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# Optimizing preplant irrigation for maize under limited water in the High Plains

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ABSTRACT

Due to inadequate irrigation capacity, some farmers in the United States High Plains apply preplant irrigation to buffer the crop between irrigation events during the cropping season. The purpose of the study was to determine preplant irrigation amount and irrigation capacity combinations that optimize yield, water productivity, and precipitation use efficiency (PUE) and minimize soil water evaporation losses prior to planting. The CERES-Maize model embedded in the RZWQM2 model in combination with long-term climatic data from 1986 to 2014 for southwest Kansas were used for this research.

Experimental data from 2006 to 2009 was used to calibrate and validate the model. Model performance was satisfactory with high index of agreement (IA > 0.88). Relative root mean square error (RRMSE) ranged between 4.5% and 27%. Under very limited irrigation capacity (2.5 mm/day), applying 75–100 mm of preplant irrigation produced median yields that were 10–17% higher than not applying preplant irrigation. However, even at limited irrigation capacity the benefit of preplant irrigation were only realized if the seasonal yield potential was in the range of 6000 to 10,000 kg/ha corresponding to years with normal seasonal rainfall. Irrigation capacity had a stronger effect on maize grain yield compared to preplant irrigation amount. Preplant irrigation increased ET and transpiration under 2.5 mm/day irrigation capacity. Preplant irrigation amount did not have a substantial impact on water productivity at high and moderate irrigation capacity but had second order dominant effect under limited irrigation capacity. At low irrigation capacity (2.5 mm/day) increasing preplant irrigation increased median PUE up to 18% although the effect was second order dominant. Negligible water losses through deep percolation from 2.4 m soil profile were simulated. Increasing preplant irrigation resulted in significantly higher soil water evaporation losses prior to planting at all irrigation capacities. Overall preplant irrigation is beneficial under very limited irrigation capacity but is not necessary under sufficient irrigation capacity in most years. The decision to apply preplant irrigation should be evaluated and implemented carefully in combination with other agricultural water management technologies and strategies such as soil water monitoring, drip irrigation, and residue management.



## 1. Introduction

In the U. S. south and central High Plains, groundwater levels in the Ogallala aquifer are declining due to water withdrawals for irrigation exceeding average annual recharge (McGuire, 2004). This results in diminished well capacities that eventually became incapable of meeting full crop water needs during the summer growing season. For this reason, some irrigators on fine and medium textured soils apply preplant irrigation from groundwater to ensure that the soil profile has adequate water before planting to help their low irrigation capacity systems to better keep up with the crop water needs during the growing season. Preplant irrigation (also known as preseason, dormant season, off-season, or winter irrigation) is a water management strategy in which water is applied prior to or several months before planting. This practice is common to the U.S. South and Central High Plains (including areas in western Kansas, eastern Colorado and the panhandles of Texas and Oklahoma) as previously reported by Stone et al. (1994). Surveys conducted in western Kansas in the later part of the 20th

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**Table 1**
Preplant and growing season irrigation and growing season precipitation for a field study from 2006 to 2009 at Kansas State University Southwest Research-Extension Center near Tribune, Kansas (Schlegel et al., 2012).

| Year | Preplant irrigation (mm) | Growing season irrigation (mm) | | | Growing season precipitation (mm) |
|---|---|---|---|---|---|
| | | 2.5[a] (mm/day) | 3.8 (mm/day) | 5 (mm/day) | |
| 2006 | 76 | 243 | 320 | 483 | 176 |
| 2007 | 76 | 183 | 257 | 397 | 205 |
| 2008 | 76 | 209 | 278 | 375 | 238 |
| 2009 | 76 | 225 | 299 | 453 | 364 |

[a] Irrigation capacity.

century indicated over 60% of respondents used some form of preplant irrigation (Kromm and White, 1990). Recent droughts of 2011 and 2012 coupled with declining well capacities have stimulated interest again in preplant irrigation.

The major question for the producers is: when should preplant irrigation be used or when is it beneficial? Also, what is the best way to implement preplant irrigation in order to minimize nonproductive water losses that make this practice inefficient? Optimum preplant irrigation strategies target minimizing soil water evaporation, enhancing precipitation capture and storage and eliminating deep drainage. Preplant irrigation water is lost through two major processes; deep drainage and soil water evaporation. In wet years preplant irrigation might also use up storage that would have been used by spring rainfall which reduces rainfall storage efficiency. Stone et al. (2008) simulated efficiency of preplant irrigation and reported that available water in the soil at the time of the preplant irrigation application had the greatest effect on storage efficiency, which decreased dramatically when available water was greater than 60%. Stone et al. (2008) also reported that preplant irrigations made in the early spring were more efficient compared to irrigation made in the fall. Soil water during the off season is influenced by soil water at harvest which in turn is influenced by irrigation scheduling during the growing season. Given the significant effect of soil water on efficiency of preplant irrigation, a need exists for dynamic site specific decision support tools that can be used for predicting soil water over time and space and to assess need for and effect of preplant irrigation on soil water evaporation, transpiration, deep drainage, crop yield, and water productivity. Such a decision support tool can be developed from whole system agricultural models.

