Supplementary Material: Description and Parameterization of the Model CSS_Zoner

Introduction

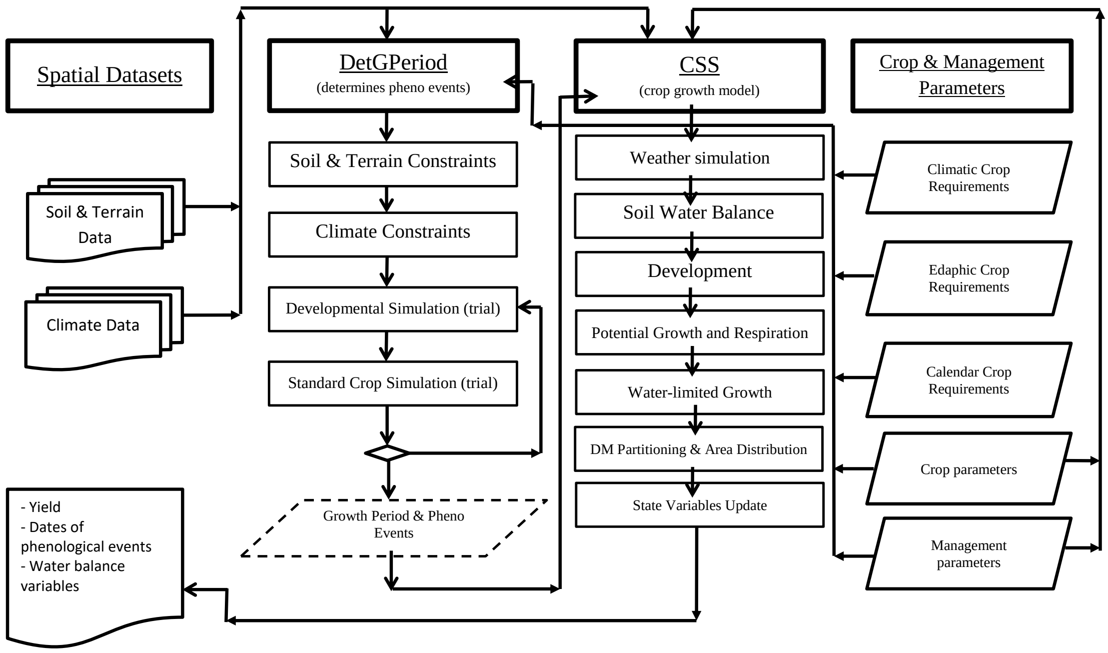
FAO uses a global agro-ecological zoning (GAEZ) methodology for application at global, national, and regional levels. GAEZ simulation are based on 10 or 30 arc-min latitude/longitude spatial climate datasets. There is no possibility of direct access to the code to perform modifications, thus there is no possibility of changing crop management, and GAEZ assessments are at a resolution of 5 arc-min.

In this study, we needed greater resolution since the area of our study was a small and diverse area. Our spatial datasets of weather, terrain, and soil had greater resolution than those available for GAEZ and we aimed at 30 arc-s potential and actual yields assessments. Therefore, we were compelled to use a system that fully served our objectives, which has been validated for Portuguese conditions and that could evolve according to our needs.

The model simulated the growth and production of any annual crop, biennial or perennial, under rainfed or irrigated conditions. Inputs were the main climate variables, texture and soil depth, the necessary plant requirements and management parameters. The model was programmed in Visual Basic.

Model Structure and Function

The CSS_Zoner is a modelling solution in Visual Basic that integrates a module, which determines the crop growth period (DetGPeriod), and a generic growth model (CSS) (Scheme S). Input consisted of spatial datasets concerning soil and climate, and crop and management parameters for all contemplated crops (twenty six crops, including one perennial, olive) [1].



Scheme S1. Flowchart of CSS_Zoner.

The DetGPeriod first determined the frost-free period (FFPeriod). Then, the strategy varied with crop type (spring/summer; winter; optional, perennial).

