WATER PRODUCTION FUNCTIONS FOR HIGH PLAINS CROPS

Thomas J. Trout[1]
Walter Bausch[2]
Gerald Buchleiter[3]

ABSTRACT

Increasing demands on limited water supplies will require maximizing crop production per unit water. Field studies are being carried out near Greeley, Colorado to develop water production functions for crops grown in the Great Plains. These yield per unit water relationships can be used to determine if deficit irrigation is economically desirable and how to best manage limited water supplies. A field facility, the Limited Irrigation Research Farm, was developed specifically to carry out limited irrigation research. Irrigation water is applied through drip irrigation systems; precipitation and reference evapotranspiration (ET) is measured with a weather station; soil water content is measured with time-domain reflectometry (TDR) and neutron probes; canopy temperatures are monitored; and growth, ground cover, biomass, and yields are measured. Yields are related to irrigation applications, crop ET, and crop transpiration. Initial results with corn, sunflower, wheat, and dry beans show linear relationships between yield and crop ET and transpiration.

BACKGROUND

Past studies have shown that the reduction in yield with deficit irrigation is usually less than the reduction in irrigation water applied - for example, a 30% reduction in irrigation results in only a 10% reduction in yield. This means the marginal productivity of irrigation water applied tends to be low when water application is near full irrigation. This results either from increased efficiency of water applications (less deep percolation, runoff, and evaporation losses from irrigation and better use of precipitation) with deficit irrigation, or from a physiological response in plants that increases productivity per unit water consumed when water is limited. Economically managing limited water supplies may involve deficit irrigation rather than reducing acreage. Likewise, if water supplies can be transferred or sold for other uses and the value is higher than the value of using the water to produce maximum yields, selling the water can increase the farm income.

In Colorado, there is continuing need for additional water supplies for growing cities, groundwater augmentation, and environmental restoration. This water is usually purchased from agriculture through “buy and dry” – purchasing the water rights and fallowing the land. Limited irrigation may be an alternative way to provide for other water needs while sustaining productive agriculture. However, in fully allocated basins where one farmer’s return flows becomes water supplies for downstream users, only the

---

[1] USDA-ARS Water Management Research, 2150 Centre Ave., Ft. Collins, CO 80526. Thomas.trout@ars.usda.gov
[2] USDA-ARS Water Management Research, 2150 Centre Ave., Ft. Collins, CO 80526
[3] USDA-ARS Water Management Research, 2150 Centre Ave., Ft. Collins, CO 80526

consumed portion of irrigation supplies – that lost to evapotranspiration - can be sold and the return flows must be maintained. Thus, it becomes critical to evaluate limited irrigation based on reductions in water consumptive use (CU) or equivalently, evapotranspiration (ET) rather than irrigation applications.

Improved irrigation efficiency is not likely to produce much transferable water because it results primarily in a reduction of return flows rather than a reduction in ET. If significant transferable water is to be produced by deficit irrigation, it must result from reduced ET. For deficit irrigation to provide economic benefits to growers, it must result in improved efficiency of the crop to convert ET to yield. Thus, the “maximize crop per drop” slogan must in reality be to maximize crop per consumptively used drop.

Although many limited irrigation studies have been carried out in the high plains and around the world, we feel there continues to be a need for more information on crop responses to deficit irrigation. So, in 2008, USDA-ARS began a field study of the water productivity of 4 high plains crops – corn, dry beans, wheat, and sunflower - under a wide range of irrigation levels from fully irrigated to rainfed. We are measuring ET of the crops under each of these conditions. We also strive to better understand and predict the responses of the crops to deficit irrigation so that limited irrigation water can be scheduled and managed to maximize yields.

THE LIMITED IRRIGATION RESEARCH FARM - LIRF

A 50 acre research farm northeast of Greeley, CO was developed to enable the precision water control and field measurements required to accurately measure ET of field crops. The farm, originally known as the Potato Research Farm and later as the Northern Colorado Research and Demonstration Center had been operated collaboratively by CSU and ARS for many years (in the 1980s, Harold Duke and students conducted surge irrigation trials there), but had not been in active research for over 20 years. The predominately sandy-loam soils and good groundwater well are ideal for irrigation research.

Four crops – winter wheat, field corn, sunflower (oil), and dry beans (pinto) are rotated through research fields on the farm. Crops are planted, fertilized, and managed for maximum production under fully irrigated conditions, but are irrigated at 6 levels that range from fully irrigated to only 40% of the fully irrigated amount. Deficit irrigations are timed to maximize production – usually by allowing relatively higher stress during early vegetative and late maturity stages and applying extra water to reduce stress during reproductive stages.

We apply irrigation water with drip irrigation tubes placed on the soil surface in each row. In this way we can accurately measure applications and know that the water is applied uniformly. This is essential to be able to complete the water balance. Water applied to each irrigation plot is measured with flow meters. Four crops, six irrigation levels, and 4 replications result in 96 individual plots.

A CoAgMet (Colorado Agricultural Meteorological Network) automated weather station is located on the farm near the center of a one acre grass plot. Hourly weather data from the station are used to calculate ASCE Standardized Penman-Monteith alfalfa reference evapotranspiration (ETr). Soil water content between 6 inches and 6 ft depth is measured by a neutron probe from an access tube in the center of each plot. Soil water content in the surface 6 inches is measured with a portable TDR system. Irrigations are scheduled using both predicted soil water depletions based on ETr estimations, and measured soil water depletion.

Plant measurements are taken periodically to determine crop responses to the water levels. We record plant growth stage and measure canopy cover with digital cameras. The digital cameras along with spectral radiometers and an infrared thermometer are mounted on a “high boy” mobile platform and driven through the plots weekly. Indicators of crop water stress such as stomatal conductance, canopy temperature, and leaf water potential are measured periodically. At the end of the season, seed yield and quality as well as total biomass are measured from each plot. On one field on the farm, crop ET is measured with energy balance instruments (Bowen Ratio method) for well-watered crops. These measurements allow crop coefficients to be estimated for the crops. On other fields on the farm, we are cooperating with CSU faculty to test wheat and dry bean varieties under varying irrigation levels.

An important part of the research is to extend the results beyond the climate and soils at LIRF. We are working with the ARS Agricultural Systems Research group to use this field data to improve and validate crop models. Once we have confidence in the models, we can estimate crop water use and yields over a wide range of conditions.

RESULTS

This project began in 2008. We will summarize the first two years of corn results in this article. Figure 1 shows the yield:water relationship for corn for each year. Irrigation applications (the lines on the left side in the figure) varied from about 430 mm (17”) for the fully irrigated crop down to 120 mm (5”). When precipitation is added (about 230 mm (9”) each growing season), deep percolation below the root zone is subtracted, and depletion of stored soil water is included, the remaining evapotranspiration for the crops varied from about 590 mm (23”) down to 380 mm (15”). Of that ET, about 60 – 90 mm was evaporation from the soil surface and the remainder was transpiration through the plants. Soil evaporation would be higher with sprinkler or furrow irrigation. Irrigations were timed such that plant water stress for the deficit irrigation levels was least between tasseling and soft dough (growth stages VT to R4).

The top (red) data in the figure are total above ground biomass (dry weight) and the bottom lines (blue) are grain yields. Grain yields varied from 13 Mg/ha (200 bu/ac) at full irrigation down to 6 Mg/ha (100 bu/ac) and biomass was about double grain yields. Hail damage in 2009 resulted in about 15% lower grain yields but little difference in total biomass. Harvest index (the portion of total biomass that is grain) ranged from 50 – 60% and did not vary with irrigation level.

The water production function for grain (blue lines) based on applied irrigation water curves downward as the water application decreases, showing that the decrease in yield for each unit decrease in water applied is relatively small when the deficit is small, but the rate of yield decrease gets larger as the deficit increases. This means that the marginal value of irrigation water is relatively low near full irrigation, showing the potential benefit to the farmer of transferring water to higher-valued uses. The marginal value of water increases from about 1.3 kg/m^3 (60 bu/ac-ft) of water applied near full irrigation to 3 kg/m^3 (150 bu/ac-ft) at the lowest irrigation level.

