Computers and Electronics in Agriculture 77 (2011) 118–125

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Application note

# PhenologyMMS: A program to simulate crop phenological responses to water stress

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ARTICLE INFO

*Article history:*
Received 6 June 2010
Received in revised form 29 March 2011
Accepted 11 April 2011

*Keywords:*
Simulation model
Decision support systems
Crop development
Growth stages
Crop management
Seedling emergence

ABSTRACT

Crop phenology is fundamental for understanding crop growth and development, and increasingly influences many agricultural management practices. Water deficits are one environmental factor that can influence crop phenology through shortening or lengthening the developmental phase, yet the phenological responses to water deficits have rarely been quantified. The objective of this paper is to provide an overview of a decision support technology software tool, PhenologyMMS V1.2, developed to simulate the phenology of various crops for varying levels of soil water. The program is intended to be simple to use, requires minimal information for calibration, and can be incorporated into other crop simulation models. It consists of a Java interface connected to FORTRAN science modules to simulate phenological responses. The complete developmental sequence of the shoot apex correlated with phenological events, and the response to soil water availability for winter and spring wheat (*Triticum aestivum* L.), winter and spring barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), proso millet (*Panicum milaceum* L.), hay/foxtail millet [*Setaria italica* (L.) P. Beauv.], and sunflower (*Helianthus annus* L.) were created based on experimental data and the literature. Model evaluation consisted of testing algorithms using "generic" default phenology parameters for wheat (i.e., no calibration for specific cultivars was used) for a variety of field experiments to predict developmental events. Results demonstrated that the program has general applicability for predicting crop phenology and can aid in crop management.

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## 1. Introduction

Phenology, or the relationship between climate and the sequence and timing of developmental events or stages, provides a foundation for understanding crop development and growth. Farmers increasingly are basing management on crop developmental stages to enhance economic crop yields while maintaining environmental quality. For instance, as non-agricultural demand for water increases in many arable lands, timing limited irrigation water with critical developmental stages to maximize yield is receiving much interest. Of similar importance, accurate prediction of developmental stages is needed in crop simulation models and decision support aids. Fortunately, a long history of research in plant development and phenology has created a significant understanding and ability to predict developmental events. This is founded on the fundamental concept that plant development is orderly and predictable (Rickman and Klepper, 1995; McMaster, 2005). The genetics of the plant determines the pattern of development, and environmental conditions (e.g., temperature, photoperiod, nutrients, and water availability) can alter the developmental rates.

Several deficiencies remain in accurately predicting phenology in variable environments and management systems. One deficiency is that considerably less research has examined the impacts of water deficits (degree, timing, and history) on crop phenology (McMaster et al., 2009), despite the obvious influence of water deficits on some developmental phases (e.g., germination, emergence, grain filling). Further, phenological responses to water deficits vary among crops, cultivars, and developmental events. With few exceptions (e.g., SHOOTGRO, Zalud et al., 2003), crop phenology simulation models do not explicitly consider the influence of water deficits on phenology. Simulation models with more detailed energy balance submodels (e.g., ecosys, Grant et al., 1995; STICS, Brisson et al., 2003) can somewhat address phenological responses to water deficits by estimating and using plant temperature rather than air temperature, yet plant temperature alone will not necessarily predict phenological responses to water deficits correctly (McMaster et al., 2009). Without fundamental knowledge of development and quantification of phenological responses to water deficits for specific crops, a suitable foundation does not exist to

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0168-1699/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.compag.2011.04.003

predict crop development under variable environmental conditions to scientists, producers, and other practitioners. Such a foundation to transfer knowledge would also aid in developing decision support technologies and parameterization of crop models such as EPIC (Williams et al., 1989), ALMANAC (Kiniry et al., 1992), and GPFARM (McMaster et al., 2002a, 2003a; Ascough et al., 2007). In addition, mechanistic models for certain crops with detailed phenology submodels such as DSSAT (Jones et al., 2003), APSIM (McCown et al., 1996; Keating et al., 2003), and SHOOTGRO (McMaster et al., 1992b; Zalud et al., 2003) could improve their ability to simulate the effects of environmental factors such as limited soil water.

The objective of this paper is to provide an overview and basic statistical evaluation of the Phenology Modular Modeling System (PhenologyMMS) decision support technology software tool developed to simulate the phenology of various crops for different levels of soil water. In providing this overview, the PhenologyMMS Java-based interface and the general science behind the decision support software are briefly described.

## 2. Materials and methods

### 2.1. Overview of PhenologyMMS decision support software

The stand-alone PhenologyMMS V1.2 software tool consists of a Java interface integrated with FORTRAN modules to simulate phenological responses and has three primary goals: (1) to aid in adoption by a variety of users, the stand-alone program needs to be as simple as possible with minimal information or calibration required by the user; (2) to facilitate incorporation into other crop simulation models, standard programming practices and modularization approaches are incorporated into the design and programming of the process-based science modules; and (3) to serve as a learning tool, information is provided on crop phenology. The user interface has a series of screens to provide default inputs and parameters that can be modified by the user, runs the science modules to predict the occurrence of specific developmental stages, and allows users to view output results. Access to information such as the developmental sequence diagrams of crops, growth staging scales, and supporting documentation is accessed through the interface system and help buttons.

