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Title: Evaluating GPFARM Crop Growth, Soil Water, and Soil Nitrogen Components for Colorado Dryland Locations

Contributing Scientists: James C. Ascough II, Gale H. Dunn, Daniel B. Palic, Gregory S. McMaster, Allan A. Andales, Lucretia A. Sherrod, Lajpat R. Ahuja, and Neil C. Hansen

Location: James C. Ascough II, Gale H. Dunn, Daniel B. Palic, Gregory S. McMaster, Lucretia A. Sherrod, and Lajpat R. Ahuja, USDA-ARS Agricultural Systems Research Unit, Fort Collins, CO; Allan A. Andales and Neil C. Hansen, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO.

Summary: GPFARM is a farm/ranch decision support system (DSS) designed to assist in strategic management planning for land units from the field to the whole-farm level. This study evaluated the regional applicability and efficacy of GPFARM based on model performance for dry grain yield, total soil profile water content, crop residue, and total soil profile residual NO_3-N across a range of dryland no-till experimental sites in eastern Colorado. Field data were collected from 1987 through 1999 from an on-going, long-term experiment at three locations in eastern Colorado along a gradient of low (Sterling), medium (Stratton), and high (Walsh) potential evapotranspiration. Crop rotation alternatives were winter wheat (Triticum aestivum L.), corn (Zea mays L.), sorghum (Sorghum bicolor L.), proso millet (Panicum miliaceum L.), and fallow. GPFARM simulations generally agreed with observed trends and showed that the model was able to simulate location differences for the majority of model output responses. GPFARM appears to be adequate for use in strategic planning of alternative cropping systems across eastern Colorado dryland locations; however, further improvements in the crop growth and environmental components of the simulation model would improve its applicability for short-term (tactical) planning scenarios.

Introduction

The USDA-ARS Agricultural Systems Research Unit (ASRU) has developed a decision support system named GPFARM (Great Plains Framework for Agricultural Resource Management). GPFARM 2.6 encompasses stand-alone components such as a user interface, simulation model, and databases (Ascough et al., 2002; McMaster et al., 2002; Shaffer et al., 2000) that, when used in conjunction with other components (e.g., farm economic budgeting and multi-criteria decision analysis modules), provide a unique decision support tool for farmers and ranchers. The general purpose of GPFARM is to serve as a whole-farm/ranch DSS for strategic planning across the Great Plains by considering production, economic, and environmental impact analysis, thereby allowing assessment and comparison of alternative agricultural management systems. GPFARM has been evaluated in several different ways, including general farm/ranch testing with producers (i.e., expert opinion evaluation), experimental field plot or scientific testing, and trend analysis. However, further evaluation is needed at a whole-system level to quantify crop yield and water quality model output response, especially for strategic planning under the environmental conditions in the immediate target area of eastern Colorado. In addition, many corrections and enhancements have continued to be made to the GPFARM 2.6 modules. Therefore, the main objective of this study was to evaluate the long-term (i.e., multi-year) performance of GPFARM 2.6 in simulating grain yield, soil water, crop residue, and soil NO_3-N across a north-to-south potential evapotranspiration (PET) gradient in eastern Colorado dryland cropping systems. Additional results and discussion concerning this study are presented in Ascough et al. (2007).

Materials and Methods

GPFARM Simulation Model

The GPFARM DSS is a conglomerate of major components designed to serve as an extensive decision support tool for farmers and ranchers. These components include: (1) a Microsoft Windows-based graphical user interface (GUI); (2) Microsoft Access databases containing soil, crop, weed, climate, chemical, and economic parameters needed in the simulations and analysis of results; (3) an object-oriented modeling framework (Shaffer et al., 2000) that integrates modules for simulating soil water dynamics, N dynamics, crop growth, weed growth, beef cattle production, pesticide transport, and water/wind erosion; (4) a set of management scenario analysis tools (e.g., a multi-criteria decision making model (MCDM), summary report tables, and a stand-alone farm/ranch economic analysis); and (5) an internet-based GPFARM information system (http://infosys.ars.usda.gov) containing numerous links to information on various farm and ranch management options. Modules that are directly related to the model output responses presented in this article include the crop growth module, soil properties module, PET module, water balance module, and C/N cycling module. For a more comprehensive description of these modules and the GPFARM DSS, see Ascough et al. (2002), McMaster et al. (2002, 2003), and Shaffer et al. (2004).

Site Description and Cropping Systems

The long-term sustainable Dryland Agroecosystems Project (DAP) was initiated in 1985 at three sites in eastern Colorado (Sterling, Stratton, and Walsh) to evaluate the effects of cropping intensity on production, water use efficiency, and selected soil chemical and physical properties (Peterson et al., 1993). This experiment has three major variables: (1) PET gradient, (2) topography (slope position), and (3) cropping intensity under no-till management (fig. 1). Soils at each site were under conventional tillage crop-fallow management for at least 50 years prior to the initiation of this study in 1985.

