Crop models: main developments, their use in CGMS and Integrated modeling

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Main developments in Crop growth models in Wageningen

The Wageningen UR research groups PPS (http://www.pps.wur.nl/UK/) and CWE (http://www.cwe.wur.nl/UK/) have a long tradition in developing and applying crop models, based on the pioneering work of C.T. de Wit. In the 1960s and 1970s the main aim of these modeling activities was to obtain understanding at the crop scale based on the underlying processes. De Wit and co-workers developed the model BACROS and evaluated components of the model (such as canopy photosynthesis) with especially designed equipment and field experiments. These modeling approaches have served as the basis and inspiration for modeling groups around the world. A pedigree of the Wageningen crop models has been extensively described by Bouman et al. (1996).

In the 1980s a wide range of scientists in Wageningen became involved in the development and application of crop models. The generic crop model SUCROS for the potential production situation was developed (Van Laar et al., 1997), which formed the basis of most recent Wageningen crop models such as WOFOST (Van Keulen and Wolf, 1986; Boogaard et al., 1998), MACROS and ORYZA. A simplified approach with respect to simulation of dry matter accumulation was developed by Spitters and Schapendonk (1990) based on the light use efficiency (LUE): the models LINTUL for arable crops and LINGRA for grasslands. For water- and nitrogen-limited production situations, model components (e.g. components for soil water and nitrogen, crop transpiration, soil evaporation, etc.) were added to SUCROS (Figure 1).

In the 1990s the Wageningen groups focused more on applications in research, agronomic practice and policy making. In a major project (Simulation and Systems Analysis for Rice Production, SARP) of Wageningen, the International Rice Research Institute (IRRI) and 15 National Agricultural Research Systems in Asia, interdisciplinary teams of Asian scientists were trained in the development and application of simulation models. Along with this program, a wide range of issues was studied using crop models, such as: mixed cropping, effects of climate change, breeding applications, yield gap analyses, and water and nitrogen management.

In the 1990s crop models also found their application in studies at higher levels of integration, i.e. farm and regional scale. In these studies, crop models were used to quantify a broad range of land use systems; subsequently these land use systems were aggregated to farm or regional scale using various techniques (e.g. linear programming) or procedures. Studies on designing environmentally friendly systems for arable, dairy and flower bulb farms were conducted, also enabling analysis of trade-offs between economic and environmental objectives. Land use studies were carried out with a focus on interactive exploration of different development strategies for the European Union, Southeast Asia, etc. Furthermore, crop models were used to explore limits for food production capabilities at global scale (Penning de Vries et al., 1995).

This overview of currently available crop modeling approaches is derived from the article by Van Ittersum et al. (2003), who give an extensive overview of approaches and applications of the Wageningen crop models.

WOFOST model in Crop Growth Monitoring System (CGMS)

Models are also used to monitor the influence of weather on crop growth and yields, for instance in the operational Crop Growth Monitoring System (CGMS) covering the EU. The heart of CGMS is the crop growth simulation model WOFOST. The required inputs per spatial unit are daily weather data, soil characteristics, crop parameters and management practices (i.e. sowing density, planting date, etc.). WOFOST computes the instantaneous photosynthesis at three depths in the canopy and for three moments of the day. These instant values are next integrated over the depth of the canopy and the daylight period to obtain the daily total canopy photosynthesis. After subtracting the respiration losses for maintenance of the crop, assimilates are partitioned over the different plant organs (i.e. roots, stems, leaves and grains) as a function of the crop's development stage. This stage is calculated by integrating the daily development rate over time, which rate is a function of temperature. Assimilates are finally converted into structural plant material taking into account the respiration losses for this conversion. These processes that determine biomass accumulation and its distribution over the crop organs, are simulated from sowing to maturity on a hectare basis.

Growth simulations for arable crops are done with the WOFOST model (Boogaard et al., 1998) for two production situations: the potential and the water-limited. The potential situation is only determined by temperature, day length, solar radiation and crop parameters (e.g. leaf area dynamics, assimilation characteristics, dry matter partitioning, etc.). For this situation the effect of soil moisture content on crop growth is not considered and a continuously moist soil is

