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# Unified Plant Growth Model (UPGM). 1. Background, objectives, and vision

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# Unified Plant Growth Model (UPGM). 1. Background, objectives, and vision.

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**Abstract:** Since the development of the Environmental Policy Integrated Climate (EPIC) model in 1989, the EPIC-based plant growth code has been incorporated and modified into many agro-ecosystem models. The goals of the Unified Plant Growth Model (UPGM) project are: 1) integrating into one platform the enhancements from the multiple EPIC-based plant growth models, 2) further enhance the integrated UPGM model, and 3) develop a component that can be more easily linked into other agroecosystem models such as the Wind Erosion Prediction System (WEPS) and Agricultural Ecosystem Services Model (AgES). This talk discusses Objectives 1 and 2; Objective 3 is covered in Part 2. The Wind Erosion Prediction System (WEPS) model was chosen as the base platform for UPGM for many reasons including it was the most extensively modified of the EPIC-based plant code. Once the standalone UPGM component was created in Fortran 90/95, the phenology, seedling emergence, and plant height algorithms from the Phenology Modular Modeling System (PhenologyMMS) were added and tested for unstressed conditions. The UPGM component was also incorporated into the Java-based AgES model and has been tested for a range of environments. A number of issues were identified including: 1) much better linkage between the PhenologyMMS and WEPS algorithms (e.g., improving the partitioning among plant fractions) was needed, and 2) a redesign of the UPGM component was needed for easier incorporation into other agro-ecosystem models. Development of the standalone UPGM component prototype shows promise for incorporation into other agroecosystem models, and provides greater opportunity for scientists to improve or add specific algorithms in their areas of interest.

***Keywords**:* Agro-ecosystem modeling; Crop modeling; Component development; Phenology; Seedling emergence.

## 1. INTRODUCTION

Since the development of the Environmental Policy Integrated Climate (EPIC) model in 1989 (Williams et al., 1989), the EPIC-based plant growth code has been incorporated and modified into many agro-ecosystem models including the Wind Erosion Prediction System model (WEPS; Hagen, 1991; Wagner, 1996; 2013), the Soil and Water Assessment Tool model (SWAT; Arnold et al., 1995; Nietsch et al., 2009), the Water Erosion Prediction Project model (WEPP; Flanagan et al., 1995), the Agricultural Land Management Alternatives with Numerical Assessment Criteria model (ALMANAC; Kiniry et al., 1992), and the Great Plains Framework for Agricultural Resource Management model

(GPFARM; Ascough et al., 2007; McMaster et al., 2003). Modifications of the EPIC plant growth component addressed perceived shortcomings in model science or specific research needs of the models. Implementation of the EPIC plant growth component in various models has resulted in similar plant growth models, yet they differ in inputs, required parameters, and approaches for simulating specific processes. The differences among the EPIC-based plant growth components cause problems such as 1) user understanding of differences among the plant growth components is hindered, 2) improvements in one plant growth component have not been included in the other models, and 3) adding or enhancing an algorithm in one plant growth component is not readily done in other models as the model structures differ.

As a result, the goals of the Unified Plant Growth Model (UPGM) are: 1) integrate into one platform the enhancements from the multiple EPIC-based plant growth models, 2) further enhance the integrated UPGM model, and 3) develop a component that can be more easily linked into other agroecosystem models such as the Wind Erosion Prediction System (WEPS) and Agricultural Ecosystem Services Model (AgES, Ascough et al., 2012).

The objectives of this paper are to: 1) briefly describe the standalone UPGM plant growth component, and 2) present some evaluation results of enhancements added to UPGM and lessons learned. The companion Part 2 paper (Fox et al., 2018 Unified Plant Growth Model (UPGM). 2. Component development and integration with agroecosystem models. iEMSs paper #3982) will discuss efforts to develop a component that can be more easily linked into other agroecosystem models.

## 2. MATERIALS AND METHODS

### 2.1 UPGM component description

The initial task was to extract the EPIC-based plant growth component from the WEPS model into a standalone Unified Plant Growth Model (UPGM; McMaster et al., 2014a; 2014b) to serve as the model platform for reaching our long-term goal. We chose the WEPS model because: 1) plant growth processes are simulated in greater detail than other EPIC-based plant growth components, and 2) adding the WEPS changes into the other EPIC-based models would be more difficult than the reverse. Since WEPS was written in Fortran, we maintained this language but restructured the code to Fortran 90/95.

Once the UPGM standalone platform was developed, three new sub-models that we hypothesized would improve the WEPS plant growth model were incorporated and several model enhancements added from other EPIC-based plant components. These changes include:

1) Adding a new phenology sub-model. This sub-model was based on earlier work from the SHOOTGRO model (McMaster et al., 1992; Zalud et al.,2003) and PhenologyMMS decision support system (McMaster et al., 2011, 2013). This sub-model addresses two concerns in the EPIC-based plant simulation model: a) the lack of simulating important developmental stages (e.g., start of reproductive primordium initiation, anthesis/flowering, and stages for the beginning and ending leaf growth and appearance and stem growth), and the phenological response to varying water deficits.

