Development of a parasite module in APSIM - Case study: the parasitic weed *Orobanche crenata* infesting faba bean

A.M. Manschadi [1], E. Wang[2], M.J. Robertson[3], H. Meinke[2], J. Sauerborn[1]

[1] University of Hohenheim, Department for Agroecology of the Tropics and Subtropics (380), 70593 Stuttgart, Germany
www.uni-hohenheim.de Email manschad@uni-hohenheim.de
[2] Agricultural Production Systems Research Unit, DPI, 203 Tor St, Toowoomba, Australia
www.apsru.gov.au Email enli.wang@csiro.au
[3] Agricultural Production Systems Research Unit, CSIRO, Brisbane, Australia
michael.robertson@csiro.au

Abstract

The root-parasitic weeds *Orobanche* spp. infect a wide variety of crops in the Mediterranean region and have already invaded other regions with similar climatic conditions such as south Australia. Hence, a parasite module was developed within the Agricultural Production Systems Simulator (APSIM) and parameterised for simulation of development and growth of *Orobanche crenata*. Faba bean was chosen as a host crop to study the impact of O. crenata infestation on its growth and yield formation. In the model, we assume that *O. crenata* acts simply as an additional sink for assimilates and does not influence the host crop metabolism. The parasite carbon demand is calculated from the total number of parasite attachments and the potential growth rate of an individual *O.* crenata. The amount of dry matter partitioned into *O. crenata* is simulated based on the carbon demand and carbon availability of the host crop by assuming that *O. crenata* has a sink priority higher than vegetative faba bean organs, but lower than the grain bearing pods.

Simulations were run with the new parasite module and the modified APSIM-Faba bean module against experimental data from Tel Hadya in northwest Syria. The results indicated that APSIM-Faba bean module was able to simulate the faba bean biomass growth and yield formation. The parasite module, together with APSIM-Faba bean, was capable of predicting the biomass accumulation of O. crenata and the yield loss of infected faba bean plants for various infestation levels and faba bean sowing dates, as well as under different water supply conditions. Such a model can assist in the development of a systems approach to reduce negative impact of parasitic weeds.

Keywords

Host plant - parasite interaction, Mediterranean climate, Dry matter partitioning, Root-length density, Modelling

Introduction

Orobanche spp. (Broomrapes) are root-parasitic weeds that infect a wide variety of crops including the pulses and pasture legumes, oil crops and vegetables (5). Their main centre of distribution is the Mediterranean region, where large areas are heavily infested. Other regions with similar climatic conditions (Australia, South America, USA) have also been invaded. *O. crenata* Forsk. is one of the economically most important broomrape species, which causes most damage in the cool-season food legumes faba bean (*Vicia faba* L.), lentil (*Lens culinaris* Medic.), chickpea (*Cicer arietinum* L.), and pea (*Pisum sativum* L.). Reported faba bean yield losses due to *O. crenata* infestation range from 5% to complete crop failure depending mainly on the parasite seedbank in the soil, agronomic practices as well as temperature and soil moisture regimes during the growing season.

The Agricultural Production Systems Simulator, APSIM (2), is a software environment, which allows modules of crops, pastures, soil water, nutrients, and erosion to be flexibly configured to simulate diverse production systems and has been used successfully in the search for strategies for more efficient production, improved risk management, and more sustainable production systems (3). While APSIM is capable of predicting the effects of major abiotic stress factors and management options on crop performance, it does not account for the biotic constraints such as pests and diseases. In this paper we present the structure of a generic APSIM-Parasite module that allows the simulation of the impact of parasites on crop growth. The parasitic weed *O. crenata* and its host plant faba bean (*Vicia faba* L.) were used as a case study to parameterise the module. The APSIM-Faba bean module (6) was modified to interact with the parasite module and validated under Mediterranean conditions.

Methods

Experimental studies for model development and parameterisation

The data sets on faba bean – *O. crenata* interactions were obtained from field experiments in 1993-94 and 1994-95 at the research station of the International Centre for Agricultural Research in the Dry Areas (ICARDA) in northwest Syria. In both seasons, the trials were designed as split-split-plots with moisture supply (rainfed, irrigation) as main plot, crop sowing date (SD1 and SD2) as subplot, and *O. crenata* seed load (0, 50, 200, and 600 parasite seeds kg $^{-1}$ top soil) as sub-subplot, and replicated four times. Standard measurements, plant sampling procedures, and irrigation treatments have previously been described in detail (1).

Construction of the APSIM-Parasite Module

A generic APSIM-Parasite module has been constructed based on the assumptions that under sufficient resource supply (from the host) both the development and the potential growth of a given parasite are functions of environmental factors, mainly temperature. The initial number of parasites is an input parameter, given either as numbers of parasite invaded in the system or seed/larva density at certain time. The potential number of active parasites can be simulated based on the initial number and the host crop area (leaf area or root length density) or resource supply. At this stage, cross season parasite population dynamics is not simulated and may be added later, which will involve simulation of seed/egg survival as functions of environmental factors. The potential growth rate of each parasite and the active parasite population determine the demand for resources from the host crop. The growth rate of the parasites is reduced by insufficient supply of the host crop. Multiple instances can be created from APSIM-Parasite and the *Orobanche* module is an instance of it.