If the crop grows in spring/summer, DetGPeriod calculated the potential period of growth (PGPeriod), starting with the minimum temperature for sowing and the minimum temperature tolerated by the crop just before harvest. The potential crop growth period was reduced to the interception of FFPeriod and PGPeriod. If the cultivar with the shorter crop cycle did not fit in

PGPeriod, crop failure was flagged. If the duration of the cultivar that had the longer duration exceeded the PGPeriod, this period was reduced to the longer cultivar duration. For rainfed cultivation, the program searched for the longer actual growth period (AGPeriod) that allows the crop to successfully grow and produce before a critical low-level of available water occurs. A standard C_3 or C_4 crop model was used in this quest, which was simplified in dry matter partitioning and yield subroutines, but computed water use and soil water storage in the root zone.

Winter crops were dealt with differently, since the main concerns were that: (i) sowing should be early enough for the crop to grow before critical damage temperatures occur; but (ii) if sowing was too early, frost damage may occur in the flowering/grain set period. Hence, successive sowing/planting dates were analyzed until the probability of frost damage in the flowering/grain set period was low. The remaining strategy was similar to spring/summer crops. A final photoperiodic and vernalization calculation was performed to determine the viability of the crop.

Crops that may be sown either in autumn/winter or in spring, started by finding a growing season as crops of the first type. If the crop was not viable, the program tried to find a growth period for the crop as a spring crop.

Perennial crops called for a subroutine that calculated the time of bud burst and flowering, using a two-stage approach to simulate chilling and forcing processes [2]. For perennials, no iteration was performed, and there was only a viability check within DetGPeriod.

The Crop Simulation System (CSS) was developed at the University of Lisbon to simulate the production and yield of crops at potential and water limited levels. The main objectives of the system were to be simple and user-friendly; use corroborated approaches for growth and development processes under Mediterranean conditions; minimize the number of input parameters; and use a common structure for all crops.

CSS is a crop growth model at production levels I and II, is dynamic and mechanistic and uses a daily time step. It is similar to many existing models, although with a narrower scope than some, but it uses basically the same approaches (Table S1). Such models are for example SWAT [3], DSSAT [4], SUCROS [5], and CropSys [6].

Object Control manages inputs and outputs and communication between the objects that simulate the processes in the atmosphere-canopy-soil continuum: Astromet, Soil and Canopy.

Astromet computed photoperiod and generates weather related variables that are not in the input (PAR, vapor saturation deficit, direct and diffuse radiation, ETo (P-M), etc.).

Soil computed the soil water balance and its components. We used a simple two-layer approach, where the water balance dynamics was simulated using Darcy's equation [7] that yielded as good results as more complex and parameter demanding approaches (e.g., Richard's equation) [8].

Canopy encapsulated subroutines that simulated development, including the effect of photoperiod and vernalization, potential and water limited crop growth, dry matter partitioning and area distribution. The selected approaches are reported in Table S1.

Table S1. Approaches used in the subroutines present in object Canopy.

Process	Method Identification	Source or Similar Approach
Crop stage	Normalized developmental stage	De Melo-Abreu, 1993 [9]
Chilling and forcing (olive)	Sequential model	De Melo-Abreu et al., 2004 [2]
PAR absorption[1]	Exponential extinction & leaf absorptivity	Monsi and Saeki, 1953; Goudriaan, 1977 [10,11]
Gross Assimilation	Photosynthetic efficiency, modulated by temperature and CO_2	Monteith, 1977, Tubiello et al., 2007; Jones, 2014 [12–14]
Respiration	Respiration coefficients & Q_{10}	McCree, 1982; De Wit, 1965 [15,16]
Transpiration	*p*-parameter & water available	Allen et al., 1998 [17]

Water-limited net assimilation	Water use efficiency, modulated by saturation vapor deficit	Tanner and Sinclair, 1983 [18]
Dry matter partitioning	Allometry	Vieira et al., 2009 [19]

[1] In the case of olive crop simulation, the extinction coefficient for PAR absorption was calculated using a 3D model of extinction of radiation by the canopy [20].

Parameterization

Most parameters of the CSS_Zoner were defined by calibration of the sub-models where they were included, using our own datasets, datasets published or made available by personal communication. In some cases, the values of the parameters were the result of statistics that used values from homologous parameters found in published reports or model manuals. For this purpose the following sources were instrumental: Van Heemst [21], Penning de Vries et al. [22], Neitsch et al. [3], and Souza et al. [23].

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