2) Adding a new seedling emergence sub-model. This sub-model was based on earlier work from the SHOOTGRO model (McMaster et al., 1992; Zalud et al.,2003) and PhenologyMMS decision support system (McMaster et al., 2011, 2013). This sub-model addresses the concerns in the EPIC-based plant simulation model that if seedling emergence is simulation (not all do), seedling emergence does not respond to varying levels of soil moisture in the seedbed zone.

3) Adding a new canopy height sub-model. This sub-model was based on earlier work from the PhenologyMMS decision support system (McMaster et al., 2011, 2013). This sub-model is similar to that used in WEPS, but uses the phenology sub-model to predict the period when stem elongation is occurring. Canopy height in both WEPS and this sub-model responds to varying water deficits (not all EPIC-based plant components do).

4) Adding plant N stress. This was necessary since WEPS did not simulate plant N stress that was part of most EPIC-based plant components. Concepts/code from EPIC/SWAT were re-incorporated into UPGM.

5) Adding $CO_2$ response. Code from the SWAT plant component were incorporated to simulate $C_3$ and $C_4$ plant photosynthesis/growth and stomatal/ET responses to varying levels of $CO_2$.

Because the UPGM standalone plant growth model did not have water or nitrogen balance routines, and as an initial test of incorporating the UPGM component into another agro-ecosystem model, we linked UPGM with the AgroEcoSystems Services Model (AgES) model (Ascough et al., 2012, McMaster et al., 2014a). AgES is a component-based model for simulating soil-plant-water-nutrient processes in a spatial context. An initial benefit of linking UPGM with AgES is that this allows us to test three EPIC-bases plant components: SWAT (the original model in AgES), WEPS, and UPGM.

**2.2 Data sets for model evaluation**

Many data sets have been used to develop and evaluate the UPGM, WEPS, and SWAT plant components, however, two main data sets relevant to this paper for testing the phenology sub-model are: 1) the Greeley Irrigated experiment, and 2) the Drake Farm dryland landscape experiment. Brief overviews of each experiment are provided below.

1) Greeley irrigation experiment. This experiment was conducted at the USDA-ARS Limited Irrigation Research Farm (LIRF) located near Greeley, CO USA (40˚26'50"N, 104˚38'12"W, 1425 m elevation), which receives approximately 250 mm of annual precipitation. Soils are predominately Olney fine sandy loam with Otero sandy loam in small areas. Drip irrigation was used for precise control of irrigation. Experimental treatments consisted of dryland (Dry), fully irrigated (Wet), and irrigation treatments only at the jointing (J), anthesis (A), or jointing and Anthesis (J+A). Twenty-four winter wheat varieties were grown in each treatment.

2) Drake Farm winter wheat dryland landscape experiment. This experiment started in 2001 on a farm field (40.61 N, 104.84 W, elevation range 1559-1585 m) located east of Fort Collin and west of Ault, CO USA (four years of phenological data are presented here). Annual precipitation is approximately 250 mm. The field is approximately 100 ha, with topographic undulations and soil variation (Green et al., 2009). The soils include Wagonwheel coarse silty loam (a course-silty, mixed, superactive, mesic Aridic Calcuistept), Colby fine silty loam (a fine-silty, mixed, superactive, calcareous, mesic Aridic Ustorthent), and Kim fine sandy loam (a fine-loamy, mixed, active, calcareous mesic Ustic Torriorthent). Slopes at the phenology sites within the field vary from 0.65 to 8.4% and aspects range from 26 to 209$^o$ clockwise from north. Further details are provided in McMaster et al. (2012).

**3. RESULTS AND DISCUSSION**

The SWAT and WEPS models have been extensively used and evaluated for a wide variety of conditions and crops and will not be discussed here. Rather, a major emphasis of this paper is to show some results testing our hypothesis that adding a new phenology sub-model which responds to varying water deficits to UPGM would result in more accurate simulations of phenology. While one benefit of the new phenology sub-model is the ability to simulate nearly all developmental stages of a crop (Figure 1 gives an example of some stages for winter wheat), testing this hypothesis is limited to very few stages that are simulated in SWAT and WEPS. Comparisons between the three models for simulating the start of canopy senescence and physiological maturity for winter wheat under varying water deficits showed an improvement of UPGM over SWAT and WEPS (Figures 2 and 3). A large part of this improvement by UPGM is expected because SWAT and WEPS do not respond to varying water deficits, so differences between fully irrigated (Greeley Wet) and dryland (Greeley Dry) treatments were not captured.