Development of the Orobanche module

The *Orobanche* model presented here was developed based on the results of our own experimentation and data from literature. The model was parameterised using only the data set from the field experiment in 1994-5, since in 1993-4, the method applied to create different *O. crenata* seed densities (using a rake) failed in mixing the parasite seeds with the top 15 cm soil.

(a) Phasic development

Parasites are classified into four developmental stages: (a) visible tubercles >1 mm with or without crown roots; (b) buds; (c) underground shoots; and (d) emerged plants. Thermal time (?Cd, degree-days), calculated as the summation of daily mean soil temperature at 10 cm depth above a base temperature (TBASES), is used to predict the dates of occurrence of *O. crenata* developmental stages. The thermal duration of various stages was derived from the results of growth chamber, greenhouse and field experiments (1).

(b) Total number of parasite attachments

The total number of parasite attachments at the harvest of faba bean crop (TORNO) is a function of *O. crenata* seed density (ORSD) and maximum faba bean root length density (RLD) in the top 15 cm soil when 1.039 < RLD ≤ 2 cm cm^{-3}. For RLD greater than 2 cm cm^{-3}, the TORNO appears to be dependent on ORSD only (Eq. 1).

TORNO = 685.4 * (1 - EXP(-0.0027*ORSD)) * min{1.0, (0.5*RLD)} (1)

The daily number of visible *O. crenata* attachments (ORNO) is simulated as a function of TORNO and accumulated soil thermal time after faba bean emergence (DTSUMS).

ORNO = TORNO * EXP (δ * (DTSUMS - DTSUM4)) (2)

Where, DTSUM4 is the soil thermal time from faba bean emergence to the emergence of *O. crenata*. The value of δ was estimated as 0.012 based on the experimental results.

(c) Potential and actual biomass growth rate

Simulation of biomass growth of *O. crenata* is based on the assumptions that (i) *O. crenata* acts just as an additional sink for assimilates without influencing the host metabolism, and (ii) the parasites accumulate biomass after having reached the bud stage. The potential growth rate of an *O. crenata* plant (PGROR) is defined as the maximum growth rate under unlimited carbon supply. It is calculated as a function of temperature sum (DTTSUM) (Manschadi et al., 2001):

PGROR = 0.009 DTT / (1 + EXP (-0.009 * DTTSUM + 7.9)) (3)

DTT and DTTSUM are the daily and total thermal time (?Cd) from the emergence of faba bean onwards using a base temperature of 0?C (?Cd).

The total potential growth of all the *O. crenata* (DEMAND) is PGROR times the number of parasites having reached bud stage. The total actual growth rate of all *O. crenata* plants is the smaller one of DEMAND and assimilate supply (SUPPLY) from the host crop. The SUPPLY is calculated in the faba bean module based on sink strength as described in the next section. The total SUPPLY is partitioned to each parasite according to its demand to get the actual growth rate of each parasite.

Modification on APSIM-Faba bean Module

The APSIM-Faba bean module (6) is developed on the basis of the APSIM-Legume model (4) and simulates faba bean growth and development on a daily time step. An additional subroutine is added in the APSIM-legume module to account for the partitioning of biomass to parasites using the parasite carbon demand (DEMAND) as input. Before grain-filling stage, parasite has the highest priority for carbon. Pod growth rate is adjusted based on the remaining biomass (if there is any) after meeting parasite demand. The remainder goes to host crop leaf and stem according to the proportions defined in the host crop partitioning subroutine. After grain-filling, grain has the highest priority for carbon to meet its demand. Grain demand may be reduced by reduction in pod growth, thus it is adjusted based on the current pod weight, pod/grain fraction and the ratio of pod to *O. crenata* growth rate in the previous 5 days. The remaining assimilates after grain demand is partitioned to parasite and other host crop organs using the same procedure as before grain filling.

Results

For the simulations reported here, the APSIM-Parasite module was linked to the modified APSIM- faba bean, soil water, soil nitrogen, crop residue, and soil temperature modules. Comparisons between model simulations and the measured data indicated that the APSIM-Faba bean was able to reproduce the faba bean leaf area development, biomass production, and yield formation in both seasons reasonably well. Only with delayed sowing and irrigation the model tended to overestimate the biomass production (Fig. 1). The new parasite module, together with APSIM-Faba bean, was capable of predicting the phenology and biomass accumulation of *O. crenata* (Fig. 2a) for various parasite infestation levels and faba bean sowing dates, as well as under different water supply conditions. The associated yield losses of infected faba bean plants were simulated less accurately (Fig. 2b). This was mainly due to the harvest index approach used in the APSIM-Faba bean model, which lacks the required flexibility to accurately predict yield when pod number is reduced by *O. crenata* infestation.