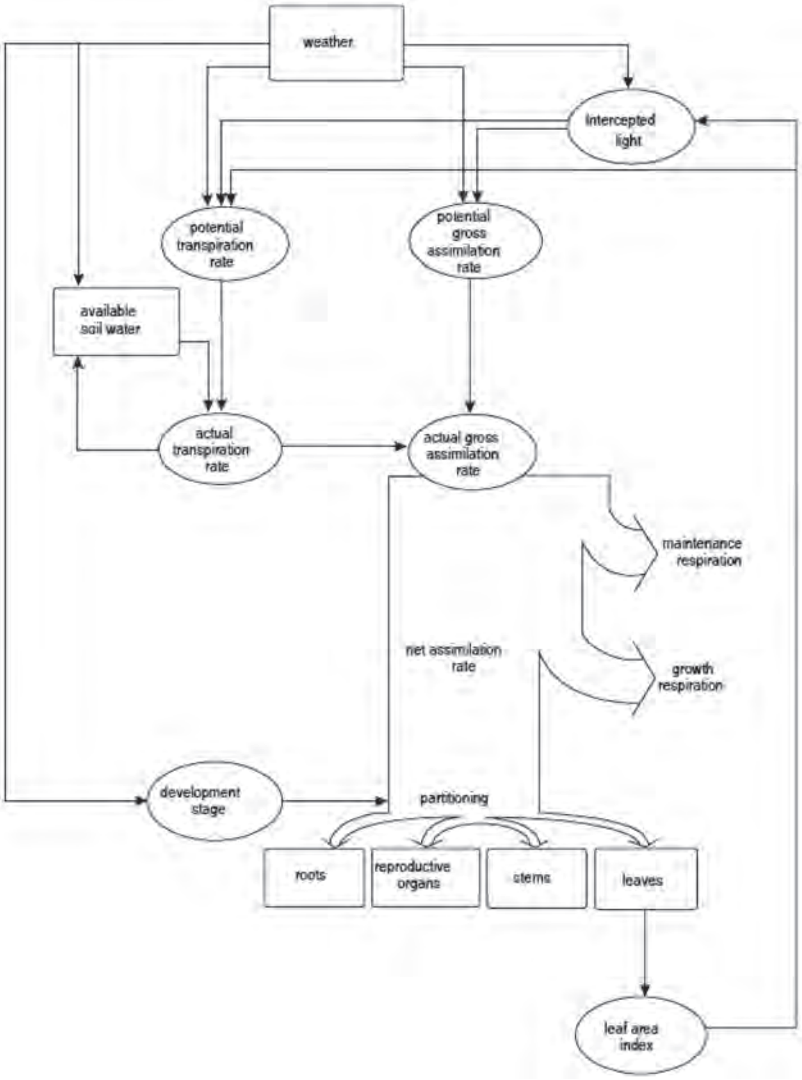

Figure 1 Basic structure of the crop model SUCROS (source: Kropff and Van Laar, 1993)

assumed. In the water-limited situation soil moisture content determines whether the crop growth is limited by drought stress or not. Therefore, soil water dynamics are simulated over time, indicating the soil moisture content in the rooted zone. In both the potential and water limited situations optimal supply of nutrients is assumed and damage caused by pests, diseases, weed and/or extreme weather events is not considered.

The first version of WOFOST in CGMS was coded in Fortran and data were stored in ASCII files. Migration to a relational database ORACLE was the next major upgrade. Data IO was coded in ProFortran. In 1995 the development contract ended and CGMS was delivered to the Joint Research Centre of the European Commission (EC-JRC). From then on, EC-JRC took over and migrated the (Pro)Fortan code into C++, keeping the model description identical. Though the code base is structured in different routines and libraries, it is not a real component based system. Therefore, new thematic issues like climate change that require different process description or coupling with other models, cannot easily be accomplished as that requires (major) code changes.

Recent development in Crop models and Integrated modeling systems

The recently finalized SEAMLESS project (for more information, see www.seamless-ip.org; being funded by the EU 6th Framework Research Programme) had the overall objective to overcome fragmentation in European efforts of modeling agricultural systems, and to provide a better information basis for impact assessment of agricultural and environmental policies. It has developed a computerized and Integrated Framework (SEAMLESS-IF) to assess and compare, ex-ante, alternative agricultural and environmental policy options, allowing analysis (a) at the full range of scales (farm to EU and global), (b) of the environmental, economic and social contributions of agriculture towards sustainable rural development, and (c) of a broad range of issues, such as environmental policies, effects of an enlarging EU and trade liberalisation.