Other data sets and evaluation (e.g., McMaster et al., 2014 for unstressed corn) show similar results in simulating phenology, and also show that seedling emergence and canopy height are simulated more accurately than SWAT and WEPS.

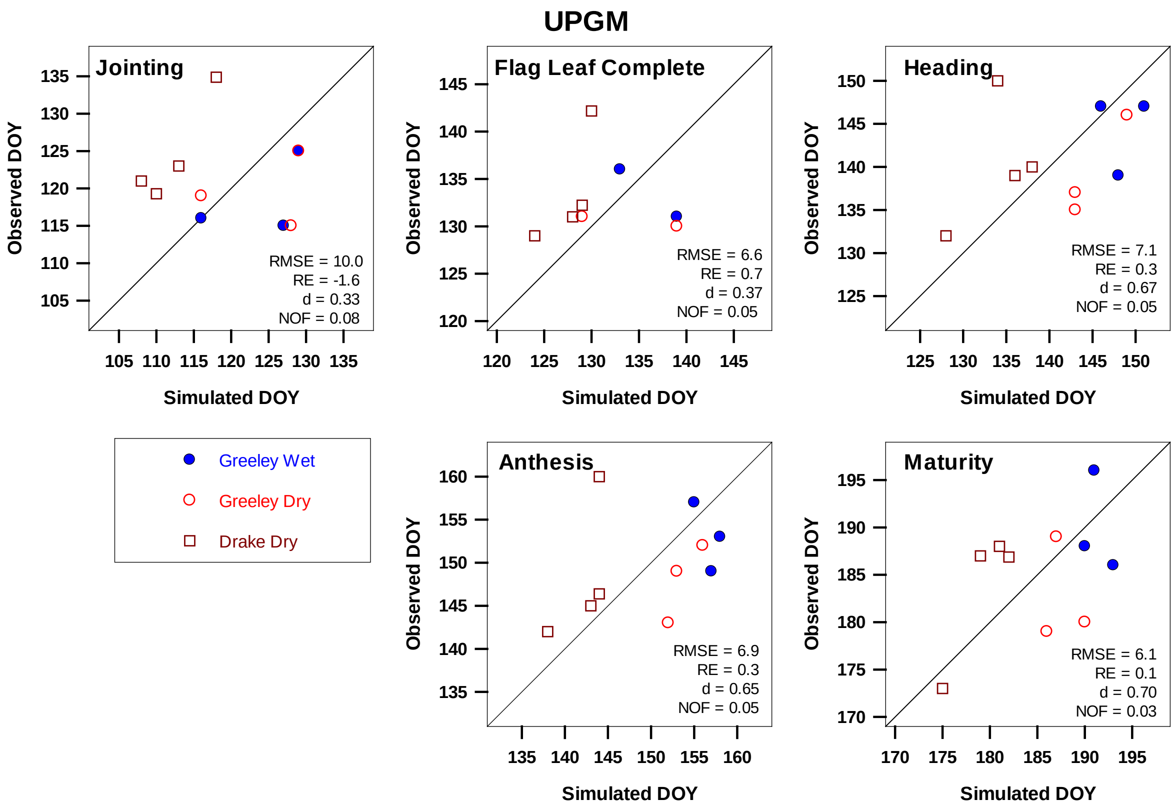


**Figure 1.** Simulating five developmental stages of winter wheat by the UPGM plant component in the Agro-Ecosystem Services (AgES) model. Default parameters were used for all models. The "Greeley" data set is for fully irrigated (Wet) and dryland conditions (Dry); Drake data set is for a dryland experiment in a small watershed

