Parameterizing GPFARM: An Agricultural Decision Support System for Integrating Science, Economics, Resource Use, and Environmental Impacts

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Abstract: Few farmers and ranchers adopt agricultural software such as decision support systems (DSS). While numerous decision aids are available, most are too difficult for producers to use, exclude components (e.g., economic budgeting, weeds, multicriteria decision analysis) necessary for meaningful use on farms and ranches, and usually suffer from poor understanding by scientists of producer needs and how they process information. The USDA-ARS Great Plains Framework for Agricultural Resource Management (GPFARM) decision support system has been developed that integrates a graphical user interface, data from farms and ranches, soil-plant-weed-water-N-erosion simulation modules, an economic analysis package, and a multicriteria decision making (MCDM) toolbox. The purpose is to assist U.S. Great Plains producers in selecting alternative management scenarios for whole farm and ranch systems that are economically viable and environmentally sound. A major user requirement for GPFARM is to make the DSS as easy and quick to set up and use as possible. This means that plant parameters must be supplied to the user. Developing this parameter database for a large regional area differing in climate, soils, and management practices is made very difficult both by the known genotype by environment interaction (G X E) and the uncertainty in the variability (and distribution) of most parameters. This paper addresses the work, and complications, of creating a crop parameter database focusing on winter wheat (*Triticum aestivum* L.). One important plant parameter (thermal time from sowing to maturity) and predicting grain yield (the result of the entire parameter database) are both examined from the perspective of the G X E interaction. Some conclusions drawn from this analysis are: 1) for both thermal time and yield, the relative rankings of varieties were not consistent whether considering within or between treatments across years, showing the difficulty of simulating the G X E interaction, and 2) selected parameters must be set for at least dryland and irrigated conditions to better capture the G X E interaction.

Keywords: Decision support systems; Modeling; Parameterization, Plant genotype

1. INTRODUCTION

Agricultural software developers are increasingly producing products (e.g., decision support systems, simulation models, budgeting, record keeping, irrigation/N/weed control management) for use by farmers and ranchers. Unfortunately, few producers adopt these products, especially the decision support systems (DSS) and simulation models [Ascough et al., 2002]. There are many reasons for this including missing components needed by the producer (e.g., economic budgeting, weeds, multicriteria decision analysis for sorting through the information created for the producer), lack of integration between agricultural enterprises (e.g., cropping and rangeland systems), and poor understanding by scientists of the needs of producers and how they process information. However, perhaps the most important reasons are that these products are viewed as too difficult to use and the investment of time and effort to learn, set up, and run the software is not returned in value to the producer.

Prior to initiating the GPFARM (Great Plains Framework for Agricultural Resources) DSS, we tried to identify the requirements of the principal users, farmers and ranchers, for a DSS that would address strategic planning for their entire enterprises and each management unit (e.g., selecting cropping or rangeland systems, best management practices) to maximum economic return and sustainability. User requirements were identified by meeting with producers, conducting a survey of 800 producers and consultants in the Great Plains [Ascough et al., 1999;2002], working directly with producers on their farms and ranches, and building on our prior experience in building simulation models and DSS.

Developing a comprehensive DSS such as GPFARM for complex agricultural systems presents many difficulties including adequately evaluating the DSS and reducing the time and effort to learn, set up, and run the DSS. It was clear from the beginning the crop growth model used to simulate plant growth and yield had to be both simple to use and robust enough to cover the Great Plains, U.S.A. where different species and varieties are grown in vastly differing environments and management practices. Further, we would need to provide a default crop/variety database required to simulate plant growth for the user.

Adequately determining plant parameters for simulation models and DSS has been a major obstacle in successfully releasing these products. Some projects have attempted to collate a set of parameters for species and varieties, but generally these are both incomplete and do not deal adequately with the genotype by environment (G X E) interaction. Research efforts to use functional genomics are beginning, but are at the infancy stage and much work remains before this approach is useful for software such as GPFARM.

Breeders have long known of the reality of the G X E interaction, and indeed this is why yield trials are located across sites and years. The genotype can be viewed on either the species or variety level, and for purposes of this paper we will focus on the variety level. Farmers normally select varieties based on at least two criteria: 1) varieties "best-adapted" for the region based on their specific site conditions; and 2) specific management practices being used (e.g., different varieties used for dryland vs. irrigated conditions). The problem is that we are using a simple plant growth model in GPFARM that provides a default crop parameter set where parameters are only distinguished among species. The plant growth model in GPFARM uses the normal approach that specific species parameters are changed to reflect varietal differences, if known. But given that for a crop such as wheat, with over 100,000 lines, it is unrealistic to provide a default database covering differences between lines, new lines are continually being introduced, and there is still the G X E interaction problem. An essential implication of the G X E interaction is that as the environment changes, genotypes do not respond in the same manner. Crop models, especially the simpler ones, do not simulate this reality. Rather, they assume that as a parameter controlling the rate or timing of a process is changed, all genotypes have the same response pattern across all environments. This then leads to the question of how accurately does a species-based parameter set predict crop yield in decision support systems such as GPFARM? Are varietal parameters in some form required to accurately simulate yields?