A main objective of the approach in SEAMLESS-IF was to develop a software architecture that allows re-usability of model and database components and knowledge in model chains for integrated assessment (for more information, see Van Ittersum et al., 2008). Key models in SEAMLESS-IF are APES, FSSIM, EXPAMOD and SEAMCAP of which the first one, the modeling platform for cropping systems, will be described in the following. The models simulate different aspects (from bio-physical to market) of the system at different levels of organization (from field to farm to region to EU), and are linked from cropping system to farm (i.e. FSSIM) and from farm to market and policies at the EU level (i.e.

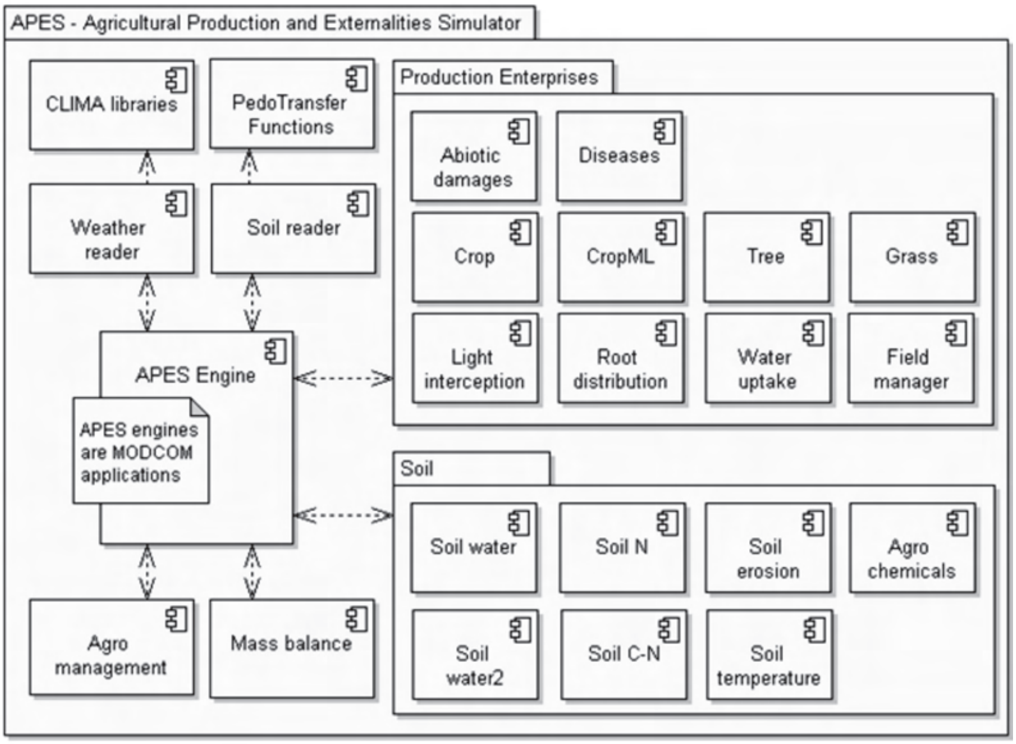

Figure 2 Components in the APES (source: Donatelli et al., 2009)

SEAMCAP). The software infrastructure that allows the (re-) use and linkage of the different components in SEAMLESS-IF, is described below.

APES modeling platform
APES (Agricultural Production and Externalities Simulator) is a *modular*, deterministic simulation modeling platform targeted at estimating the bio-physical behaviour of agricultural production systems in response to the interaction of weather, soils and different agro-technical management options (Donatelli et al., 2009). Using mostly modeling approaches already made available by research and previously tested in other simulation tools, APES runs at a daily time-step in the communication among components and simulates one dimensional fluxes at field scale. APES computes the yields, both averages and variability across years, as well as the other consequences of cropping (e.g. nitrate leaching).

APES consists of several components (Figure 2) representing land uses (crops, grassland, vineyards, orchards and agroforestry), soil water, carbon and nitrogen, soil erosion, pesticide fate, and agro-management activities.

Software infrastructure of SEAMLESS-IF: SeamFrame
The main components of SeamFrame are: the modeling environment, project manager, processing environment and the domain manager (Figure 3). The SeamFrame server interacts with the SEAMLESS database and knowledge base. SeamFrame uses ontology to structure domain knowledge and semantic meta-information about components in order to facilitate organisation, retrieval and linkage of knowledge in components. To guarantee consistency between the database and the ontology, the domain manager generates the relational database schemas from the ontology. The ontologies and their content are stored in a so-called knowledge base (Rizzoli et al., 2008). The use of ontologies to semantically annotate the component models allows, among other things, for checking the match between sources in terms of linking the proper output variables of a component to the input variables of a second component.

