Proceedings of the 23rd Annual Central Plains Irrigation Conference, Burlington, CO., February 22-23, 2011
Available from CPIA, 760 N. Thompson, Colby, Kansas

WATER USE OF OILSEED CROPS

Rob Aiken
Research Crop Scientist
Email: raiken@ksu.edu

Freddie Lamm
Research Irrigation Engineer
Email: flamm@ksu.edu

K-State Northwest Research--Extension Center
Colby Kansas
Voice: 785-462-6281 FAX: 785-462-2315

Abdrabbo A. Aboukheira
Associate Research Scientist
Agricultural Water Management and Irrigation Technology
Columbia Water Center, The Earth Institute, Columbia University
New York, NY
Voice: 212-854-7219 Fax: 212-854-7081
Email: aas2243@columbia.edu

INTRODUCTION

Water use of a crop, with adequate available soil water supply, is primarily affected by its canopy and weather conditions (Tanner and Sinclair, 1983; Albrizio and Steduto. 2005; Suyker and Verma, 2010). These effects are represented by seasonal crop coefficients and the potential evaporative demand (ETp) of the atmosphere (Allen et al., 2005). The crop coefficient indicates the fraction of potential ET which the crop is expected to utilize on a given day. The crop coefficient value typically changes with crop stage. Crop water productivity (also known as water use efficiency) refers to the amount of biomass or economic yield produced with a given amount of water use. This article will present oilseed crop water use and crop water productivity field results from the U.S. central High Plains. Also, we review findings of environmental and management factors which can improve the water productivity of oilseed crops in this region.

Oilseed crops

The primary oilseed crops considered here are canola (winter or spring), soybean and sunflower. Limited information is available for other spring oilseed crops (Indian Brown Mustard, Baltensperger et al., 2004; Crambe, Nielsen, 1998) and summer oilseed crops (Safflower, Istanbulluoglu et al., 2009; Lesquerella, Puppala et al., 2005). In the U.S. central High Plains, winter canola is typically planted in mid-August, flowering in mid-May and matures in early July (Rife and Salgado, 1996); spring canola can be planted early March, flowering in late-May and maturing in mid-July (Aiken, 2010). Figure 1 shows expected water use and crop productivity for spring canola (Nielsen, 1998). Soybean can be planted in

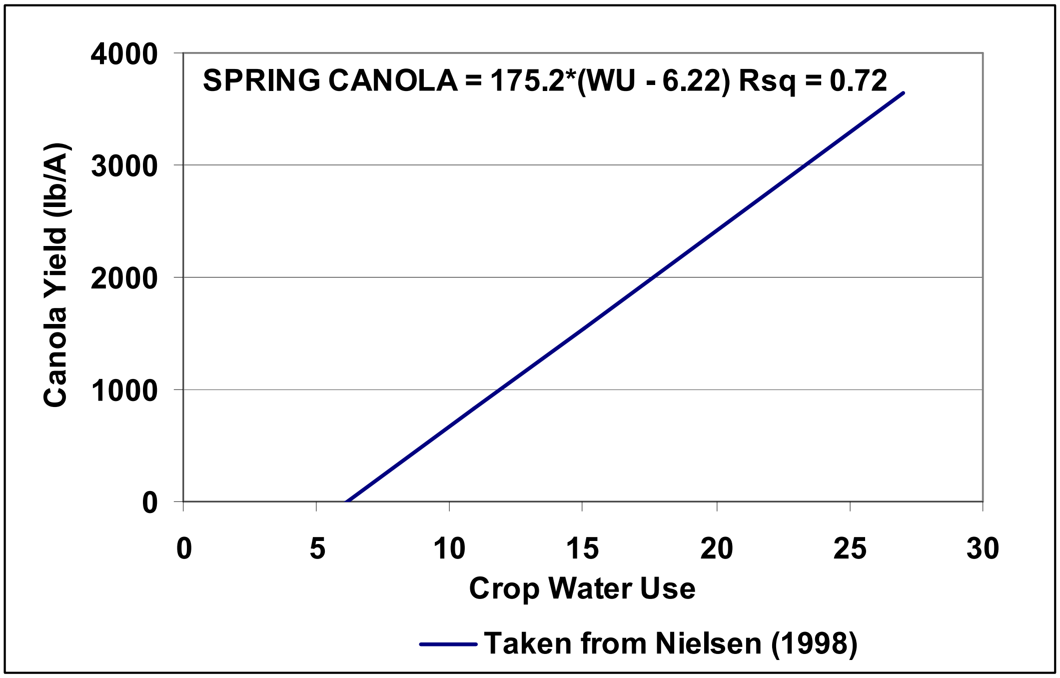

Figure 1. Expected oilseed yields of spring canola are presented, in relation to expected crop water use (soil water depletion plus precipitation and irrigation) in this crop water production function (taken from Nielsen, 1998).

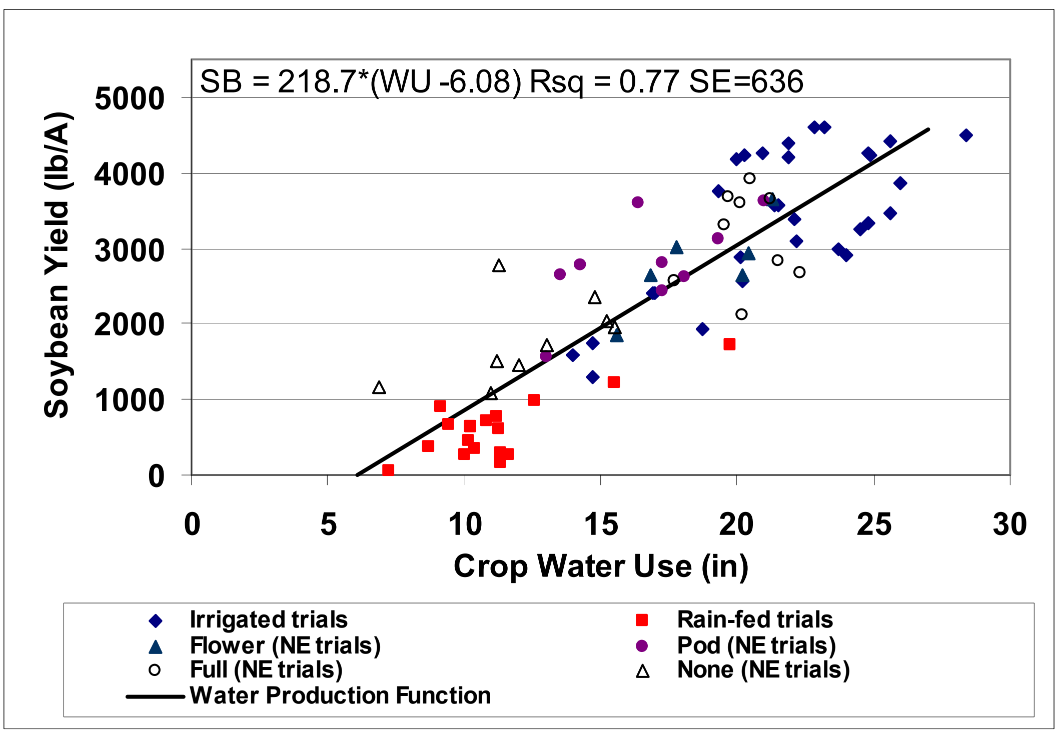

Figure 2. Expected oilseed yields and crop water use of soybean are derived from Colby, KS and Nebraska trials (NE trials indicate irrigation delayed to begin at flowering or pod development (Ellmore et al., 1988, Specht et al., 1989).

early May, flowering in mid-July for late-September harvest (Kranz et al., 2005). Sunflower is planted in mid-June to avoid pests, flowering in mid-August for harvest in late-September or early October (Rogers et al., 2005). Double-cropped soybean or sunflower can be planted after wheat harvest in early-July with flowering in late August and early October maturity. Figures 2 and 3 show expected crop productivity and water use for these summer oilseed crops. These spring and summer oilseed crops provide opportunities to shift irrigation applications among fields throughout the growing season (Klocke et al., 2006). Aiken and Lamm (2006) discussed crop development stages and yield sensitivities to water deficits for these crops.

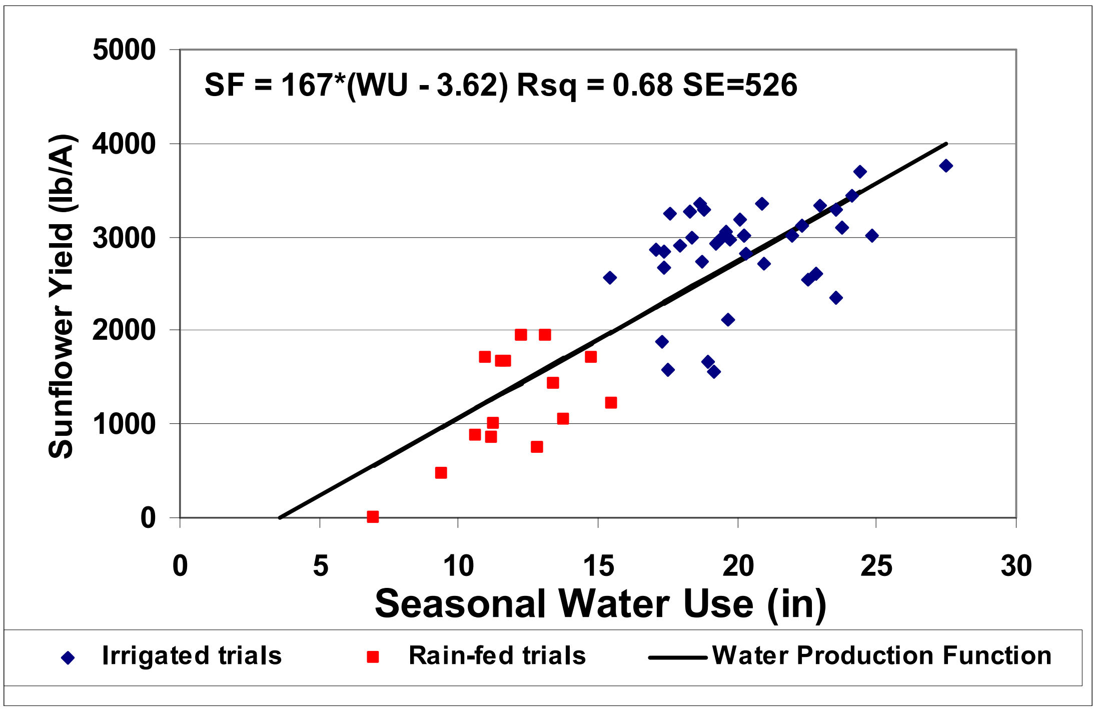

Figure 3. Expected oilseed yields and crop water use of sunflower are derived from Colby, KS trials.

WATER PRODUCTION FUNCTIONS

Crop Water Use

Oilseed yield is expected to increase with water use, up to a maximum yield potential (Anastasi et al., 2010; Demir et al., 2006; Payero et al., 2005). The oilseed yield-water use relationships (Fig. 1 - 3) show that a certain amount of water use (i.e. intercept of line with water use axis) is required before oilseed yield is expected. This apparent 'yield threshold' (6.2" for spring canola, 6.1" for soybean and 3.6" for sunflower) indicates the amount of water use required before the first unit of yield is obtained. The magnitude of this yield threshold can vary, to some extent, depending on early season soil water evaporation, prevailing humidity conditions and water used in vegetative growth. The rate of yield increase, relative to increased water use (slope of the yield response line), represents a measure of water productivity (175.2 lb/A-in for spring canola, 218.7 lb/A-in for soybean and 167.0 lb/A-in for sunflower). This factor is affected by inherent crop productivity, growing conditions (particularly amounts of sunshine and effects of atmospheric temperature and humidity) and harvest index (the fraction of biomass represented by economic yield). These water productivity functions have been developed from experimental data (e.g. Colby, KS, Tribune, KS, Akron, CO, North Platte, NE). The similarity in predicted yield responses to water use indicates applicability throughout the region.

Crop Water Productivity

A comparison of water productivity functions (Figure 4) for spring canola, soybean and sunflower (corn is also shown, for comparison) indicates the apparent yield threshold is least for sunflower, but largest for soybean (among oilseed crops). In contrast, the marginal water productivity (yield increase per additional unit of water use beyond the yield threshold) is largest for soybean and least for sunflower; water productivity for spring canola is intermediate. The inherent productivity of corn exceeds that of oilseed crops. Suyker and Verma (2010) reported that corn had 50% greater assimilation, 100% greater biomass productivity than soybean. Figure 4 indicates that relative corn productivity can exceed this rate. This difference is primarily due to the greater inherent

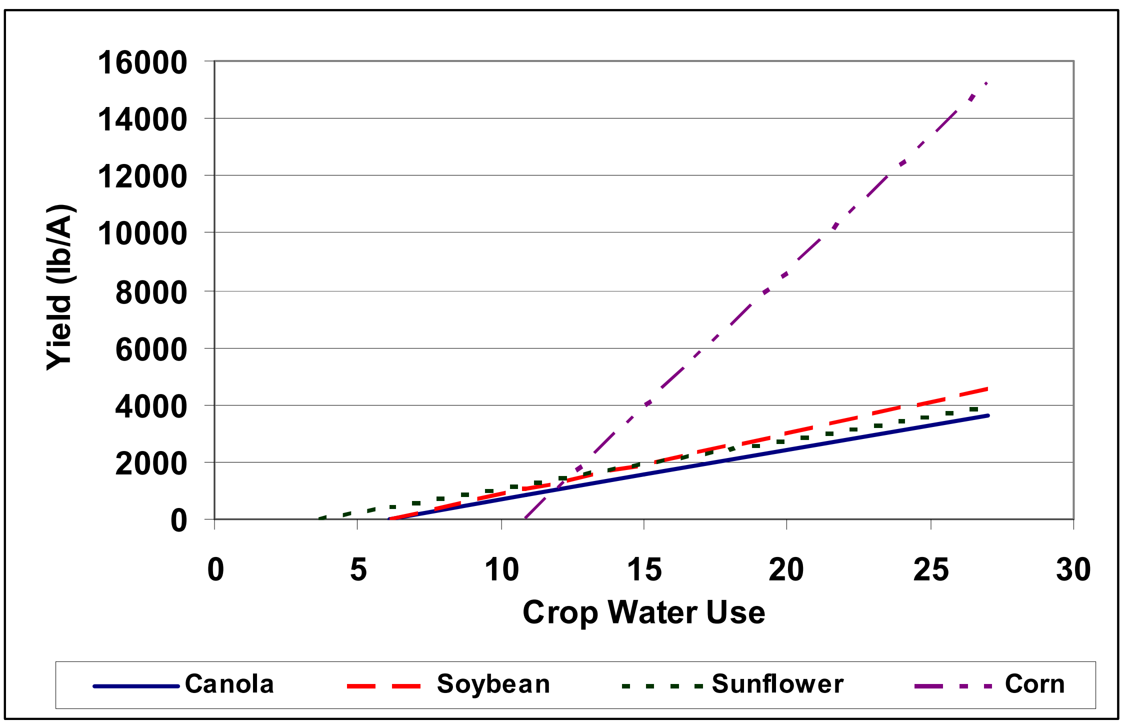

Figure 4. Crop water production functions for spring canola, soybean, sunflower and corn. The crop water production for corn was taken from Stone (2003); those for oilseeds are presented in Figures 1-3.

productivity[1] of warm-season grasses as well as the larger energy content of oilseeds, which require greater use of assimilates[2]. However, when oilseed yields are converted to a glucose equivalent, the water productivity of sunflower (~180 lb/A-in) is similar to that of cool-season crops (e.g. wheat, ~300 lb/A-in), which also rely on C3 physiology (Grassini et al., 2009). Further, the yield thresholds of oilseed crops appear to be less than that of corn; and the harvest price of oilseeds are typically greater than that of corn. As a result oilseeds may provide greater economic returns to water use than other crops at intermediate levels of irrigation.

An upper limit to water productivity of oilseed crops is likely constrained by the characteristics of C3 physiology and the large assimilation requirements for oil or protein biosynthesis. Crop water productivity may approach this upper limit when 1) irrigation is delayed (minimizing evaporation from soil surface) when available soil water is sufficient for vigorous canopy expansion to intercept radiation and increase the crop transpiration fraction of ET; 2) harvest index approaches the maximum potential; and 3) growing conditions are optimal, with minimal pest damage.