This paper describes preliminary results of work related to developing plant-related parameters needed for predicting crop yield by the GPFARM DSS. Specifically, we address two aspects of the G X E interaction problem for winter wheat: 1) we examine a specific parameter, the thermal time from planting to maturity, and 2) we evaluate entire crop-related parameter databases for yield prediction.

2. GPFARM 2.0 DSS OVERVIEW

GPFARM 2.0 encompasses three stand-alone components that, when used in conjunction with other components (e.g., environmental impacts assessment module, GIS spatial visualization module, and multicriteria decision support module) provide a unique decision support tool for farmers and ranchers [Ascough et al., 2001; McMaster et al., 2002]. The first stand-alone component is a computer model that simulates crop and animal (beef cattle) growth, soil water movement, nitrogen cycling and transport, weed growth, pesticide transport, and water/wind erosion. The second component is an economic analysis tool, capable of taking yield and cost data from the simulation model or directly from user input and providing a detailed economic analysis. The third stand-alone component is an agricultural information system. This WWW-based system contains links to information on crops and crop pests, livestock and livestock pests, agricultural chemicals, and other agriculture-related topics.

Graphical User Interface. Continued extensive effort is being directed towards working with farmers and ranchers to simplify the interface and address how they process information.

Economic model. The stand-alone economics model was developed specifically for GPFARM in collaboration with agricultural economists at Colorado State University, Fort Collins, Colorado, USA. It is intended to capture all costs and returns of crop and rangeland production (by management unit, field, or whole farm/ranch). Farm/ranch enterprise budgeting procedures are completed by the user and merged with other user-supplied information to calculate gross income, total costs, and net returns. Users can perform a breakeven analysis or view enterprise budget reports that show costs vs. returns on the whole enterprise, individual management unit or crop, or by year. Detailed economic analysis also is available for machine, labor, financial, animal, and materials input.

GPFARM science computer model consists of modules within an object-oriented framework [Shaffer et al., 2000]. The main modules of GPFARM are briefly discussed below. Some modules were incorporated from existing agricultural water quality models and modified to varying degrees, while other modules were developed specifically for the GPFARM DSS.

Rangeland system module. This new module simulates pasture and beef cattle dynamics on rangeland systems. Daily production of five plant functional groups is simulated: cool-season grasses (C_3), warm-season grasses (C_4), legumes, forbs, and shrubs. All functional groups respond to soil moisture and temperature. Herd dynamics and growth are simulated for five classes of animals: mature cows, heifers, female and male calves, and bulls. Bulls are managed as a second herd, and forage consumption and daily weight gain or loss are estimated by the model. The percent of replacement heifers and culls retained or sold each year are user-defined. Calf crop is determined by the number of bulls and duration of time bulls are with open cows. Cattle nutritional needs can be met by either supplemental feed using a least-cost ration approach or forage from the pasture. The user controls all management activities such as calving dates, rotation among pastures, and the buy/sell dates of livestock.

Weed module. This is a newly developed module. Both the effects of weed pressure levels on final crop yield and the weed population dynamics as affected by management and competing crop are simulated. Fifteen annual weed species (and also herbicide resistant forms if known) are parameterized in default databases for the weed-crop interactions.

C and N cycling module. This module is based on the NLEAP model [Shaffer et al., 1991]. Submodules simulate soil C and N cycling and surface residue. Residues decay to form soil organic matter and mineralization, immobilization, nitrification, ammonia volatilization, and denitrification are simulated.

Water balance module. This module is a simplification of the RZWQM water balance routines [Ahuja et al., 2000], and uses a coarser time step between precipitation events to determine soil water fluxes. The daily water budget and chemical balance module simulates the soil water content of each soil layer based on precipitation, surface runoff, ET, and snow water content. Soil hydraulic properties are adjusted due to tillage, residue cover, soil crust, and soil macropore presence. Upward flux from water tables and restrictive soil layers on water and chemical leaching is simulated.

