From: Agronomy Field Research 2009, Kansas Agric. Exp. Stn. Report of Progress 1017, April 2009

Forecasting Wheat and Sorghum Yields with the Kansas Water Budget[1]

R. M. Aiken, L. R. Stone, and A. J. Schlegel

Summary
Weighting factors (which quantify yield effects of water deficits) of the Kansas Water Budget (KWB) were evaluated with respect to wheat and grain sorghum productivity. Simple and accurate models of crop water use and productivity with sparse input requirements can support simulation of hydrologic, yield formation, and soil conservation processes at regional scales. An inverse solution for weighting factors minimized predictive error from the KWB for water deficit effects on wheat and grain sorghum yields observed over 40 site-years at two western Kansas locations. Knowledge of weather and soil effects on crop water use and productivity can enhance decision support for soil, residue, and crop management as well as inform strategic planning for regions subject to reduced aquifer withdrawal.

Introduction
Crop grain yields can be estimated or forecast by using weather data and computer models of crop water use and productivity, such as the KWB (Khan, 1996). Often, rainfall is not sufficient to meet the water required by a wheat or grain sorghum crop, which reduces yield potential. Because the yield effect of limited water changes with crop development, the KWB uses weighting factors for four separate crop development stages to calculate yield effects. Yields of winter wheat and grain sorghum observed over 40 site-years at two western Kansas locations were used to evaluate yield estimates of KWB and to determine whether modified weighting factors would improve KWB yield estimates.

Procedures
The KWB model simulated soil water with the water budget method by using a Jensen-Haise calculation of potential evapotranspiration (ETp) from daily ambient temperature extremes and solar radiation; a crop coefficient function and a water deficit function for actual evapotranspiration (ETa); daily precipitation and effective irrigation; a constant runoff fraction and a Wilcox equation for soil water drainage. Grain yield (Y) was calculated as a linear proportion (k) of effective evapotranspiration (ETe), modified by a yield threshold (YT):

$$Y = k(ET_e - YT)$$

[1] This research was supported in part by the Ogallala Aquifer Program, a consortium between the USDA-Agricultural Research Service, Kansas State University, Texas AgriLife Research, Texas AgriLife Extension Service, Texas Tech University, and West Texas A&M University.

Effective evapotranspiration was calculated from ETp, Eta, and a set of weighting factors (WF, Table 1) corresponding to portions of the growing season with differential yield sensitivity to water deficits (indicated by the subscripted i):

$$ET_e = ET_p \bullet \sum\left(WF_i \bullet \frac{ET_{ai}}{ET_{pi}}\right), \sum WF_i = 1$$

Crop (winter wheat or grain sorghum) productivity and soil water depletion were observed in three long-term, rain-fed crop sequence studies conducted at Tribune and Colby, KS, and a limited-irrigation study at Colby. Soil water status at planting and harvest was determined by neutron thermalization; grain yields were determined by hand harvest (Colby) or machine harvest (Tribune). Khan (1996) reported soil hydraulic properties required by the Wilcox drainage function. Initial soil water conditions were adjusted to match field observations. The crop coefficient function was scaled, linearly, to relative maximum leaf area index (rLAImax), assuming this occurred at anthesis and that canopy light absorption approached a maximum at LAI = 3. Canopy formation observed at Colby was regressed on vegetative ETa simulated by KWB and used to estimate rLAImax at Tribune. Daily ETp, ETa, plant-available water, and total soil water were calculated according to the KWB algorithm (Khan, 1996). The inverse solution for WFi involved adjusting the four values for WFi to minimize predictive error—root mean squared error (RMSE) and mean bias error (MBE) of yield values calculated by KWB.

Results

Soil profile water status was calculated by KWB with little bias (MBE, Table 2 and Figure 1) but similar precision (RMSE) to interannual variation for the wheat crop; model precision increased substantially for the grain sorghum crop, which included limited irrigation studies at Colby. Optimized weighting factors (Table 1) improved precision and bias components of predictive accuracy for wheat yield but not grain sorghum yield.

References

Khan, A.H. 1996. Kansas water budget: Educational software for illustration of drainage, ET and crop yield. Ph.D. dissertation. Kansas State University, Manhattan.