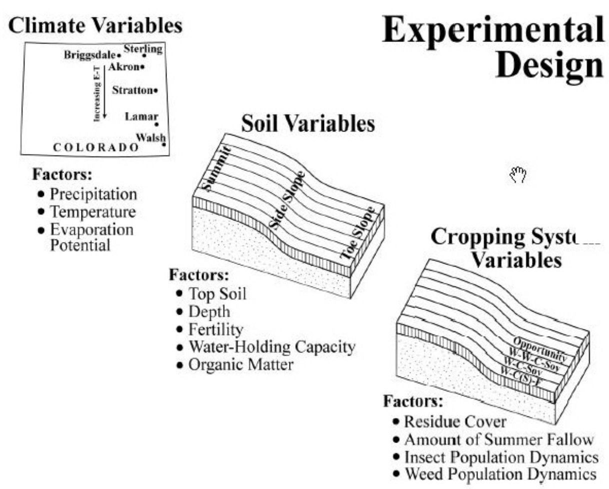

Figure 1. Schematic diagram of the Dryland Agroecosystems Project experimental design with climate, soil, and cropping system variables (from Peterson et al., 2000).

The three sites represent a gradient of increasing PET from north to south, but all have similar long-term mean annual precipitation (ranging from 15 to 17 inches; table 1). The deficit water (i.e., precipitation minus open-pan evaporation) also increased from north to south, with -46, -52, and -63 inches/year^{-}, for Sterling, Stratton, and Walsh, respectively. At each site, a topographic variable is represented by summit, sideslope, and toeslope landscape positions. Each slope position is correlated to a unique soil series common to the geographic area such that nine different soil series are represented across the three sites (Peterson, et al., 1993).

Table 1. Elevation, mean annual temperature, mean annual precipitation, and other climatic properties of the eastern Colorado experimental sites (adapted from Sherrod et al., 2005).

Experimental Site	Elevation (ft)	Mean Annual Temp. (°F)	Mean Annual Precipitation (1961-1990) (in)	Days Above 90°F (days)	Growing Season Open-Pan Evaporation (in)	Deficit Water[a] (in)	Relative Potential Evapotranspiration (PET)
Sterling	4400	49	17	42	63	-46	Low
Stratton	4380	51	16	54	68	-52	Medium
Walsh	3720	54	15	64	78	-63	High

[a] Deficit water = precipitation - open-pan evaporation.

Various cropping systems, representing cropping intensities, were placed in strips across soil series sequences at each site. The cropping systems were wheat-fallow [WF], wheat-corn (or sorghum for the Walsh site)-fallow [WC(S)F], and wheat-corn (or sorghum for the Walsh site)-millet-fallow [WC(S)MF]. Each crop was present in each cropping system every year. The cropping system were as follows: WF had an intensity factor of 0.50 (cropped years divided by total years in the rotation), and the intensity factors for WC(S)F and WC(S)MF were 0.67 and 0.75, respectively. Crops were planted using no-till planters and drills that only disturbed the soil in a narrow band to allow for a seed row. Fertilizer N (32-0-0) and P (10-34-0) were applied based on annual soil tests for available N and P.

Measured Data

Measurements relevant to the evaluation of GPFARM 2.6 included daily weather data, grain yield, soil water content, crop residue, and soil residual NO_3-N. Additional variables were measured (e.g., final dry matter biomass), as described by Peterson et al. (2000), but were not considered in this study. An automated weather station at each site measured daily maximum and minimum air temperature, mean relative humidity, precipitation, total solar radiation, wind direction, and mean wind speed. Grain yield was measured with a plot combine, while total aboveground biomass was measured at harvest by hand sampling. The harvest indices (grain yield/total biomass) were determined from the hand samples. Soil water content (12 inch increments down to a depth of 60 inches) was measured at strategic times (e.g., bi-weekly during summer months) in each cropping system by use of a neutron attenuation probe. Crop residue was measured at planting and immediately before harvest for each crop in each cropping system. Soil residual NO_3-N (at varying increments down to a depth of 60 inches) was measured prior to planting to determine fertilizer N requirements.

Results and Discussion

Grain Yield Evaluation

With the exception of corn yield, model performance was reasonable for long-term mean annual yields between locations (table 2) but was less satisfactory for individual years. Only winter wheat and proso millet were grown at all three locations, with Walsh having significantly lower observed yields than Sterling and Stratton for both crops. Both corn and winter wheat had significantly higher observed yields at Stratton, whereas proso millet yield was significantly highest at Sterling. GPFARM simulations of winter wheat grain yield showed significantly lower yields at Walsh (matching the observed) but could not distinguish statistically ($P \leq 0.05$) between Sterling and Stratton (with simulated yield at Stratton being slightly less than Sterling, the opposite of the observed). Model simulations of proso millet yields could not statistically distinguish between the three locations, although the simulated yield at Walsh was lowest, matching the trend of observed yields being lowest at Walsh. In addition, GPFARM was able to correctly simulate corn grain yield differences between Sterling and Stratton.