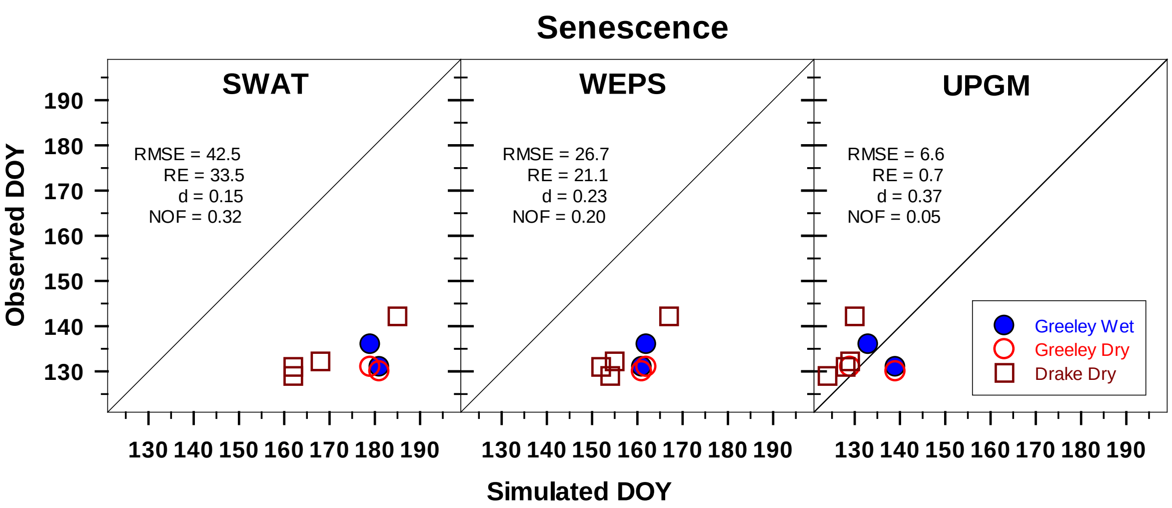


**Figure 2** Simulation of winter wheat canopy senescence by three plant growth components (SWAT, WEPS, and UPGM) in the Agro-Ecosystem Services (AgES) model. The "Greeley" data set is for fully irrigated (Wet) and dryland conditions (Dry); Drake data set is for a dryland experiment in a small watershed

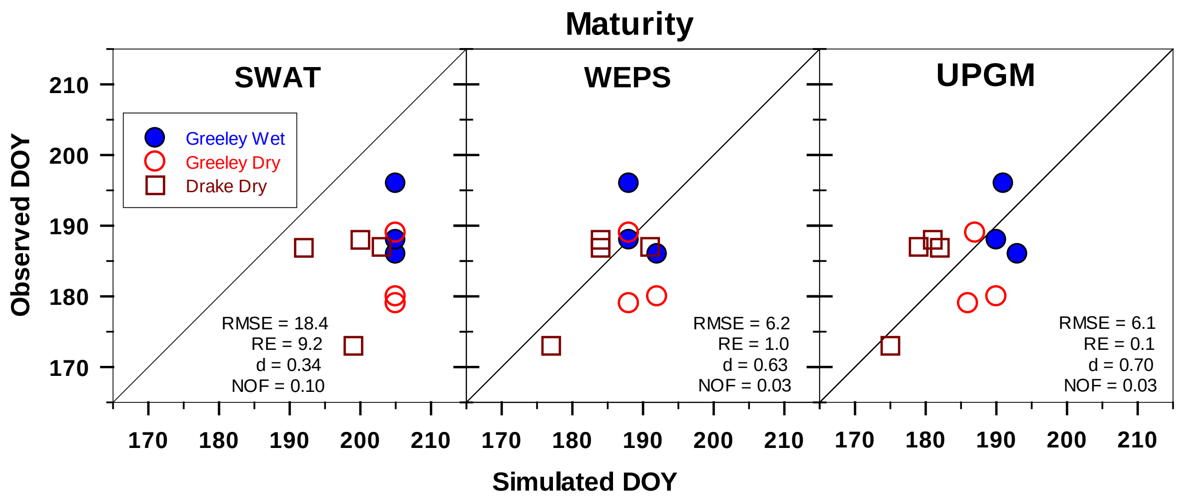


**Figure 3.** Simulating winter wheat physiological maturity by three plant growth components (SWAT, WEPS, and UPGM) in the Agro-Ecosystem Services (AgES) model. Default parameters were used for all models. The "Greeley" data set is for fully irrigated (Wet) and dryland conditions (Dry); Drake data set is for a dryland experiment in a small watershed

## 4. SUMMARY AND OUTLOOK

The UPGM model provides a platform for consolidating enhancements from various EPIC-based plant growth components used different agro-ecosystem models and then further improving UPGM. The new sub-models added to UPGM (e.g., phenology, seedling emergence, and canopy height) improve the robustness and accuracy of the plant growth component by including responses to varying water deficits. However, further work is needed to better integrate the phenology model into the rest of the WEPS model, particularly to better time the partitioning between leaf, stem, and reproductive fractions. Other future model enhancements include: 1) adding and validating more crops parameterized for the phenology, seedling emergence, and canopy height sub-models, 2) providing more cultivar or maturity class choices for each species, and 3) adding the ability to simultaneously simulate up to 11 species/functional groups from the ALMANAC model that allows for simulating cover crops, weed species, and better characterization of perennial systems such as pastures and rangelands.

Finally, although the current standalone UPGM platform provides a component that can be incorporated into agricultural models, the component design needs improvement to aid in incorporating UPGM into other models. Several lessons have been learned in replacing the plant growth components in the WEPS and AgES models, and this will be discussed in the Part 2 paper [Fox et al., 2018 Unified Plant Growth Model (UPGM). 2. Component development and integration with agroecosystem models. iEMSs paper #3982].

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