IMPROVING CROP WATER PRODUCTIVITY

Increase Transpiration Fraction

Delaying initial irrigation can reduce evaporation from the soil surface prior to canopy closure (Conner et al., 1985) and increase the crop transpiration fraction of ET. Specht et al. (1989) reported soybean yields equivalent to scheduled irrigation when irrigation was delayed to flowering or mid-pod stages. A similar response was reported by Lamm (1989a) with greater or equal soybean yields occurring with reduced irrigation during the vegetative period. However, maintaining sufficient soil moisture for vigorous canopy formation may require irrigation prior to canopy closure. Rapid canopy formation is vital to productivity as conversion of sunlight into biomass requires light interception by a healthy crop canopy (Albrizio and Steduto, 2005; Suyker and Verma, 2010).

Soybean and sunflower crops appear to differ in response to soil water deficits. Soybean exhibited tolerance of soil drying by maintaining non-stress photosynthetic rates when available soil water was 47% of full water-holding capacity (Wang et al., 2006). Also, soybean reduced crop transpiration by 67% under these deficit conditions. In contrast, sunflower maintained crop water use near non-stress rates when available soil water was 40% of water-holding

---

[1] Plants with C4 physiology characteristically have greater CO_2-fixing efficiency than plants with C3 physiology--due to Kranz anatomy and PEP carboxylase which permit sequestration of the Rubisco enzyme in bundle sheath cells where O_2 concentrations are typically maintained at less than 2%.

[2] The fraction of a sugar molecule which results in oil (33%) or protein (40%) is substantially less than that for starch (83%); see Tanner and Sinclair (1983), p. 13.

capacity (Casadebaig et al, 2008). Also, sunflower reduced leaf expansion rates when available soil water was 60% of full capacity, indicating sunflower producitivity declines under water deficits while water use continues at rates near the expected maximum. These results indicate a potential advantage to soybean--maintaining productivity while reducing transpiration under vegetative water deficits. Lamm (1989b) demonstrated increased water productivity for soybean by reducing irrigation during vegetative development.

Spring oilseed crops such as spring canola avoid evaporative losses, as crop canopy is established under cool conditions with modest evaporative demand. Water productivity can be increased by minimizing evaporative losses from soil by delaying initial irrigation, seeking rapid canopy closure, or planting a early spring oilseed which forms canopy under conditions of low evaporative demand.

Managing Harvest Index

Increasing harvest index (the fraction of biomass represented by economic yield) can improve crop water productivity. Establishing yield potential involves components of yield (plant population, potential seeds per plant[3], actual seeds per plant and seed mass). Vega et al. (2001) showed that seeds per plant increased with plant growth rate during seed set for soybean and sunflower. The indeterminate growth of soybean permitted branching and continued flowering, for continued increase in seeds per plant for plants with large growth rates. In contrast, the rate of seed set for sunflower was smaller at the greatest growth rates, compared to rate of seed set at intermediate growth rates due to limits in the potential number of seeds per head. It follows that yield formation in sunflower is more sensitive to sub-optimal populations than indeterminant crops such as soybean. Likewise, the indeterminant spring oilseed crops, such as canola, should be able to compensate for low population with increased branching and flowering.

Maintaining vigorous growth during floral development and seed set is critical for all grain crops, but can depend on weather conditions as well as crop management. Grassini et al., (2009) found that harvest index in sunflower was reduced under cloudy or hot conditions (low photothermal quotient, ratio of photosynthetically-active radiation to temperature) during the flowering period. Andrade (1995) reported that soybean yield formation was most sensitive to water deficits during seed fill, while sunflower yield was sensitive to water deficits during flowering and seed fill stages; canola exhibits yield sensitivity during flowering and seed fill (Champolivier and Merrien, 1996; Istanbulluoglu et al., 2010). Increased harvest index can be favored by planting optimal populations, selecting appropriate planting dates, varieties or hybrids, and avoiding water deficits for vigorous growth during floral development and seed fill.

---

[3] Components of yield for indeterminant crops, such as soybean and canola, include pods per plant and seeds per pod. Determinant crops, such as sunflower, typically have seeds arranged in a single head.

Genetic Advance

Genetic gain in crop water productivity may result from restricted transpiration, crop tolerance of soil water deficits and increased harvest index. Hufstetler et al., (2008) compared adapted soybean lines with non-adapted accessions; adapted lines had greater crop water productivity and lower transpiration rates at night than accessions. Lines also differed in sensitivity of transpiration to soil water deficit thresholds and in recovery upon re-wetting. Sinclair et al. (2000) screened 3,000 soybean lines and identified eight with substantial tolerance of N2 fixation to soil drying. This trait could enhance the growth response of soybean to a delayed irrigation strategy (see Increase Transpiration Fraction, above). Developing varietals and hybrids which maintain crop productivity and yield formation under water deficits and environmental stress can increase crop water productivity.

