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YEAR TO YEAR VARIATIONS IN CROP WATER USE FUNCTIONS

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INTRODUCTION

As well capacities continue to decline, many producers cannot meet full crop evapotranspiration (ET) if they decide to irrigate all their acres. To optimize net returns they have to allocate limited water resources to a mix of crops. In addition, they have to efficiently manage the water during the season in order to maximize crop water use efficiency. Crop water use functions also known as production functions have been widely used by agronomists, engineers and economists to quantify crop yield response to water (Howell, 1990). Although production functions have proved to be robust and useful for long term planning, they are not well suited for predicting crop yield response to water on short time scales (e.g., daily or seasonal) because they exhibit substantial year to year variation and they are site specific (Steduto et al., 2012). Several studies have reported the year to year variation in crop water use curves (Vaux and Pruitt, 1983; Trout and Bausch, 2012, Klocke et al., 2015). Vaux and Pruitt (1983) reviewed literature on crop production functions from several studies and noted that there was a great deal of variability in both the estimated coefficients and functional forms of the productions functions from year to year and from site to site.

INTER-ANNUAL VARIATION IN CROP YIELD VERSUS IRRIGATION FUNCTIONS

Corn Yield Response to Water at Garden City Kansas

More recently work by Klocke et al. (2015) based on a long term limited irrigation cropping systems study at Garden City Kansas showed that crop water use functions varied substantially from year to year as shown in Figure 1. The study consisted of 6 frequency based irrigation treatments ranging from dry land to full irrigation. Irrigation frequencies included irrigating every 5, 7, 8, 12, 16 and 22 days.

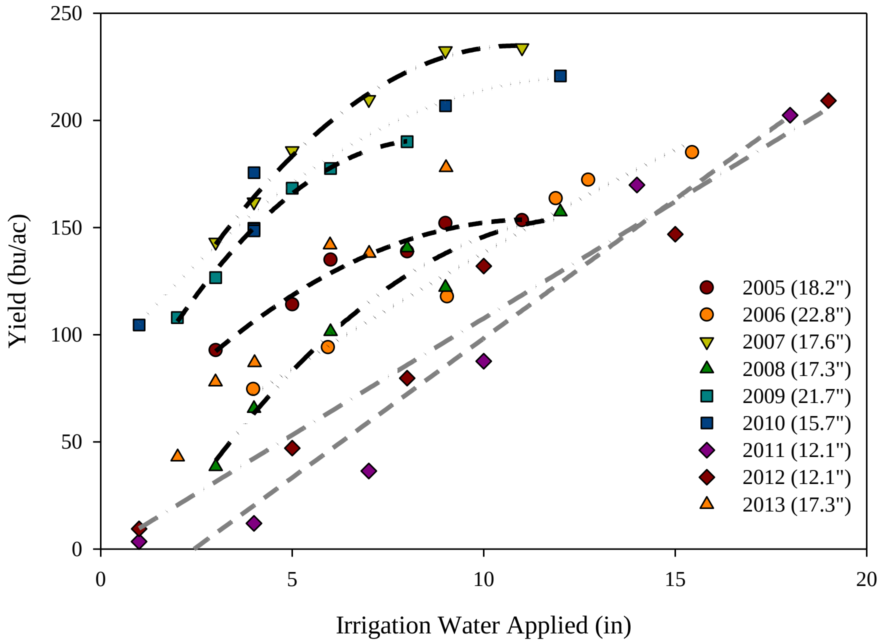

Figure 1. Corn response curves to irrigation from 2005 to 2013; the numbers in parentheses are annual rainfall recorded at Garden City Kansas.

The substantial year to year variability shown by the different curves in Figure 1 indicates that production functions are not well suited for making short term or seasonal water management decisions. The observed variability can be attributed to several factors including: 1) seasonal changes in rainfall amounts and patterns, 2) changes in evaporative demand, 3) cultural practices (e.g., irrigation management, fertility management, weed management, pest and insect management), 4) salinity, 5) differences in crop cultivars and their response to water use, 6) effect of water deficit at different growth stages and inter-dependency of growth stage water stress effects and 7) other miscellaneous factors such as hail or freeze damage. Howell (1990) gives a review of how some of the above factors influence major crop production processes such as CO_2 assimilation, transpiration and dry matter production. It can be seen in Figure 1 that during wet years without hail, the yield versus irrigation function are curvilinear while for the two drought years of 2011 and 2012 the response functions were linear mimicking the yield versus evapotranspiration relationship which is typically linear. This probably indicates that during drought years crop water use efficiency was high with little losses to percolation and runoff thus the yield versus irrigation curve approximated a straight line. Hail damage occurred in 2005, 2006 and 2008 which also contributed to the increased inter-annual variations in crop yield response to irrigation water applied.