Water erosion module. For cropland, the water erosion module is based on the CREAMS erosion model [Knisel, 1980]. Characteristics of rainfall and runoff factors for each storm are used to simulate particle detachment and sediment transport. For rangelands, the module is based on the work of Lane et al. [1988] and uses distributed canopy and ground cover down the hillslope to estimate management effects on soil erosion. A quasi-steady state is assumed and sediment movement downslope obeys continuity of mass.

Environmental impacts module. In this module, nitrate and pesticides are co-transported with water with possible retardation from soil adsorption.

Crop Growth Module. This module is based on the crop growth module of the WEPP simulation model [Arnold et al., 1995] which is a modified version of the EPIC crop growth submodel [Williams et al., 1989]. The module uses concepts of daily accumulated heat units; harvest index for partitioning grain yield; Monteith=s approach for determining potential biomass [Monteith, 1977]; and water, N, and temperature stress adjustments to daily growth. Crop/variety-specific parameters are kept in a default database to simulate daily growth. Currently GPFARM is parameterized for winter wheat, maize (*Zea mays* L.), sunflower (*Helianthus annuus* L.), sorghum [*Sorghum bicolour* L. (Moench)], proso millet (*Panicum miliaceum)*, and foxtail/hay millet (*Setaria italica*).

3. PARAMETERIZING CROP GROWTH MODULE

3.1 Setting crop parameters

The crop growth model requires a number of plant-related parameters such as the thermal time from sowing to emergence and maturity, base temperature, optimal temperature, harvest index, radiation use efficiency, maximum LAI, etc. The beginning parameter data set for winter wheat was derived from default parameters from the EPIC/ALMANAC/SWAT/WEPP projects [Arnold et al., 1995] that all use the EPIC plant growth model as the foundation.

Parameters were then adjusted based on literature, data, and theory for winter wheat varieties grown in the West Central Great Plains. For instance, the thermal time from sowing to emergence and maturity was corrected for our varieties and conditions and the more commonly used base temperature of 0°C was used rather than the default 4°C base temperature. Since water stress clearly reduces the thermal time for winter wheat to reach maturity [McMaster, 1997], different default values were evaluated depending on dryland or irrigated conditions. This was tried because the simulation model does not account for any corrections to the thermal time based on environmental factors such as photoperiod, water/N levels, CO_2, etc.

3.2 Testing parameters

The primary data set used to evaluate crop parameters was based on a two-year study conducted at the Colorado State University ARDEC farm (denoted ARDEC) and initiated in 1999. Twelve winter wheat varieties differing in heat and drought tolerance were grown under two treatments: dryland and irrigated. Most varieties are commonly used in this region, but several are adapted to other environments (e.g., Norstar, Siouxland). Experimental design was a split-plot with dryland/irrigation the main-plot factor and variety the subplot (four replications).

The second data set used was based on the long-term Dryland Agroecosystems Project for 3 sites in eastern Colorado initiated in 1986 (denoted DAP). Different rotations (e.g., wheat-fallow, wheat-corn-fallow, wheat-corn-millet-fallow) were grown under no-tillage management at different topographic positions of a catena.

4. RESULTS AND DISCUSSION

4.1 Thermal time from sowing to maturity

Thermal time from sowing to maturity is known to vary considerably among varieties and among locations (with water stress being a primary factor; [McMaster, 1997]). Both Figures 1 and 2 show genotype variation within the same location for two different environmental conditions (dryland and irrigated). Clearly more thermal time is required to reach maturity under irrigated conditions (244.9 and 280.6 GDD for 1999-00 and 2000-01, respectively, with all varieties pooled). Pooled means differed between years: 390 GDD for dryland and 354 GDD for irrigated. Within a year and treatment, varieties differed in their thermal time by 142.9 (dryland, 2000-01), 190.4 (irrigated, 1999-00), 227.2 (irrigated, 2000-01), and 293.4 (dryland, 1999-00) GDD. Model parameters used (based on other data sets) were slightly high in 1999-00 and much too high for 2000-01. Changing the parameters based on dryland or irrigated conditions resulted in the best results rather than just using one value.