Table 2. Evaluation statistics for simulated grain yield, total soil profile water content, crop residue, and total residual soil profile NO_3-N at the eastern Colorado experimental sites.

	Location	Years	Observed Mean	GPFARM Mean
Winter wheat yield			Bu/Ac	Bu/Ac
	Sterling	1989–1999	39	40
	Stratton	1988–1996	45	38

	Walsh	1989–1997	33	32
Corn yield			Bu/Ac	Bu/Ac
	Sterling	1988-1999	68	92
	Stratton	1990-1996	82	109
Proso millet yield			Bu/Ac	Bu/Ac
	Sterling	1988-1992	37	35
	Stratton	1988-1992	34	37
	Walsh	1989-1990	23	29
Sorghum yield			Bu/Ac	Bu/Ac
	Walsh	1988-1997	49	47
Total soil profile water content			inches	inches
	Sterling	1988-1999	11	12
	Stratton	1988-1998	12	13
	Walsh	1988-1998	12	13
Crop Residue			Tons/Ac	Tons/Ac
	Sterling	1988-1999	1.7	1.6
	Stratton	1987-1997	1.6	1.7
	Walsh	1988-1997	1.0	1.4
Total soil profile residual NO_3^-			Lbs/Ac	Lbs/Ac
	Sterling	1988-1999	60	52
	Stratton	1987-1997	70	65
	Walsh	1987-1997	62	46

Soil Water Content, Crop Residue, and Soil Residual NO_3-N Evaluation

GPFARM better simulated trends between locations (both magnitudes and differences) in total soil water content and crop residue than it did for grain yield predictions (with the exception of sorghum grain yield). Similarly, GPFARM correctly distinguished differences in total soil residual NO_3-N between locations but moderately underestimated mean values at all three locations. For total soil profile water content and residual NO_3-N, Stratton had the highest values for both observed and simulated totals (table 2). Sterling had the highest amount of crop residue based on observed data, but GPFARM simulations showed Stratton with the highest amount of crop residue. In simulating differences between locations, GPFARM was able to correctly distinguish statistically significant differences ($P \leq 0.05$) between all locations for both crop residue and total soil profile residual NO_3-N. For total soil profile water content, observed data showed statistically significant differences between Sterling and the other locations, but no difference between Stratton and Walsh (table 2). In comparison, GPFARM predicted statistically significant differences between all locations for total soil profile water content (table 2).

Summary and Conclusions

Compared to other more complex agricultural system models, and considering the intended purpose of GPFARM (i.e., to serve as a whole-farm/ranch DSS for long-term strategic planning across the Great Plains), the model appears to have reasonably simulated average grain yield (with the exception of corn), total soil profile water content, crop residue, and total residual soil profile NO_3-N pooled across landscape positions at the eastern Colorado experimental sites. Overpredictions in corn yield was a result of the inability of the GPFARM crop growth model to correctly respond to soil water deficits at critical growth periods. GPFARM model performance was reasonable for long-term mean annual winter wheat, proso millet, and sorghum grain yield predictions, but was less satisfactory for winter wheat and proso millet on an annual basis (data not shown). GPFARM simulations of total soil water content in the profile were quite reasonable. Crop residue predictions were also very reasonable for Sterling and Stratton, but not as robust at Walsh. Simulated mean values of total residual soil profile NO_3-N were moderately underestimated at all three locations.

GPFARM correctly simulated long-term location differences in corn grain yield, crop residue, and total soil profile residual NO_3-N. Results were mixed on simulated statistical differences in winter wheat grain yield, proso millet grain yield, and total soil profile water content. However, the model correctly predicted that the Sterling and Stratton experimental sites were generally more productive in grain yield than the Walsh site. In general, GPFARM had more trouble simulating location differences for grain yield than for total soil profile water content, crop residue, and total soil profile NO_3-N. Overall GPFARM performed reasonably well in simulating long-term statistical differences among the eastern Colorado dryland locations along an evapotranspiration gradient.

Overall analysis of simulation results using the discrete evaluation statistics shows that GPFARM appears to be adequate for strategic planning of cropping systems across multiple dryland locations, but the simulation model may be lacking in accuracy for predictions on a short-term (tactical) planning basis (especially for grain yield). It is anticipated that improvements in the crop growth and environmental components of the GPFARM simulation model will improve its accuracy for both strategic and tactical applications.

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