Whole system models integrate the physical, biological and chemical processes of an agricultural system and are very useful for extrapolating field research to different soils, climate and management, technology transfer and decision making (Ahuja et al., 2000). The need for such models and decision support tools will increase as farmers and other stakeholders demand quick transfer of research results in an integrated and usable form for site specific management. Calibrated and validated cropping systems models are an example of whole system agricultural decision support tools. Performance of these decision support tools can be enhanced by integrating them with field measurements such as soil water feedbacks. Examples of cropping systems models that can be used in assessing need and potential benefits of preplant irrigation include RZWQM2 (Ahuja et al., 2000), DSSAT-CSM (Hoogenboom et al., 2015), WOFOST (Van Diepen et al., 1989), APSIM (Keating et al., 2003), and AquaCrop (Raes et al., 2009) Agricultural systems models have been successfully applied in assessing irrigation management in the U.S. Great Plains (Saseendran et al., 2008; DeJonge et al., 2012; Ma et al., 2012; Kisekka et al., 2016a,b).

In this paper, the RZWQM2 (Root Zone Water Quality Model) was selected for the following reasons: 1) process oriented, dynamic, and simulates the impact of agricultural management practices such as tillage, residue management, irrigation, and fertility on soil water, crop production, and water quality (Ahuja et al., 2000), 2) DSSAT v4.0 has been embedded into RZWQM2 which provides a suite of detailed biophysical crop models for simulating crop growth and development (Ma et al., 2006), 3) RZWQM2 has advanced features for assessing limited irrigation strategies such as water allocation limits by period, irrigation scheduling based on ET or soil water deficit, and 4) an automatic optimization algorithm called PEST (Doherty, 2009) has also been embedded into RZWQM2 to facilitate parameter estimation which allows for reproducible and objective model calibrations.

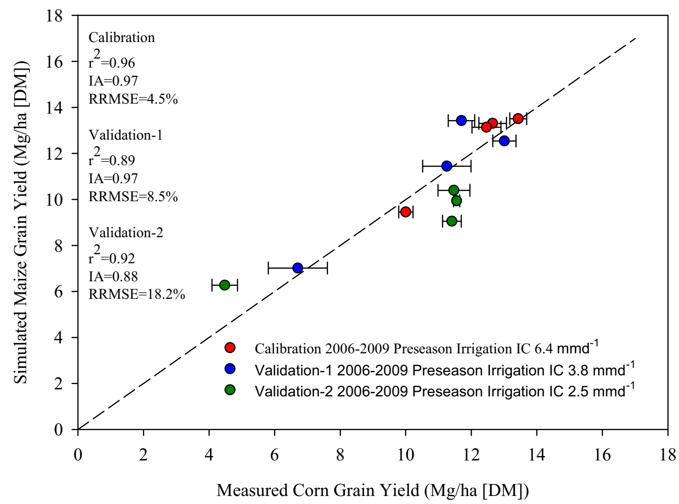


**Fig. 1.** Comparing simulated to measured maize grain yield in a preplant irrigation study that was conducted at the Kansas State University Southwest Research-Extension Center near Tribune, Kansas, IC refers to irrigation capacity, IA is index of agreement and RRMSE is the relative root mean square.

The purpose of the study was to determine preplant irrigation amount and irrigation capacity combinations that optimize yield, water productivity, and precipitation use efficiency (PUE) and minimize soil water evaporation losses prior to planting. The research involved combining short term experimental data with long-term historic climatic data (1986–2014), and crop simulation modeling to determine optimum preplant irrigation water management in the United States High Plains.

## 2. Materials and methods

### 2.1. Experimental data

A field experiment was conducted at the Kansas State University Southwest Research-Extension Center near Tribune Kansas (38.5°N, 101.7°W, and 1086 m above sea level) from 2006 to 2009. The soil at the study site is a deep well drained Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustolls). The climate of the study site is semi-arid with mean annual precipitation of 440 mm and mean annual evapotranspiration of 1943 mm (1986–2014). The growing season precipitation from 2006 to 2009 is given in Table 1. The experimental design was a factorial with preplant irrigation (0 and 76 mm), irrigation capacity (2.5, 3.8 and 5.0 mm/day)