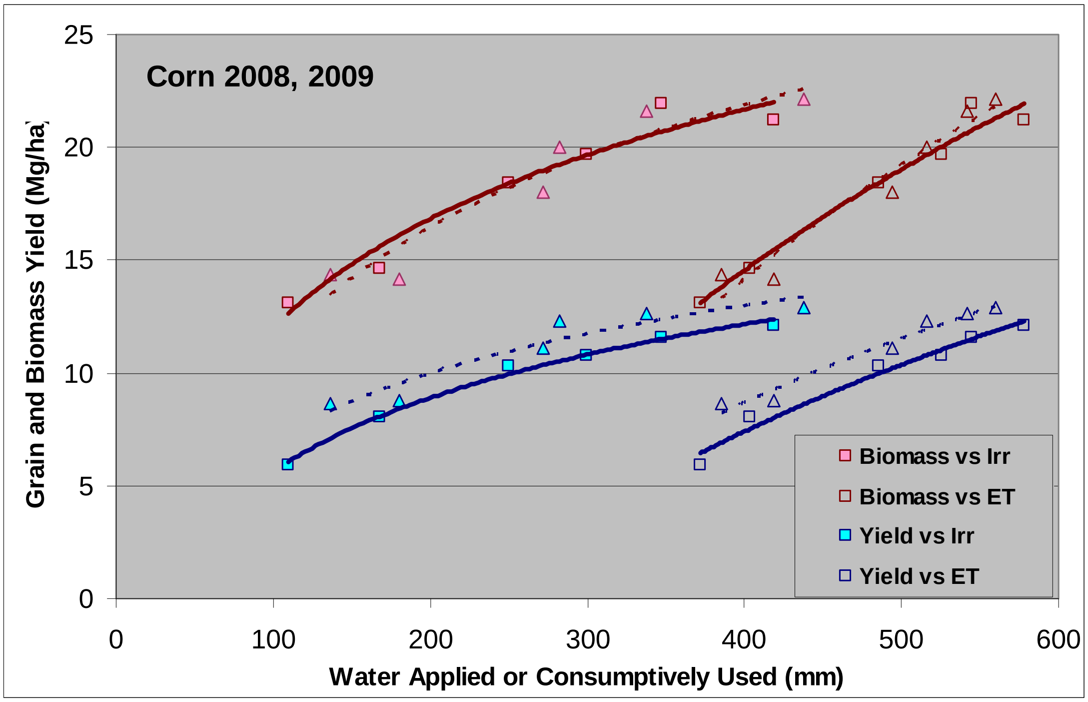

Figure 1. Water production functions for 2008 and 2009 corn. Red lines are total biomass (dry wt.). Blue lines are grain yield (15.5% moisture content). Yields are plotted relative to irrigation amount (Irr) and crop ET. Triangles and dashed lines are 2008 data. Squares and solid lines are 2009 data.

Figure 2. Comparison of corn growth condition on July 31, 2008 just before tasseling. Rows at the left and background are fully irrigated; rows at right are the lowest irrigation level.

However, the water production function for grain yield based on ET is relatively linear. This implies that the corn is equally efficient in it's use of every additional unit of water consumed and the marginal value of the consumptively used water is fairly constant over the wide range of applications – about 3 kg/m^3 (150 bu/ac-ft).

These results imply that nearly all of the increase in the marginal value of applied water with deficit irrigation results from more effective use of precipitation and increased use of stored soil water, or conversely, the lower marginal value of water near full irrigation is due to inefficient use of rainfall and irrigation water. The marginal value of applied water near full irrigation would be even smaller with less efficient irrigation systems since more of the applied water would be lost to runoff and deep percolation.

These results also imply that, based on consumptive use, there would be little or no yield benefit to deficit irrigation compared to fully irrigating only a portion of the land. In fact, fully irrigating less land would likely provide the highest economic returns due to lower production costs.

These preliminary results show the importance of developing water production functions based on the correct unit of water. If water value is based on cost of the water supply (eg. pumping costs from a well), then productivity based on applied water is important. However, for the purpose of transferring consumptive use savings, the productivity must be based on water consumed. The value of limited irrigation based on CU savings will likely be less, and if the crop is efficient at converting increased CU to yield, there may be no economic benefit to limited irrigation.

This limited irrigation study will be continued to confirm these initial results for each of the four crops.

REFERENCES

Allen, R.G., L.S. Pereira, D.Raes, and M. Smith. 1998. Crop Evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage paper # 56. FAO, Rome.