In order to minimize the effect of inter-annual variations in weather, relative corn yield was plotted against irrigation as shown in (Figure 2). It can be seen in Figure 2 that during drought years (2011 and 2012) 18 inches of irrigation water was needed to attain maximum yield while during wet years like 2009 only 8 inches of irrigation water was required to attain maximum yield. This large variability makes it impractical to use the average crop water use function in Figure 2 for seasonal prediction of crop yield response to water applied. However it can be seen from Figure 3 that uncertainty in crop yield response to water decreased as the amount of irrigation increased, probably due to the reduced effect of variable weather conditions.

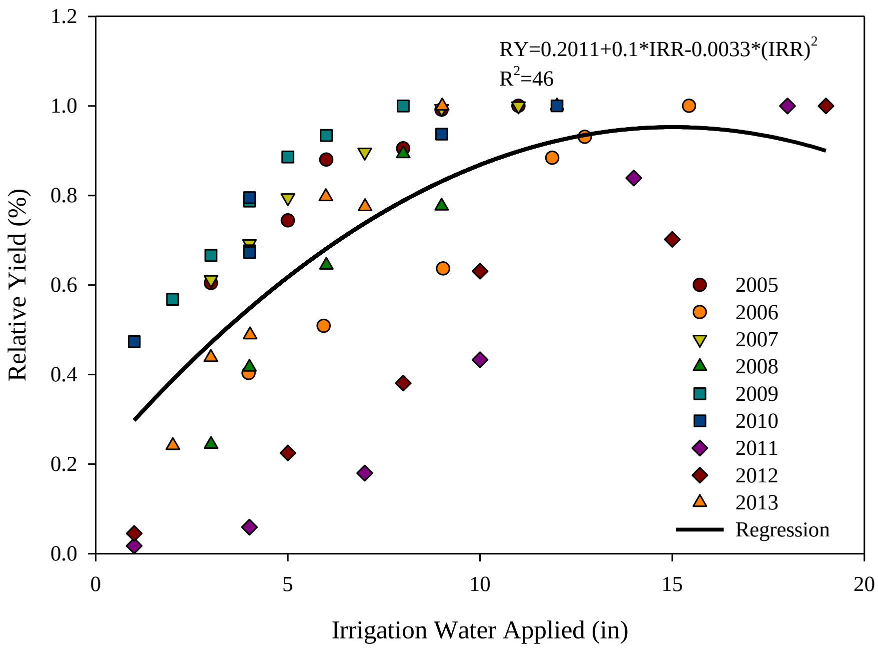

Figure 2. Corn relative yield response to irrigation from 2005 to 2013 at Garden City Kansas.

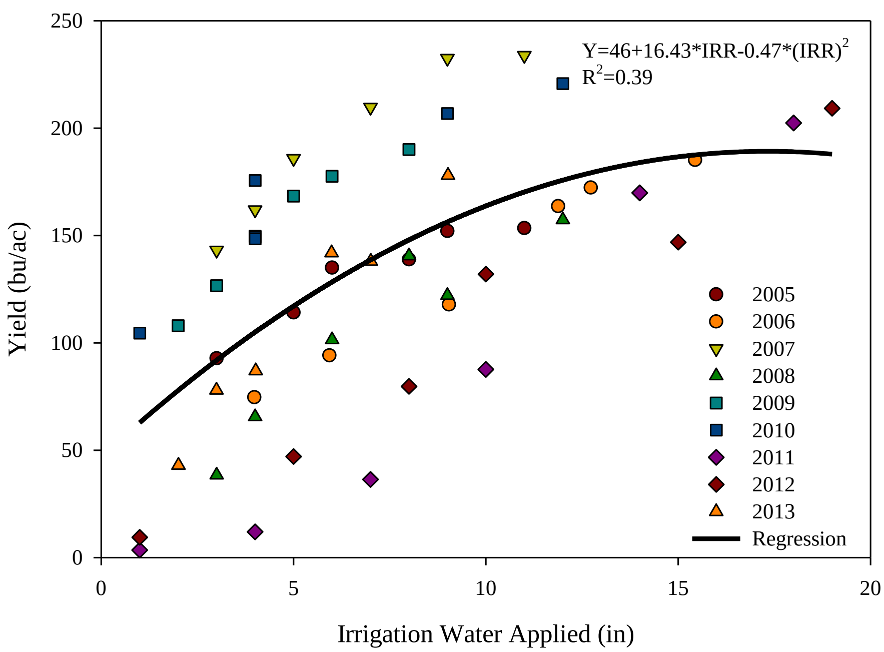

Figure 3. Corn yield response to irrigation from 2005 to 2013 at Garden City Kansas.

Weather Conditions during the Study Period

Figure 4 shows seasonal variation in both amount and distribution of rainfall at Garden City Kansas from 2005 to 2013. In addition, to rainfall other factors that influence production of dry matter and eventually yield include evaporative demand, solar radiation and atmospheric CO_2 concentration. Evaporative demand expressed in the form of vapor pressure deficit (VPD) shown in Figure 4 has a direct effect on the partitioning between soil evaporation and transpiration which depends on soil surface wetness (influenced by seasonal variations in rainfall distribution) and the amount of crop development (influenced by type of cultivar) and thus has a direct effect on transpiration efficiency (total dry matter produced per unit of water transpired). In Figure4 it can be seen that VPD was highest during the drought years of 2011 and 2012 and the year following the drought in 2013. This variation in VPD could probably explain the observations in Figure 2 where you needed much more water (both rainfall and irrigation) to attain maximum yield. For example you needed 8 inches of irrigation to attain maximum yield in 2009 which was a wet year with lower VPD compared to 19 inches in 2011 which was a dry year with high VPD. The rate of dry matter production is also governed by the amount of photosysthetically active radiation (PAR) that is intercepted by the plant canopy. PAR is directly influenced by the amount of solar radiation. From Figure 4 it can be seen that solar radiation varied during the study period from 2005 to 2013. Although this variation does not appear to have limited yields (e.g., 2007) with lower solar radiation but with high rainfall producer higher yields compared to 2012 with slightly higher solar radiation but low rainfall. Temperature which mainly influences crop phenology/development did not exhibit substantial inter-annual variations during the study period.

Given the dynamic nature of environmental factors and their influence on key crop production processes such as assimilation, transpiration and dry matter production, some investigators have recommended use of dynamic process-based crop growth models as an alternative to static production functions when predicting crop yield response to water on short time scales. Howell (1990) recommended using crop growth models coupled with monitoring as expert systems for making real time irrigation management decisions. Others have recommended use of crop growth models that account for the biophysical processes controlling the soil-plant-atmosphere system (Debaeke and Aboudrare, 2004; Steduto et al., 2012).

