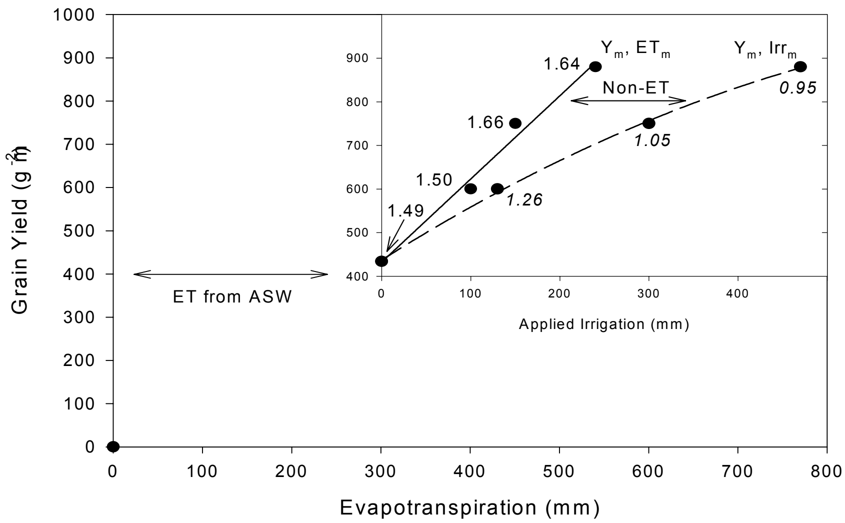

Figure 3. WUE (solid line) and IWUE (dashed line) for grain sorghum at Bushland, TX. Points along the lines represent WUE and IWUE (italics) for 0, 25, 50, and 100% ET replacement as measured with monolithic lysimeters in an automated rain shelter plot. ASW is "available soil water."

<u>Soil water measurement techniques</u>. Accurate soil water measurements are essential in irrigation management to improve WUE. Neutron scattering, capacitance, and time domain reflectometry (TDR) methods of soil water content measurement were compared in a wide variety of soils and environments. Comparisons were designed to establish the accuracy and precision of each method and particular device, the need for and amenability of the device to soil-specific calibration, the volume of measurement, and conditions of successful use (Evett et al., 2002). Figure 4 illustrates a soil column being constructed for instrument calibrations.

Figure 4. Access tubes fixed in place prior to soil packing (left), and soil column with access tubes and cables for TDR and thermocouples after packing.

<u>Remote sensing and spatial ET determination</u>. The WMRU project is investigating the SEBAL (surface energy balance algorithm for land; (Bastiaanssen et al., 1998a and 1998b and

Bastiaanssen et al., 2000) model for estimating ET in the Southern High Pains. This research is just beginning in cooperation with the University of Idaho, ARS-Kimberly, ID, and Texas A&M University. These tools could be important in the Texas Senate Bill 1 effort to determine water use across the Ogallala region. The tools certainly can be applied to other regions – the Edwards Aquifer region and the Lower Rio Grande Valley using Landsat 5 or Landsat 7 imagery.

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