Modeling environments assist users to develop and edit their executable models and datasets with as current choices MODCOM (Hillyer et al., 2003) for the biophysical models and GAMS (Brooke et al., 2006) for farm economic and market models. Modelers can use a model development tool to deliver models which will be wrapped up as components thanks to specific wrappers in SeamFrame. All model components implement an interface based on the standard Open Modeling Interface (OpenMI; www.openmi.org; Gijsbers and Gregersen, 2005). OpenMI provides a standardized interface to define, describe and transfer data between software components that run simultaneously or subsequently. The standard has been extended to meet the requirements of SEAMLESS (Gijsbers et al., 2006).

Concluding comments
Wageningen crop models have shown to be good at simulating potential production under measured climatic conditions. The development and application of models appeared to be very helpful for research purposes, i.e. to design experiments, test hypotheses and generate new research questions. The crop models still face challenges in proper simulation of dynamics in soil water, nutrients and soil organic matter. For example, modeling of soil organic matter and organic fertilisers requires major attention in view of developing ecological farming systems. For different crops often different models or model versions are applied. However, the WOFOST model is operational for a wide range of crop types, which made it suitable for yield forecasting for a large number of crops over wide areas (e.g. the EU).

The flexibility of APES and SEAMLESS-IF to integrate, select and link models, data and indicators as dependent on the application, is of key importance for future use. Technical

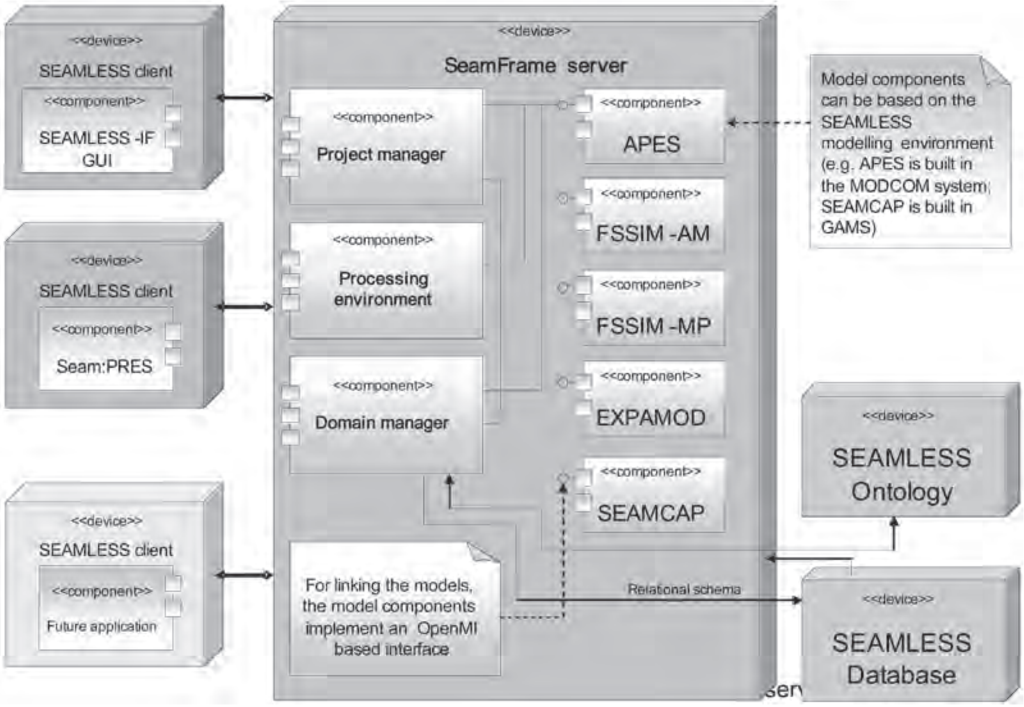

Figure 3 SEAMLESS-IF software infrastructure, with its SeamFrame server and end-user (client) applications (source: Van Ittersum et al., 2008)

coupling and re-usability of model components is greatly improved through adequate software architecture. The use of ontology strongly supports conceptual consistency of model linkages. However, the scientific basis for linking models across disciplines and scales is still weak and requires specific attention in future research. (Ewert et al., 2009). To remain informed about future developments, see the home pages of APES (http://www.apesimulator.org/) and the SEAMLESS Association (http://www.seamlessassociation.org/) .

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