### 2.2. Interface

The user begins by selecting the crop (Choose Crop button) and weather file (Choose Location/Weather File button) for a site or loading a previously created scenario (Load Scenario button) as shown in the Begin Setup screen (Fig. 1). After selecting a crop, a "generic" cultivar is assumed as the default for each species. At this point, the user can then run the program by accepting all default inputs and parameters (although generally not recommended), or continue to modify other inputs. Crops currently simulated in PhenologyMMS V1.2 are winter and spring wheat, winter and spring barley, corn, sorghum, proso millet, hay/foxtail millet, and sunflower. Historical weather data for a variety of sites in the Great Plains, USA are provided (ASCII format), but users may create their own weather files if desired. When creating user weather files, the file structure of a provided weather file should be used, and daily maximum and minimum air temperature (in °C) and precipitation (in mm) need to be provided. Once the crop and site weather file have been chosen in the Begin Setup screen (Fig. 1), users may accept the defaults in the Set Inputs screen (Fig. 2) or change them if desired. The "Set Inputs" screen is accessed by the button in the Begin Setup screen. Initial inputs are set for each crop when the crop is selected, however, certain agronomic practices such as

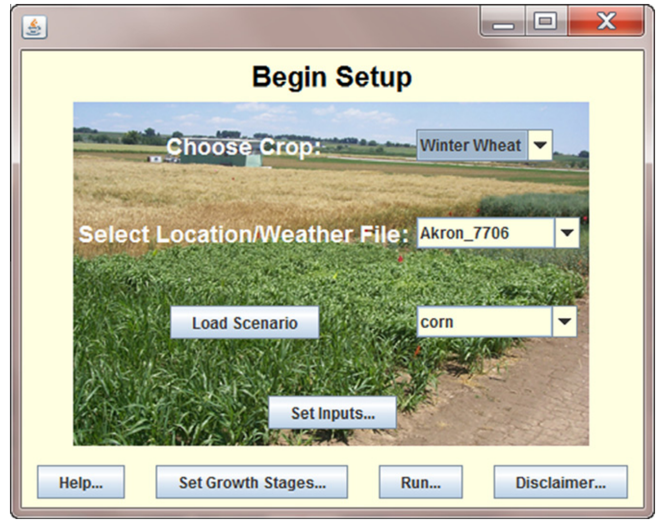


**Fig. 1.** Begin Setup screen. This screen is the first screen the user views when entering PhenologyMMS.

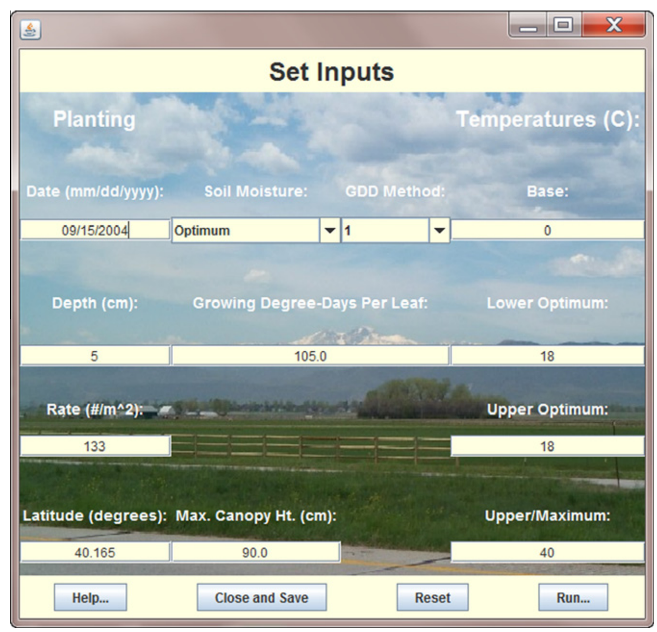


**Fig. 2.** Set Inputs screen. Example of initial inputs needed for the simulation model, with default values for winter wheat grown in northeastern Colorado, USA.

planting date vary by region and the defaults are set for northeastern Colorado, USA. Model inputs include latitude; planting practices; soil moisture condition; method for calculating thermal time as represented by growing degree-days (°C day; GDD); base, optimal, and upper/maximum temperatures; and rate of leaf appearance.

Fig. 3 shows a key screen needed for the FORTRAN process-based modules that is accessed from the "Set Growth Stages" button of the Begin Setup screen. If the default generic cultivar is not desired, limited varietal information is available and may be selected with the "Variety" button at the bottom of the screen. The general layout of the "Set Growth Stages" screen is similar for all crops. A series of rows represent different developmental phases specifically identified for each crop, with default values that can be changed by the user for each of four options (i.e., columns) to be used to simulate the growth phases: