

# IMPROVEMENTS IN IRRIGATION EFFICIENCY

**Freddie Lamm**

Research Agricultural Engineer

KSU Northwest Research-Extension Center

105 Experiment Farm Road., Colby, Kansas 67701-1697

Phone: 913-462-6281 Fax: 913-462-2315 Email: flamm@oznet.ksu.edu

## INTRODUCTION

Efficiency is the name-of-the-game these days. We are constantly reminded that we must be more efficient with our time, our money, our skills, and our resources. Yet, the working definitions of the various efficiencies that each of us use may be quite different. Sometimes the correctness of the appropriate use of an efficiency term is entirely related to one's perspective. The topic of this presentation is irrigation, so let's look at two important efficiency terms in irrigation and look at how the terms interact.

### WATER USE EFFICIENCY (*WUE*)

Water use efficiency (*WUE*) is typically defined as the crop yield divided by the amount of water used. Algebraically it can be expressed as

$$WUE = M_{\text{crop}} / V_{\text{wuse}} \quad \text{Eq. 1.}$$

where  $M_{\text{crop}}$  is equal to the mass of the crop and  $V_{\text{wuse}}$  is equal to the volume of water used. It is easy to see that increases in *WUE* can be accomplished either by increases in  $M_{\text{crop}}$  relative to  $V_{\text{wuse}}$  or by decreases in  $V_{\text{wuse}}$  relative to  $M_{\text{crop}}$ . Whereas both techniques increase the beneficial use of water, only the second technique results in water conservation directly. It is important to note that manipulation of either term must be relative to the other term in the equation. Reducing water use is not beneficial if crop yield is reduced to the same extent.

### WATER APPLICATION EFFICIENCY ( $E_a$ )

The water application efficiency ( $E_a$ ) definition as reported by Heerman et al. (1990) is algebraically expressed as

$$E_a = V_{\text{soil}} / V_{\text{field}} \quad \text{Eq. 2.}$$

where  $V_{\text{soil}}$  is equal to the volume of irrigation water needed for crop evapotranspiration to avoid undesirable water stress and  $V_{\text{field}}$  is equal to the volume of water delivered to the field.  $E_a$  is often incorrectly confused with the water storage efficiency which is the fraction of an irrigation amount stored in the remaining available crop root zone following an irrigation event. The use of water storage efficiency is discouraged by Heerman et al. (1990) because of the difficulty of determining the crop root zone and because the water storage efficiency can still be

quite low while sufficient water is provided for crop production. It is easy to manipulate  $V_{\text{field}}$  so that  $E_a$  can be equal to 1 or 100%. It should be noted that any irrigation system from the worst to the best can be operated in a fashion to achieve 100%  $E_a$  if  $V_{\text{field}}$  is low. Increasing  $E_a$  in this manner totally ignores the need for irrigation uniformity. For  $E_a$  to have practical meaning,  $V_{\text{soil}}$  needs to be considered to avoid undesirable water stress.

### INTERACTION OF WUE AND $E_a$

Algebraically it has been shown that either efficiency term can be maximized through manipulation of the various terms in the equations. However, some of these manipulations are not beneficial to the irrigator and perhaps, also not beneficial to the economic vitality of the state. Consideration of both terms is necessary to optimize beneficial use of water for crop production.

In a thorough review of crop yield response to water, Howell et al. (1990) enumerated four methods of increasing water use efficiency: 1) increasing the harvest index (ratio of crop economic yield to total dry matter production); 2) reducing the transpiration ratio (ratio of transpiration to dry matter production); 3) reducing the root dry matter amount and/or the dry matter threshold required to initiate the first increment of economic yield; or 4) increasing the transpiration component relative to the other water balance components, for example, through reductions of evaporation, drainage, and runoff.

Clearly, some of these four methods are more difficult than others. Tanner and Sinclair (1983) in a review of studies from the early 1900's to the 1980's conclude that there is very little hope for significantly improving the transpiration ratio (Method 2). Plant breeders and agronomists have made great strides in increasing the harvest index (Method 1) for many of the more important crops. Corn yields have increased an average of 2.5 bu/acre annually for the years 1968-1991 in Thomas County, Kansas due to improvements in corn hybrids and cultural practices. The actual water used by the corn has not changed appreciably although the water use efficiency has increased. The dry matter threshold (Method 3) varies some depending on the annual climatic conditions. However, it does not appear practical that it can be manipulated to a significant extent. Improved irrigation systems and practices can increase both WUE and  $E_a$  by Method 4, increasing the transpiration component relative to the other water balance components.

Crop yield is linearly related to transpiration for many field crops from the point of the dry matter threshold through the point of maximum yield (Figure 1). However, the relationship of crop yield and total water use is usually curvilinear. The area between the dotted line and the curve represents the inefficiencies caused by the irrigation system and/or inappropriate irrigation/precipitation timing or amounts. Use of irrigation water beyond the point where the dotted line and the curve join at maximum yield represents wasteful overirrigation and should be eliminated immediately. All of the points on the rising dotted line have equal WUE, so all are equally beneficial in terms of WUE. However, most irrigators are practicing irrigation

for the beneficial purpose of increasing crop yields and economically need to produce near the top of the rising leg. Lamm et al. (1993) analyzed 9 different resource allocation schemes for irrigated corn ranging from full irrigation to severely deficit irrigation. Full irrigation was found to be the most economical operating point. They concluded,

*Irrigators wishing to continue to grow corn when irrigation is limited by physical (water supply) or institutional constraints should seriously consider reducing irrigated land area to match the severity of the constraint.*

Only reductions in the area between the dotted line and the curve (Figure 1) and obviously elimination of overirrigation should be considered as opportunities where improved irrigation systems and practices can increase WUE and  $E_a$ . Many irrigators are already upgrading irrigation systems and management of their present systems to *stretch* water. The opportunity for water use reductions is significant but the ultimate reductions can not be economically obtained overnight. The irrigation sector continues to search for economical ways to reduce inefficient water use in a manner that can optimize both WUE and  $E_a$ .

