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Simulating crop–parasitic weed interactions using APSIM: Model evaluation and application

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Abstract

The parasitic weed *Orobanche crenata* inflicts major damage on faba bean, lentil, pea and other crops in Mediterranean environments. The development of methods to control *O. crenata* is to a large extent hampered by the complexity of host–parasite systems. Using a model of host–parasite interactions can help to explain and understand this intricacy. This paper reports on the evaluation and application of a model simulating host–parasite competition as affected by environment and management that was implemented in the framework of the Agricultural Production Systems Simulator (APSIM). Model-predicted faba bean and *O. crenata* growth and development were evaluated against independent data. The APSIM-Fababean and -Parasite modules displayed a good capability to reproduce effects of pedoclimatic conditions, faba bean sowing date and *O. crenata* infestation on host–parasite competition. The r^2 values throughout exceeded 0.84 (RMSD: 5.36 days) for phenological, 0.85 (RMSD: 223.00 g m^{-2}) for host growth and 0.78 (RMSD: 99.82 g m^{-2}) for parasite growth parameters. Inaccuracies of simulated faba bean root growth that caused some bias of predicted parasite number and host yield loss may be dealt with by more flexibly simulating vertical root distribution. The model was applied in simulation experiments to determine optimum sowing windows for infected and non-infected faba bean in Mediterranean environments. Simulation results proved realistic and testified to the capability of APSIM to contribute to the development of tactical approaches in parasitic weed control.

Keywords: Faba bean; *Orobanche crenata*; *Vicia faba*; Parasitic weeds; Modelling; APSIM

1. Introduction

An array of parasitic organisms inflict damage on global agricultural production. Parasitic weeds compete with host plant organs mainly for water and assimilates, leading to decreased resource availability for host growth and yield formation. One of the most noxious parasitic weeds in Mediterranean environments is *Orobanche crenata* (crenate broomrape), which frequently causes substantial yield losses in faba bean (*Vicia faba*), lentil (*Lens culinaris*), pea (*Pisum sativum*), carrot (*Daucus carota*) and other crops (Sauerborn, 1991; Riches and Parker, 1995). The extent of water and assimilate diversion from the host plant to *O. crenata* results from complex interactions of host genotype, parasite infestation level, environmental conditions and agronomic practices (Manschadi et al., 2001; Rubiales et al., 2003a). In faba bean crops, *O. crenata* acts like an additional plant organ mainly competing with pods for assimilate and thereby causing large yield losses (Manschadi et al., 2001). Sole applications of cultural, chemical, physical or biological control measures (Jacobsohn et al., 1980; Foy et al., 1989; Linke et al., 1990, to cite just a few) have proven either insufficient or impracticable, mainly due to the intimate connectivity of host and parasite. Delayed sowing of host crops can reduce the severity of *O. crenata* infection, presumably through effects of soil temperature on germination and early development of the parasite (Mesa-García and García-Torres, 1986; Sauerborn, 1989; Rubiales et al., 2003b; Grenz et al., 2005). However, this practice can also cause the seed filling period to extend into the Mediterranean dry season, thereby reducing yield potential. Site-specific optimum sowing strategies yet remain to be developed. Control of *O. crenata* is likely to be achieved through strategies integrating several approaches (Linke and Saxena, 1991; Pieterse et al., 1994). Experimental evaluations of such strategies are

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hindered by constraints of time, resources and complexity. An eco-physiological model allowing the quantification of environment – crop – parasitic weed interactions (Spitters, 1989; Kropff and Lotz, 1992) could improve our understanding of the system and facilitate assessments of the potential efficacy of possible control strategies.

A model simulating the faba bean—*O. crenata* system as affected by environment and management was developed by Manschadi et al. (2001) and integrated into the Agricultural Production Systems Simulator (APSIM) as the APSIM-Parasite module (Manschadi et al., 2003, 2004). The APSIM framework combines biophysical and management modules with a central engine to simulate crops and rotations and has been applied to various situations (Wang et al., 2003; Keating et al., 2003). APSIM-Parasite can be applied in a generic manner to all crop modules and is the first module allowing the simulation of effects of biotic stress in APSIM.

The objectives of this study were to (i) evaluate the performance of APSIM for predicting damage effects of *O. crenata* on faba bean and (ii) test the capability of the model to contribute to control strategy development. Model-predicted growth and development of faba bean and *O. crenata* were evaluated against independent field data. The applicability of APSIM-Parasite in control strategy development will be tested by using the model to determine optimum faba bean sowing windows as affected by environment and *O. crenata* infestation.

