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Assessment of winter wheat production under early sowing with supplemental irrigation in a cold highland environment using CropSyst simulation model

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ABSTRACT

The most important question in supplemental irrigation management is when and how much water to apply. It is a laborious and expensive task to develop supplemental irrigation schedules solely by conventional field experimentation. A cropping system simulation model (CropSyst) was evaluated for its ability to simulate growth, biomass, grain yield and evapotranspiration (ET) of wheat sown early with supplemental irrigation (SI). This was computed under rainfed conditions in a semiarid climate with cold winters in the highlands of Turkey. Experimental data from three growing seasons (1998–2001) were used. The experimental design incorporates Bezostia bread wheat cultivar tested under two main treatments: no irrigation at sowing (rainfed-A_1) and irrigation at sowing with 50 mm of water (A_2); and two sub treatments: rainfed (B_1) and spring supplemental irrigation to replenish the total water requirement at 0–90 cm soil profile (B_2) at the Ankara Research Institute of Rural Services. Crop input parameters were selected from the model documentation and experimental data. A few cultivar-specific parameters were adjusted within a narrow range of typical fluctuations by model calibration. Results showed that CropSyst was able to simulate yield, biomass and evapotranspiration as observed in the field experiments. Overall, the Willmott Index of agreement between simulated and observed values of grain yield, biomass and ET were 0.98, 0.76 and 0.91, respectively. CropSyst model predicted better the seasonal evapotranspiration under full supplemental irrigated conditions (A_2B_2) than under rainfed conditions (A_1B_1), with values of the Willmott index of agreement being 0.97 and 0.89, respectively. The model was run for 20 years (1982–2001) including the 4-year experimental period. Data showed that wheat grain yield could be improved by 15, 19 and 25% with applying only 50 mm of water at the sowing time of 15 October, 1 October and 15 September, respectively. In 80% of the cases, the respective SI applications would give 2.75, 2.7 and 2.95 t ha^{-1}, of the long-term average rainfed yield of 2.1 t ha^{-1}, respectively.

1. Introduction

Central Anatolia Plateau (CAP) is a typical rainfed area. It covers around 10 million hectares of cultivated land and wheat is the major crop. Annual rainfall varies from 250 mm to 500 mm and is below wheat water requirement. Wheat yield, as a result of inadequate rainfall and its suboptimal distribution is low and ranges from 0.9 to 2.5 t ha^{-1} with an average of

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less than 2.0 t ha^{-1}. This is way below the potential yield of over 6 t ha^{-1}.

Supplemental irrigation, i.e., applying limited amounts of water to alleviate drought spells in the raining season, is one way to increase productivity. To improve yield, it is necessary to integrate supplemental irrigation strategy into a comprehensive cropping system approach. However, in CAP region, both surface and groundwater resources are limited. Groundwater is used when the surface water is not sufficient, and mostly in remote areas. Depth to ground water ranges from 80 to 150 m for deep aquifers. Available information shows majority of the farmers (65%) in CAP consider their irrigation applications insufficient for maximizing wheat yield (Oweis et al., 2001). Perrier and Salkini (1991) indicated, however, that farmers tend to over irrigate and that the return for the water in terms of grain is low due to lack of proper scheduling and optimal management of irrigation water. Therefore, the most important question in SI management in CAP region is determining when and how much water to apply (Oweis, 1997). For example, Ilbeyi et al. (2006), indicated that, when early rain was inadequate for crop germination, SI, given at sowing substantially increased wheat yield by more than 65%, adding about 2.0 t ha^{-1} to the average rainfed yield of 3.2 t ha^{-1} at the highlands of Central Anatolia, Turkey. Plants emerging early in autumn, grow more vigorously and develop faster in the following spring than plants which emerge late as subject to frost, leading to higher yields with higher water productivity. Similarly, research results from highlands of Iran has shown that, 1 t ha^{-1} of rainfed yield would be increased to 2.5, 3.0 and 3.5 t ha^{-1} by 1/3, 2/3 and full supplemental irrigation, respectively (Tavakkoli and Oweis, 2004). However, these studies are laborious and expensive tasks to be undertaken by conventional field experimentations. Therefore, crop simulation models are effectively used for filling the gap and outscaling the results.

Cropping system simulation models can be used to predict the effect of weather, soil properties, plant characteristics and management practices on the soil water balance, nutrient dynamics and growth of crops. Therefore, they can enhance our understanding of cropping systems performance under different water and nitrogen regimes. Models may also be used to assess the effects of management practices and plant characteristics on crop performance over a period that is long enough to characterize the climatic variability of a site (van Keulen and Seligman, 1987), leading to improvements in the efficacy of decision-making for fertilizer and water management. However, suitable field experiments are required for model validation, a necessary step before model applications can be developed for a given region (Cabelguenne et al., 1990; Kropff et al., 1994; Lengnick and Fox, 1994).

Cropping Systems Simulation Model (CropSyst) represents an effort to simulate the growth of single crops or crop rotations in response to weather/soil/management scenarios and provide an estimate of environmental impact (Stockle and Nelson, 1994; Stockle et al., 1994). CropSyst is a multi-year and multi-crop daily time step simulation model. It has been developed to serve as an analytical tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil–plant nitrogen budget, crop canopy and root growth, dry matter production, grain yield, residue accumulation and decomposition and erosion. Management options include cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations and residue management.

The water budget in the model includes rainfall, irrigation, runoff, interception, water infiltration and redistribution in the soil profile, crop transpiration, and evaporation. The nitrogen budget in CropSyst includes nitrogen application, nitrogen transport, nitrogen transformations, ammonium sorption and crop nitrogen uptake. The calculation of daily crop growth, expressed as biomass increase per unit area, is based on a minimum of four limiting factors, namely light, temperature, water, and nitrogen. Pala et al. (1996) suggested that minor adjustments of some of these parameters, accounting for cultivar-specific differences, are desirable whenever suitable experimental information is available. Details on the technical aspects and use of the CropSyst model have been reported elsewhere (Stockle et al., 1994; Stockle and Nelson, 1994).

The objective of this study was to evaluate options for improved winter wheat production with early sowing by introducing SI in a semi-arid climate with cold winters and cool springs in the highlands using CropSyst simulation model.

2. Material and methods

2.1. *The experiment*

The data used for model validation was obtained from a field experiment conducted at the Ankara Research Institute of Rural Services (ARIRS) (30°53′N; 32°45′E; elevation: 924 m) during the 1998/1999, 1999/2000 and 2000/2001 seasons (Ilbeyi et al., 2006). The experiment was not specifically designed to

Table 1 – Summary of pre-plant soil test results for ARIRS experimental terrain

Year	Depth (cm)	Total salinity (%)	pH	Lime (%)	Organic matter (%)	Available (kg/ha)	
						P_2O_5	K_2O
1998	0–20	0.07	7.9	28.20	1.66	35.6	744.9
	20–40	0.06	8.0	27.98	1.64	24.4	588.9
1999	0–20	0.08	7.9	24.97	1.64	42.7	807.3
	20–40	0.08	8.0	26.91	1.56	46.1	791.8
2000	0–20	0.09	7.5	28.91	1.45	56.2	772.2
	20–40	0.07	7.7	28.54	1.37	46.8	620.1