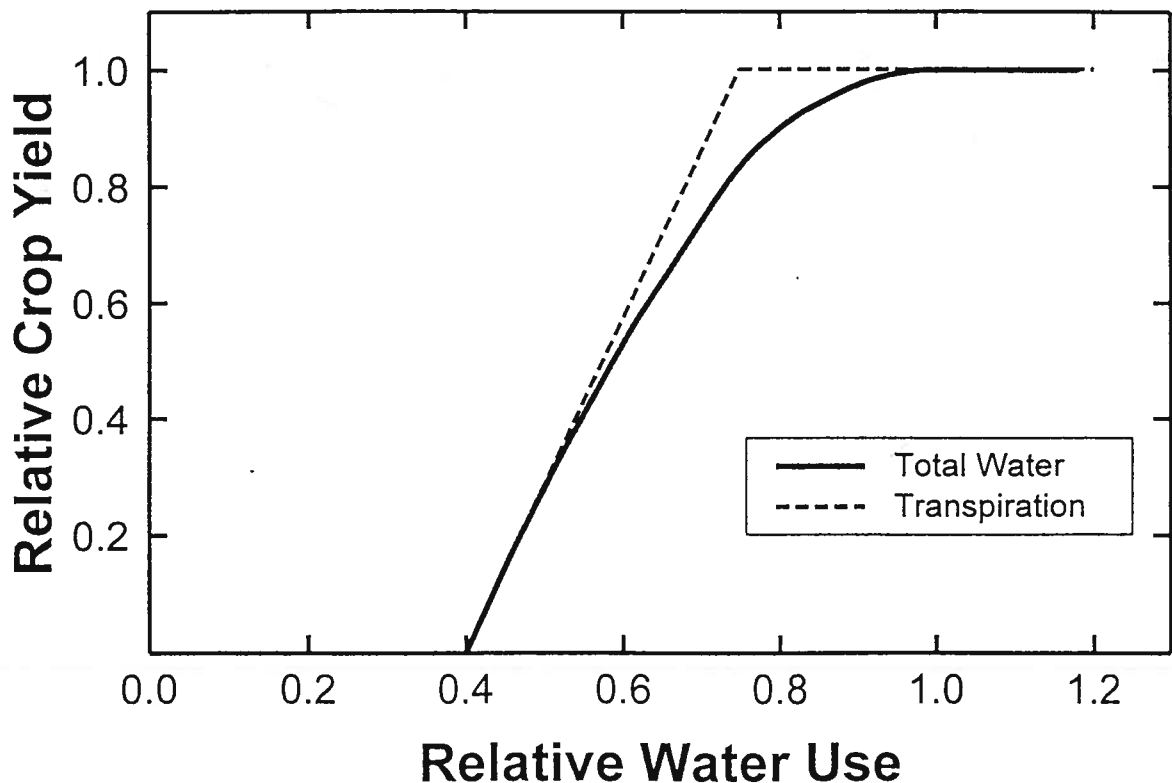


Figure 1. Hypothetical crop yield response to total water use and transpiration. Area between dotted line and curve is inefficiency. Use of irrigation water beyond where dotted line and curve rejoin (maximum crop yield) is wasteful overirrigation. Starting point for both lines is dry matter threshold. *Numbers shown for example only, actual values will vary.*

## REFERENCES

Heerman, D. F., W. W. Wallender, and M. G. Bos. 1990. Irrigation efficiency and uniformity. Chapter 6 in Management of Farm Irrigation Systems, pp. 125-149. Edited by G. J. Hoffman, T. A. Howell, and K. H. Solomon. ASAE Monograph, ASAE, St. Joseph, Michigan. 1040 pp.

Howell, T. A., R. H. Cuenca, and K. H. Solomon. 1990. Crop yield response. Chapter 5 in Management of Farm Irrigation Systems, pp. 93-122. Edited by G. J. Hoffman, T. A. Howell, and K. H. Solomon. ASAE Monograph, ASAE, St. Joseph, Michigan. 1040 pp.

Lamm, F. R., M. E. Nelson, and D. H. Rogers. 1993. Resource allocation in corn production with water resource constraints. App. Eng. in Agric., 9(4):379-385.

Tanner, C. B., and T. R. Sinclair. 1983. Efficient water use in crop production: research or re-research? Chapter 1a in Limitations to Efficient Water Use in Crop Production, pp. 1-27. Edited by H. M. Taylor, W. R. Jordan and T. R. Sinclair. American Society of Agronomy, Madison, Wisconsin. 538 pp.

*This paper was first presented at the 12th Annual Water and the Future of Kansas Conference, Feb 28 - March 1, 1995, Kansas State University, Manhattan Kansas.*