Table 1. Weighting factors used in the Kansas Water Budget to calculate effective crop water use on the basis of relative sensitivity of grain yield formation for the respective developmental stage

	Wheat		Grain sorghum	
Weighting factor	Default	Optimized	Default	Optimized
Vegetative	0.49	0.30	0.44	0.55
Flowering	0.31	0.35	0.39	0.30
Formation	0.19	0.35	0.14	0.15
Ripening	0.01	0.00	0.03	0.00

Table 2. Predictive accuracy of the Kansas Water Balance model for soil profile water and grain yield

		Stored soil water (in.) observed at harvest			Grain yield (bu/a)				
						Default		Optimized	
Crop	N	Mean (SD)	RMSE	MBE	Mean (SD)	RMSE	MBE	RMSE	MBE
Wheat	43	14.8 (2.0)	2.5	-0.2	34.0 (22.0)	31.6	-23.6	18.8	-.06
Grain Sorghum	42	15.7 (3.9)	2.0	-0.1	74 (45.0)	26.2	-1.3	27.0	-0.2

Weighting factors representing water deficit effects on yield formation were set to default values or optimized to minimize predictive error.
RMSE = root mean squared error, MBE = mean bias error.

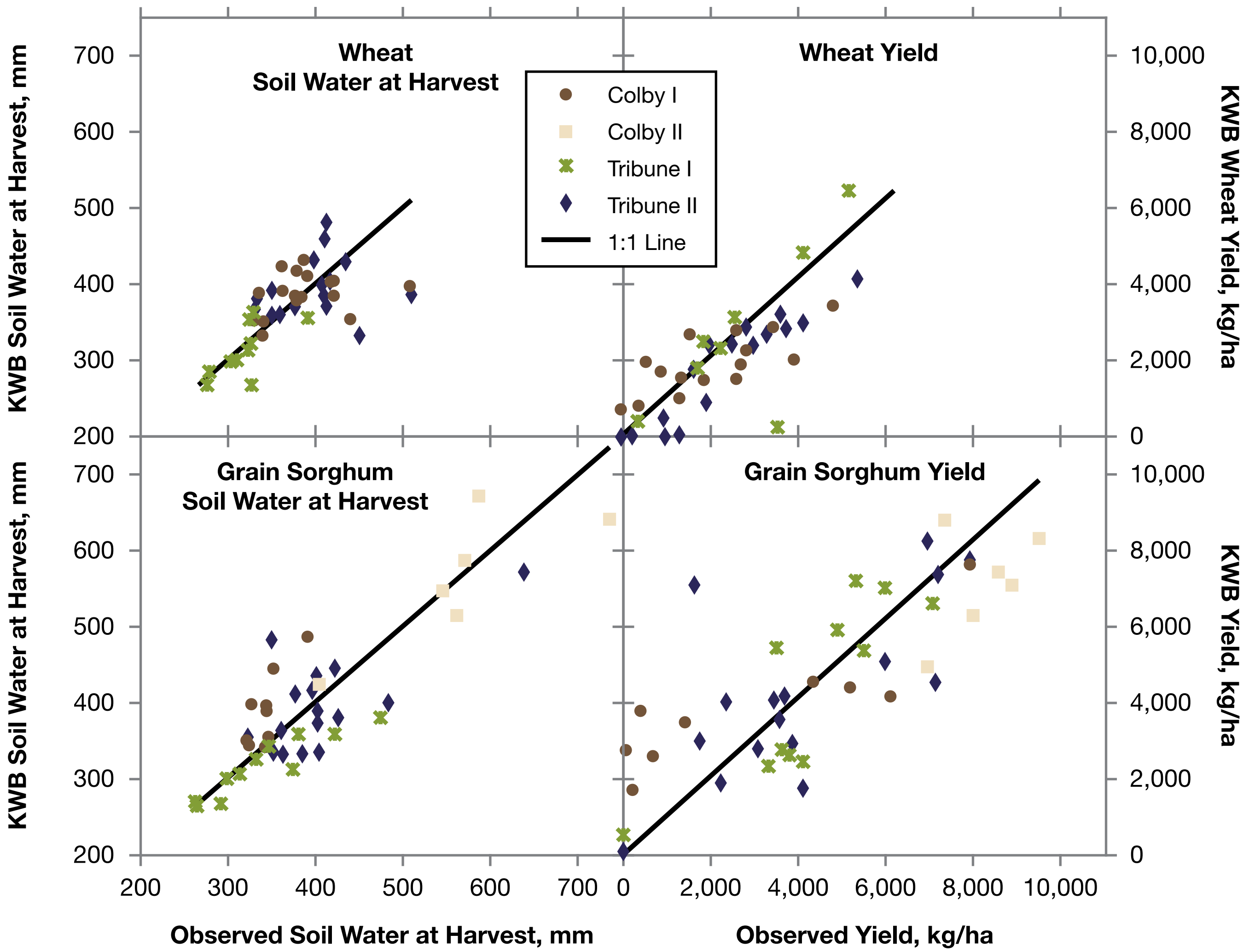

Figure 1. Predicted and observed soil water at harvest and grain yield are depicted for wheat (upper quadrants) and grain sorghum (lower quadrants) as simulated by the Kansas Water Budget.
Optimized weighting factors representing differential effects of soil water deficits were applied to the yield function, with exception of Tribune I wheat, for which default values were applied.