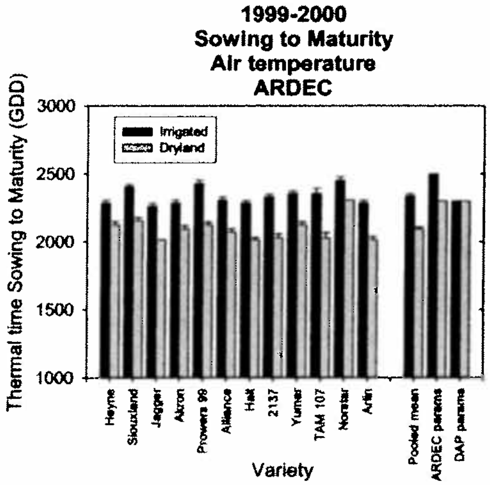

Figure 1. Observed thermal time from sowing (with 1 SE bar) to maturity for 1999-2000 at ARDEC for dryland and irrigated treatments compared to parameters used for simulation. Simulated values are the two rightmost sets of bars. Thermal time uses air temperature for calculating growing degree-days with 0°C base temperature.

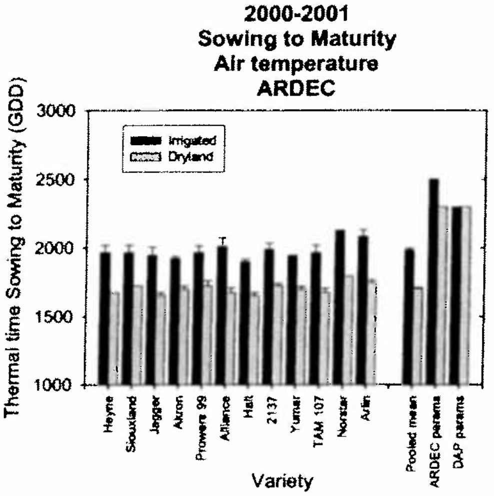

Figure 2. Observed thermal time from sowing (with 1 SE bar) to maturity for 2000-2001 at ARDEC for dryland and irrigated treatments compared to parameter used for simulation. Simulated values are the two rightmost sets of bars. Thermal time uses air temperature for calculating growing degree-days with 0°C base temperature.

4.2 Grain yield

Simulating grain yield is the result of the entire parameter dataset selected, and when different parameter datasets are compared (e.g., original default parameters from EPIC/WEPP/SWAT, calibrated for DAP validation dataset, and calibrated for the ARDEC validation dataset), mixed results are obtained (Figs. 3 and 4).

Genotypes varied with years and two different environmental conditions (dryland and irrigated). As expected, irrigated yields were higher than dryland yields, but genotypes did not maintain the same percent yield loss rankings to water stress between years (data not shown), which confirms the significant G X E interaction, and most disturbingly, the difficulty in simulating this interaction.

An improvement to using only one value per parameter to represent all varieties over all environmental conditions can be obtained by modifying certain parameters based on dryland or irrigated conditions. This improvement is reduced as the genotype being simulated increasingly differs from the genotype that is parameterized, and as environmental conditions deviate from "normal".

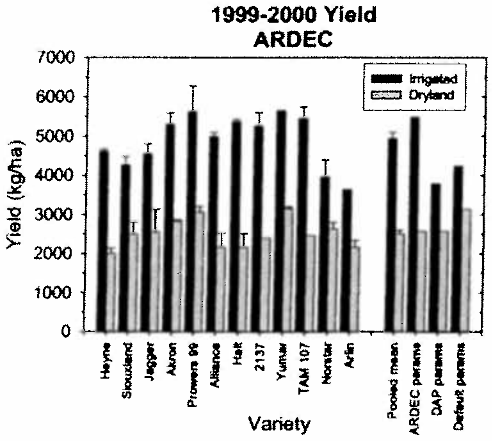

Figure 3. Observed grain yield (with 1 SE bar) for 1999-2000 at ARDEC for dryland and irrigated treatments compared to simulated grain yield for different parameter data sets. Simulated values are the three rightmost sets of bars.

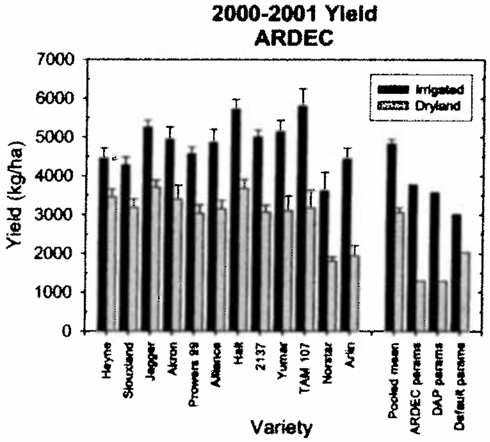

Figure 4. Observed grain yield (with 1 SE bar) for 2000-2001 at ARDEC for dryland and irrigated treatments compared to simulated grain yield for different parameter data sets. Simulated values are the three rightmost sets of bars.

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