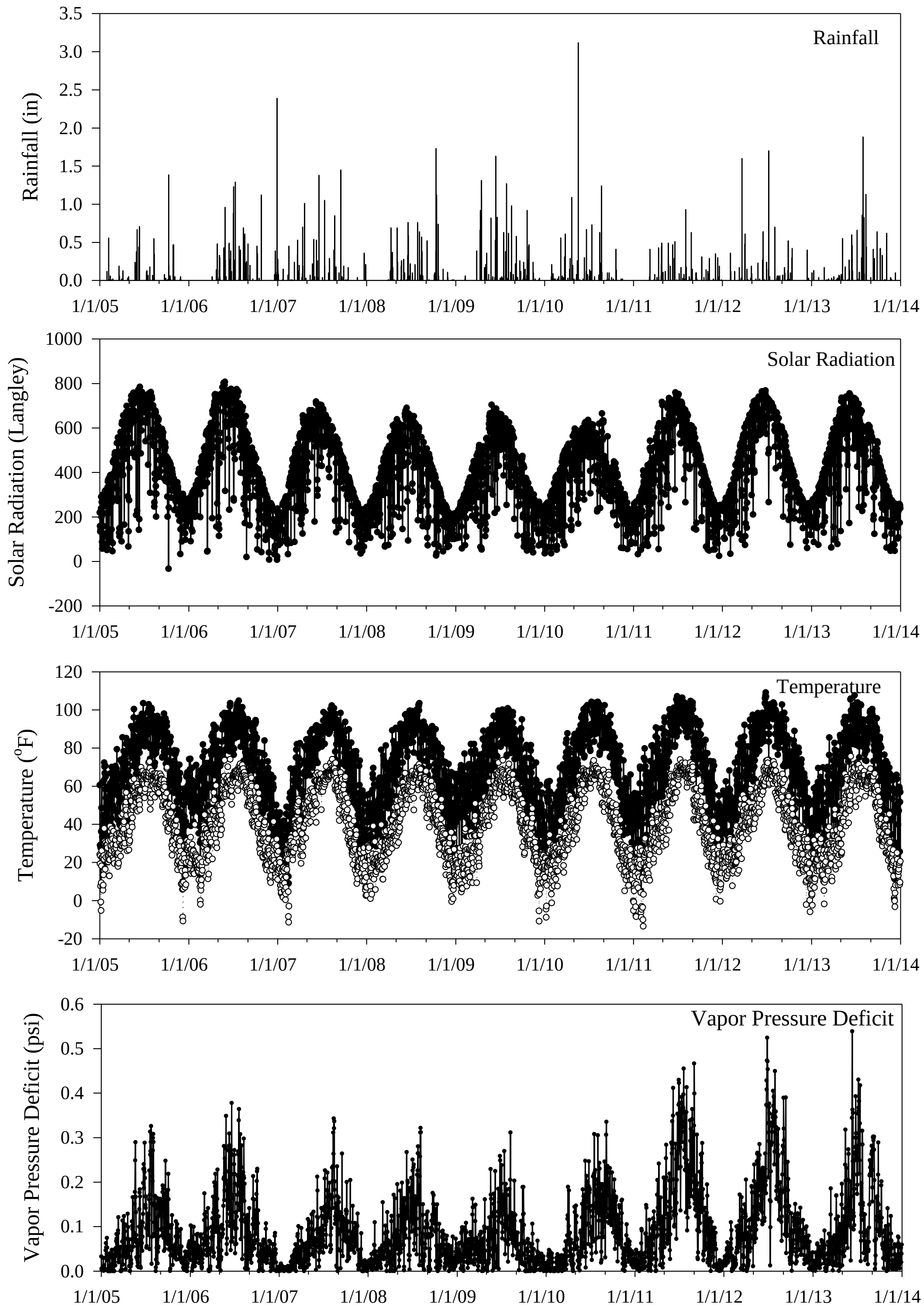

Figure 4. Weather variation during the limited irrigation cropping study at Garden City Kansas from 2005 to 2013.

Dynamic Crop Growth Models for Predicting Crop Yield Response to Water

Crop growth models can be used for both strategic and tactical irrigation water management. For example in a strategic mode they could be used for evaluating alternative irrigation management strategies (e.g., water allocation, irrigation schedules, fertility management, crop variety selection etc.) to determine the one that will optimize net returns during the season. In a tactical mode, dynamic crop growth models could be executed several times in-season with actual data such as measured or forecasted weather data, leaf area index, canopy cover and soil water with the goal being to refine prior irrigation management options selected at the beginning of the season. There are various types of process-based crop growth models that incorporate various levels of complexity (e.g., DSSAT, RZWQM, AQUACrop, APSIM, WOFST etc.). Despite their potential usefulness, simulations from crop growth models should be considered as aids and not absolute recommendations. This is because models are only simplifications of the complex biophysical system e.g., most models do not account for weed and insect pressure or even freeze or hail damage.

CONCLUSIONS

Crop yield response to water functions exhibit large year to year variations and therefore should only be used for long term planning and not seasonal prediction of crop yield response to water. Environmental and management factors that influence key processes that determine yield such as assimilation, transpiration and dry matter production need to be considered when predicting crop yield response to water on a daily or seasonal basis. Dynamic crop growth models coupled with monitoring offer promise for improved on-farm seasonal water management.

ACKNOWLEDGEMENTS

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