SUMMARY

Seasonal crop growth, in relation to crop water use, is known as a crop water productivity function; typically, these consist of a yield threshold (water use prior to expected economic yield) and a yield response (rate of yield increase per unit water use). Field studies in the U.S. central High Plains indicate sunflower has least yield threshold as well as least yield response; soybean has greatest yield threshold as well as greatest yield response. An upper limit to oilseed crop water productivity is primarily set by characteristics of the C3 physiology, which governs CO2 fixation by oilseed crops, and the large energy requirements for oil and protein biosynthesis. An adaptive management strategy can help growers achieve the maximum crop water productivity expected for oilseed crops. Components of this strategy include selecting crops and managing vegetative water supply to minimize the evaporative component of ET during vegetative growth, selecting seeding rates, planting dates and water management to ensure vigorous growth during flowering and seed-fill growth stages, and developing varieties and hybrids which tolerate water deficits to maximize harvest index.

REFERENCES

Aiken, R.M. and W.B.Gordon. 2003. Soybean productivity under drought: Effects of planting dates and maturity groups in northwest Kansas. Agronomy Field Research SRP 913. Kansas State University. Manhattan, Kansas. pp 102-104.

Aiken, R.M. and F.R. Lamm. 2006. Irrigation of oilseed crops. Proceedings of 18th Annual Central Plains Irrigation Conference and Exposition. February 21-22, 2006. Colby, KS. pp. 162-172

Aiken, R.M. R. Wolf, L. Dible and A. Oien. 2010. Planting date effects on spring oilseed production. Agronomy Field Research SRP 1030. Kansas State University. Manhattan, KS. pp. 72-77.

Albrizio, R., and P. Steduto. 2005. Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea: I. Radiation use efficiency. *Agricultural and Forest Meteorology* 130(3-4):254-268.

Allen, R.G., I.A. Walter, R. Elliot, E. Howell, D. Itenfisu and M. Jensen. 2005. The ASCE standcardized reference evapotranspiration equation. ASCE. Reston, VA.

Anastasi, U., C. Santonoceto, A. M. Giuffrè, O. Sortino, F. Gresta, and V. Abbate. 2010. Yield performance and grain lipid composition of standard and oleic sunflower as affected by water supply. *Field Crops Research* 119(1):145-153.

Andrade, F. H. 1995. Analysis of growth and yield of maize, sunflower and soybean grown at Balcarce, Argentina. *Field Crops Research* 41(1):1-12.

Baltensperger, D.D., D.J. Lyon, P.A. Burgener, G.L. Hein, C.D. Yontz, J.F. Margeim, G.E. Frickel and G.J. Foster. 2004. Brown mustard production. Cooperative Extension EC04-183. University of Nebraska. Lincoln, Nebraska. 6 pp.

Casadebaig, P., P. Debaeke, and J. Lecoeur. 2008. Thresholds for leaf expansion and transpiration response to soil water deficit in a range of sunflower genotypes. *European Journal of Agronomy* 28(4):646-654.

Champolivier, L., and A. Merrien. 1996. Effects of water stress applied at different growth stages to Brassica napus L. var. oleifera on yield, yield components and seed quality. *European Journal of Agronomy* 5(3-4):153-160.

Connor, D. J., T. R. Jones, and J. A. Palta. 1985. Response of sunflower to strategies of irrigation I. Growth, yield and the efficiency of water-use. *Field Crops Research* 10:15-36.

Demir, A., A. Göksoy, H. Büyükcangaz, Z. Turan, and E. Köksal. 2006. Deficit irrigation of sunflower (Helianthus annuus L.) in a sub-humid climate. *Irrigation Science* 24(4):279.

Elmore, R.W., D. Eisenhauer, J.E. Spect and Williams. 1988. Soybean yield and yield component response to limited capacity sprinkler irrigation systems. J Prod. Agric. 1:196-201.

Grassini, P., A. J. Hall, and J. L. Mercau. 2009. Benchmarking sunflower water productivity in semiarid environments. *Field Crops Research* 110(3):251-262.