2. Materials and methods

2.1. Model description

A configuration of APSIM version 3.2, including the SoilWat2-, SoilN2-, Residue2- and Fababean-modules (Probert et al., 1998; Turpin et al., 2003), was used to simulate non-parasitised faba bean. This configuration predicts dynamics and interactions of carbon, nitrogen and water within the crop–soil system as driven by daily weather information. APSIM-Fababean is based upon the generic APSIM-Legume template that simulates crop phenology, leaf area expansion, biomass accumulation, partitioning and senescence, as well as nitrogen and water uptake (Robertson et al., 2002). Since *O. crenata* mainly affects host yield via reductions of pod number (Manschadi et al., 2001; Grenz et al., 2005), a version of APSIM-Fababean employing a cohorting approach to yield simulation was used (Manschadi et al., 2004). During flowering, new pod cohorts are initiated daily. The number of pods in each cohort is a function of assimilate supply and the genotype-specific minimum supply required to set a pod (Stützel, 1995). Assimilates are allocated to cohorts in descending order of physiological age. Pod growth depends on physiological age of the cohort, maximum pod weight of the genotype, potential duration of the reproductive phase and potential pod growth rate, modified by temperature and assimilate supply. Pod detachment is based on the ratio of assimilate supply to demand (Batchelor et al., 1994).

To simulate parasitised crops, APSIM-Soiltemp, which calculates soil temperature, and a version of APSIM-Parasite configured for *O. crenata* were added. APSIM-Parasite calculates *O. crenata* phasic development based on the assumption that development rate is mainly a function of soil temperature (Mesa-García and García-Torres, 1986; Arjona-Berral et al., 1987). Parasite cohorts are initiated daily. Parasite number in each cohort is a function of host root length density and initial parasite seedbank level. Potential carbon demand of each parasite depends on a stage-dependent growth rate, modified by ambient temperature. Assimilate partitioning to parasites is the minimum of total parasite demand and assimilate supply by the host, with parasites having higher sink priority than vegetative faba bean organs and newly formed pods, but lower priority than pods in the seed filling phase (Fig. 1) (Manschadi et al., 2001). In infected

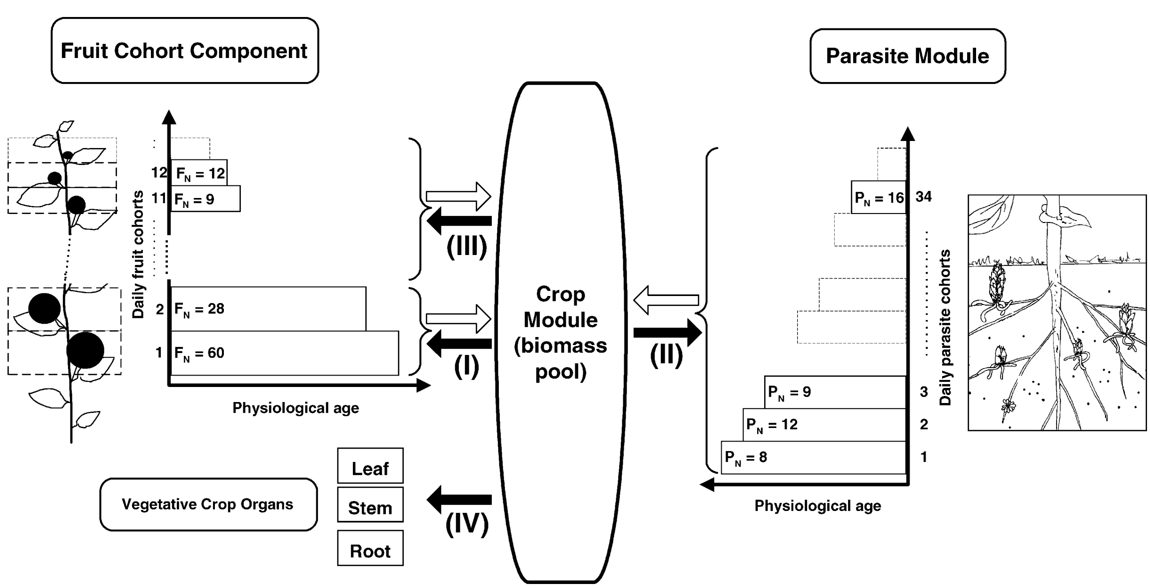

Fig. 1. Schematic representation of the simulation of cohorts of crop fruits and parasites. F_N and P_N indicate the number of fruits and parasites in each cohort, respectively; arrows represent carbon demand (open) and supply (closed); roman numerals show the priority order for assimilate partitioning. From Manschadi et al. (2004).