The model is currently being evaluated using independent data from various faba bean cultivars and locations and will be extended to other host plant – *Orobanche* associations, such as sunflower – *O. cumana*. Further, an *Orobanche* population dynamics module is under development and will be linked to APSIM. A pod number/size approach is being investigated for better simulation of parasite and faba bean pod competition.

Conclusion

The preliminary results indicate that the parasite (*Orobanche)* module is able to simulate the interaction between *O. crenata* and faba bean. With these new components, APSIM could then assist in the development of a systems approach to reduce the negative impact of parasitic weeds and to delineate areas where the parasite poses an actual or potential risk to crop production.

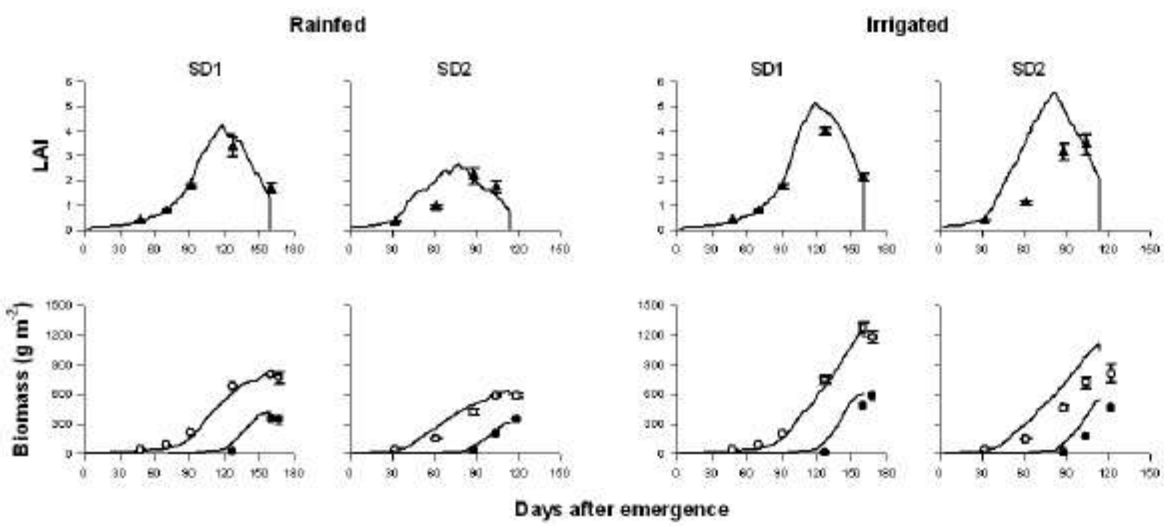

Fig. 1: Simulated (curves) and measured (points) leaf area index (LAI), shoot (open circles) and pod (pod wall plus seed) biomass (closed circles) of faba bean grown without *Orobanche* infestation in 1994-95; SD1 and SD2 indicate the first (Nov. 7) and second (Dec. 12) sowing date, respectively; bars: standard error.

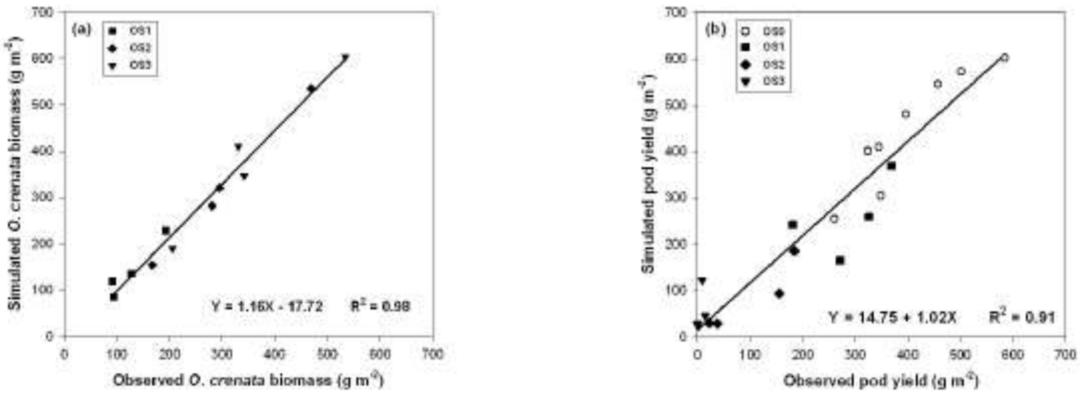

Fig. 2: Comparison of simulated and observed *Orobanche crenata* biomass (a, RMSE=26.6gm^{-2}) and faba bean pod yield (b, RMSE=59.3g m^{-2}) for various parasite seed densities, crop sowing dates and moisture regimes; OS0, OS1, OS2, and OS3 indicate 0, 50, 200, and 600 *O. crenata* seeds kg $^{-1}$ soil, respectively.

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