Hufstetler, E. V., H. R. Boerma, T. E. Carter, Jr., and H. J. Earl. 2007. Genotypic Variation for Three Physiological Traits Affecting Drought Tolerance in Soybean. *Crop Sci* 47(1):25-35.

Istanbulluoglu, A. 2009. Effects of irrigation regimes on yield and water productivity of safflower (Carthamus tinctorius L.) under Mediterranean climatic conditions. *Agricultural Water Management* 96(12):1792-1798.

Istanbulluoglu, A., B. Arslan, E. Gocmen, E. Gezer, and C. Pasa. 2010. Effects of deficit irrigation regimes on the yield and growth of oilseed rape (Brassica napus L.). *Biosystems Engineering* 105(3):388-394.

Klocke, N.L., L. R. Stone, G. A. Clark, T. J. Dumler, and S. Briggeman. 2006. Water allocation model for limited irrigation. Applied Engineering in Agriculture. Vol. 22(3): 381-389.

Kranz, W.L. R.W. Elmore. and J.E. Specht. 2005. Irrigating Soybean. Nebraska Cooperative Extension G98-1367-A. 7 pp.

Lamm, F.R. 1989a. Irrigation scheduling of soybeans with evapotranspiration reports. Agricultural Research Report of Progress 576. Northwest Research—Extension Center. Kansas State University. Manhattan, KS. pp 32-34.

Lamm, F.R. 1989b. Crop responses under various irrigation scheduling criteria. In Proceedings of the Central Plains Irrigatibon Short Course, Colby, KS. February 13-14, 1989. pp. 97-104.

Nielsen, D.C. 1998. Comparison of three alternative oilseed crops for the central Great Plains. J. Prod. Agric. 11:336-341).

Payero, J. O., S. R. Melvin, and s. Irmak. 2005. Response of soybean to deficit irrigation in the semi-arid environment of West-Central Nebraska. *Transactions of the ASAE* 48(6):2189-2203.

Puppala, N., J. L. Fowler, T. L. Jones, V. Gutschick, and L. Murray. 2005. Evapotranspiration, yield, and water-use efficiency responses of Lesquerella fendleri at different growth stages. *Industrial Crops and Products* 21(1):33-47.

Rife, C. and P. Salgado. 1996. Canola production guide for the Great Plains. Kansas Agricultural Experiment Station Contribution No. 96-392-S. Manhattan, Kansas. 17 pp.

Rogers, D.H., M. Alam and J. Schneekloth. 2005. High Plains Sunflower Production Handbook. Kansas State University. Manhattan, Kansas. 38 pp.

Sinclair, T. R., L. C. Purcell, V. Vadez, R. Serraj, C. A. King, and R. Nelson. 2000. Identification of Soybean Genotypes with N2 Fixation Tolerance to Water Deficits. *Crop Sci.* 40(6):1803-1809.

Specht, J. E., R. W. Elmore, D. E. Eisenhauer, and N. W. Klocke. 1989. Growth stage scheduling criteria for sprinkler-irrigated soybeans. *Irrigation Science* 10(2):99.

Stone, L.R. 2003. Crop water use requirements and water use efficiency. Proceedings of 15th Annual Central Plains Irrigation Conference and Exposition. February 4-5, 2003. Colby, KS. pp. 127-133.

Suyker, A. E., and S. B. Verma. 2010. Coupling of carbon dioxide and water vapor exchanges of irrigated and rainfed maize-soybean cropping systems and water productivity. *Agricultural and Forest Meteorology* 150(4):553-563.

Tanner, C.B. and T.R. Sinclair. 1983. Efficient water use in crop production: Research or re-search?. In H.M. Taylor, W.R. Jordon and T.R. Sinclair, (Eds.) Limitations to efficient water use in crop production. American Society of Agronomy. Madison, WI.

Vega, C. R. C., F. H. Andrade, V. O. Sadras, S. A. Uhart, and O. R. Valentinuz. 2001. Seed Number as a Function of Growth. A Comparative Study in Soybean, Sunflower, and Maize. *Crop Sci* 41(3):748-754.

Wang, L., T. Zhang, and S. Ding. 2006. Effect of drought and rewatering on photosynthetic physioecological characteristics of soybean. *Acta Ecologica Sinica* 26(7):2073-2078.