Modeling and Evaluation of Maize Under Full and Limited Irrigation

Kendall DeJonge[1], Allan Andales[2], James Ascough II[3], Neil Hansen[2]

[1]Department of Civil and Environmental Engineering, Colorado State University; [2]Department of Soil and Crop Sciences, Colorado State University

[3]USDA-ARS, Agricultural Systems Research Unit, Fort Collins CO

Introduction

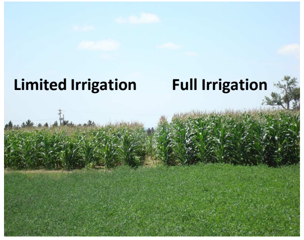
Population growth in urbanizing areas such as the Front Range of Colorado has led to increased pressure to transfer water rights from agriculture to municipalities (Water Center of CSU Newsletter 2010, 27(1)). For example, in the South Platte River basin of Colorado, between year 2000 and 2030 the population is expected to increase by 65%, while the irrigated area is expected to decrease by 37% (Camp Dresser & McKee 2007). To sustain agriculture in these areas, an alternative to full water rights transfer would be water leasing, which would require rotational fallowing or limited irrigation management.

Many studies of limited or deficit irrigation of maize have emphasized minimizing water stress during critical reproductive growth stages in order to maximize yields (i.e. Doorenbos and Kassam 1979, *FAO 33*; Klocke et al. 2007, *Trans. ASABE* 50(6); Payero et al. 2009, *Ag. Water Mgmt.* 96).

Crop simulation models such as CERES-Maize can be used to assess crop management strategies such as limited irrigation (Hoogenboom et al. 2004, DSSAT v4.0). In a recent and local example, Saseendran et al. (2008, Water Resources Res. 44) simulated various water allocations and amounts in northeastern Colorado with CERES-Maize, finding that split irrigation applications of 20% of total water applied during vegetative growth stages and 80% during reproductive growth stages obtained the highest yield for varying irrigation allocations. Few studies comparing CERES-Maize with field observations provide a detailed statistical analysis, especially in regard to limited irrigation applications.

Objective

Statistically determine the CERES-Maize (v4.0) model's ability to accurately differentiate between full and limited irrigation treatments in northeastern Colorado in terms of evapotranspiration (ET), crop growth, yield, water use efficiency (WUE), and irrigation use efficiency (IUE).

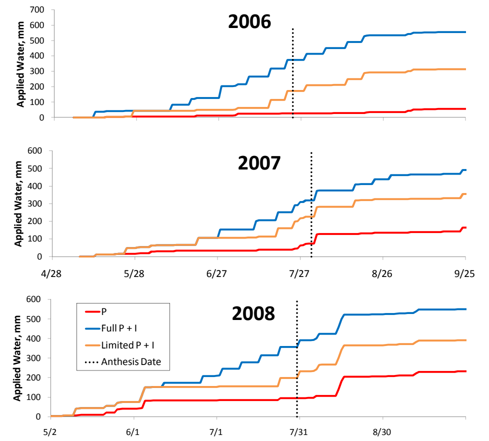


Statistical Evaluation

Four statistical criteria were used to evaluate differences between the model and observations. These include the Nash-Sutcliffe Efficiency coefficient (E_{NS}, Nash and Sutcliffe 1970, *J. Hydrology* 10(3)), root mean square deviation (RMSD), normalized objective function (NOF), and relative error (RE), as defined below. O and P denote observed and predicted values, respectively.

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad RMSD = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \qquad NOF = \frac{RMSD}{\bar{O}} \qquad RE = \frac{\sum_{i=1}^{n}(P_i - O_i) * 100.0}{\sum_{i=1}^{n} O_i}$$

Precipitation (P) and Irrigation (I)



Experimental Design

- Location at CSU Agricultural Research Development and Education Center facility north of Fort Collins, fine loam soils
- Two treatments (Full and Limited Irrigation), 4 replicates each (RCBD), 12 rows – 26 m length
  - Full Irrigation – no water stress, ever
  - Limited Irrigation – no water stress during reproductive stages

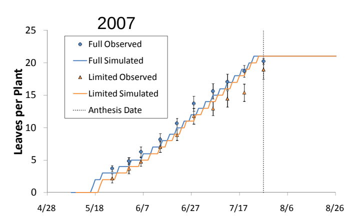
    (some early irrigation required to ensure germination and stand growth)
- Irrigations performed with linear irrigation system, low impact drop nozzles, once per week maximum
- Monitored for crop growth (total leaf count, leaf area index (LAI), height), development (phenology stages), soil water content (neutron moisture meter), ET by water balance (top 1 m soil profile), and final grain yield
- Onsite weather station provided potential ET

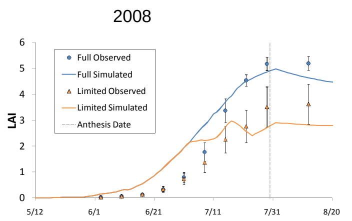
CERES-Maize Crop Model

- In DSSAT4 suite of models, daily time step
- Simulates aspects relevant to crop growth
  - Weather, soil water distribution, nitrogen distribution, plant growth (vegetative and reproductive), evapotranspiration
- Allows for management decisions
  - Planting (date, population), fertilizer (date, method, amount), irrigation (date, method, amount)
- Growth parameters calibrated to match growth timing and yield

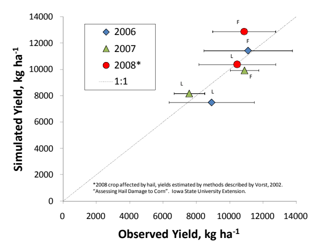
Results

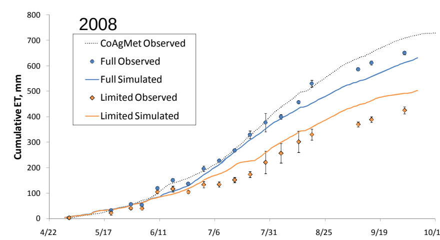
Crop growth in terms of phenological timing and leaf growth matched observations, although the model performed better for full irrigation than limited. LAI underpredicted in late season, although more grossly in limited treatment.





Yield matched closely in all years and treatments. Soil water content or total water in top 1 m of soil did not have good prediction, however ET by water balance performed much better. ET tended to be overpredicted for full irrigation, and underpredicted for limited irrigation.





Statistical values indicate that full irrigation was simulated more accurately than limited irrigation. Statistics performing the best are in red.

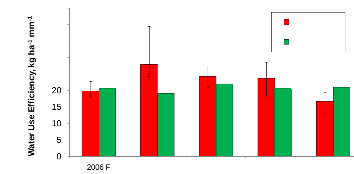
	Total Leaf Number (2007)		Leaf Area Index (2008)	
	Full	Limited	Full	Limited
N	390	370	70	70
Pavg	11.51	11.22	2.59	1.79
Oavg	12.12	10.46	2.25	1.56
E_{NS}	**0.949**	0.900	**0.896**	0.666
RMSD	**1.284**	1.663	**0.691**	0.841
NOF	**0.106**	0.159	**0.307**	0.537
RE (%)	**-5.0**	7.3	15.1	**14.5**

Total Water in Top Meter of Soil (mm)	2006		2007		2008		All Years	
	Full	Limited	Full	Limited	Full	Limited	Full	Limited
N	50	46	44	44	72	72	166	162
Pavg	257	205	317	266	289	236	287	235
Oavg	253	232	326	309	313	296	298	281
RMSD (mm)	**55**	62	**44**	72	**32**	71	**43**	69
NOF	**0.217**	0.268	**0.134**	0.234	**0.102**	0.239	**0.144**	0.245
RE (%)	**1.6**	-11.7	**-2.7**	-13.7	**-7.8**	-20.3	**-3.9**	-16.3

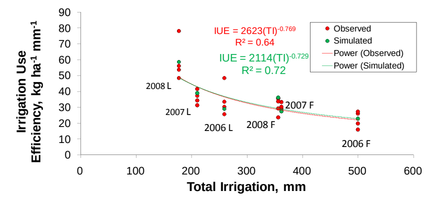
Cumulative Evapotranspiration (mm)	2006		2007		2008		All Years	
	Full	Limited	Full	Limited	Full	Limited	Full	Limited
N	50	46	44	44	72	72	166	162
Pavg	294	198	189	163	265	215	254	196
Oavg	297	174	200	157	286	184	273	174
E_{NS}	0.751	**0.759**	**0.947**	0.805	**0.977**	0.884	**0.966**	0.835
RMSD (mm)	96	**55**	**37**	54	**31**	44	61	**50**
NOF	0.323	**0.313**	**0.186**	0.343	**0.110**	0.241	**0.222**	0.289
RE (%)	**-1.0**	13.5	-5.9	**4.0**	**-7.4**	16.7	**-7.2**	12.7

Yield (kg/ha)	2006		2007		2008		All Years	
	Full	Limited	Full	Limited	Full	Limited	Full	Limited
N	4	4	4	4	4	4	12	12
Pavg	11421	7491	9925	8164	12872	10371	11406	8675
Oavg	11107	8916	10891	7575	10863	10451	10954	8981
RMSD (kg/ha)	**2321**	2633	1218	**989**	2591	**2001**	2128	**1992**
NOF	**0.209**	0.295	**0.112**	0.131	0.239	**0.191**	**0.194**	0.222
RE (%)	**2.8**	-16.0	-8.9	**7.8**	18.5	**-0.8**	4.1	**-3.4**

WUE showed a difference in treatments for two years of observations, but not at all for simulations.



IUE shows a strong trend for both simulations and observations. IUE is higher at lower irrigation levels.



Summary and Conclusions

The CERES-Maize model accurately simulated treatment differences between full and limited irrigation, but performed better overall for full irrigation. Crop growth simulations had a high value of accuracy, although LAI was underestimated in the late season, especially with limited water. Total water was slightly underestimated overall, although this trend was much more prevalent in the limited treatment. Because of this trend, ET by water balance was overestimated by the model. Because the model accurately predicts differences between treatments in yield, but underpredicts differences in ET, the model sees no difference between treatments when calculating WUE. However IWUE, a function of yield and applied irrigation, shows a strong trend for both model and observations. Improvement of model stress functions and estimation of ET with limited water are suggested, especially in terms of sensitivity and/or uncertainty analysis.