Simulating damage effects of parasitic weeds in APSIM: A generic cohort-based approach

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Abstract

Parasitic weeds of the genus *Orobanche* (broomrapes) cause substantial yield losses to a wide variety of crops in Mediterranean-type environments. Being unable to assimilate carbon, *Orobanche* species act as an additional sink for assimilates. Thus crop yield loss is primarily the consequence of a shift in assimilate partitioning from host plant organs to parasites.

This study describes a mechanistic modelling capability for simulating the biomass competition between legume crops and parasitic weeds within the Agricultural Production Systems Simulator (APSIM). A generic cohort-based approach has been adopted to simulate daily age classes (cohorts) of legume pods and parasites. Each cohort is characterised by the number of pods/parasites, their physiological age (degree-days) and potential assimilate demand. Total available assimilate is partitioned among cohorts according to their potential demand and a sink priority scheme. A supply to demand ratio for each pod cohort is used to determine pod abortion.

The model was parameterised for faba bean (*Vicia faba* L.) infested with the parasitic weed *Orobanche crenata* Forsk. (crenate broomrape) and evaluated against independent datasets. Model evaluation revealed the capability of APSIM's fruit cohort component to simulate the observed dynamics of pod setting and yield formation for faba bean crops exposed to various levels of abiotic and biotic (*O. crenata*) stresses. With this modelling capability, APSIM can assist as a systems analysis tool in developing integrated parasitic weed management strategies that minimise crop yield losses.

Media summary

A new cohort-based approach in APSIM provides a simple and generic framework for predicting the yield losses of legume crops due to parasitic weeds infestation.

Keywords

Modelling, Faba bean, *Orobanche crenata*, pod dynamics, sink strength, assimilate competition

Introduction

The root-parasitic weeds of the genus *Orobanche* (broomrapes) cause severe damage to a wide variety of crops including legumes, oil crops and vegetables in the Mediterranean region and have already invaded other regions with similar climatic conditions such as south Australia. As achlorophylous parasites, *Orobanche* spp. are entirely dependent on the host plant for the supply of photosynthates. Crop yield loss is primarily the consequence of changed allocation of assimilates and varies as a result of complex interactions between parasite soil seedbank, agronomic practices and environmental conditions (Manschadi et al. 2001). Thus quantitative understanding of the mechanisms controlling biomass partitioning in the host plant – parasitic weed system would allow to (i) predict more realistically the expected crop yield losses; and (ii) develop and evaluate integrated *Orobanche* control strategies.

The Agricultural Production Systems Simulator, APSIM, is a software environment that allows modules of crops, pastures, soil water, nutrients, and erosion to be flexibly configured to simulate diverse production systems (Keating et al. 2003). In a case study, we used APSIM-Parasite to simulate the damage effects of parasitic weed *Orobanche crenata* on faba bean growth (Manschadi et al. 2003). While the parasite module was capable of predicting the biomass accumulation of *O. crenata*, the associated yield losses of infested faba beans were simulated less accurately. This was mainly due to the harvest index (HI) approach used in the APSIM-Faba bean module, which lacks the required flexibility to accurately predict crop yield when pod number is reduced by *O. crenata* infestation. Deficiencies of the HI approach in predicting grain growth and yield have also been reported for sorghum exposed to various levels of abiotic stresses during the reproductive phase (Hammer and Broad 2003).

This paper reports on the (i) development of a generic fruit cohort component in APSIM for simulating crop yield based on classes (cohorts) of reproductive organs; (ii) parameterisation of the fruit cohort component for faba beans grown under a wide range of environmental conditions; and (iii) evaluation of the fruit cohort component and APSIM-Parasite module using independent data sets on faba beans infested with *O. crenata*.

Methods and Materials

Experimental studies for model parameterisation

Field experiments for the parameterisation of APSIM were conducted 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. The trials included various treatments of moisture supply (rainfed, irrigation), crop sowing date, and *O. crenata* seed load (0, 50, 200, and 600 parasite seeds kg $^{-1}$ top soil) (Manschadi et al. 1998).

Experimental studies for model evaluation

The data sets for the evaluation of APSIM's fruit cohort component and Parasite module were obtained from the field experiments performed at two locations in Adana province (Turkey) during 2000-01 and 2001-2002 seasons. The trials were designed as split-split-plots with *O. crenata* infestation as main plot, faba bean sowing date as subplot, and faba bean cultivar as sub-subplot, and replicated four times. Prior to sowing, plots were artificially infested with *O. crenata* seeds at densities of 25 and 200 viable seeds kg^{-1} soil to a depth of 15cm, or left as untreated control. Data collection included meteorological variables, soil water content, crop and parasite phonological development, and sequential biomass harvests.

Overview of the fruit cohort component and the Parasite module

The fruit cohort component simulates the yield of legume crops based on the growth of individual age classes or cohorts of fruits. Starting at flowering, new cohorts of reproductive sinks are initiated on a daily basis. Pod addition rate depends on the actual crop growth rate divided by a genotype-specific minimum assimilate requirement to set a pod. The potential growth rate per pod depends on its physiological age and is calculated as a function of genetic input parameters describing the maximum dry weight of a pod, potential duration of reproductive phase, and potential pod growth rate during the grain-filling phase. Actual pod growth rate is subsequently modified by temperature and carbon supply. Biomass partitioning among the pod cohorts is governed by the sink priority order: pods in the grain-filling phase, pod walls, addition of new pods and vegetative structures. The ratio of carbon supply to demand for each cohort is used to determine pod abortion (Fig. 1). Water stress is assumed to shorten the duration of reproductive phase and thereby induces an increase in pod growth rate.

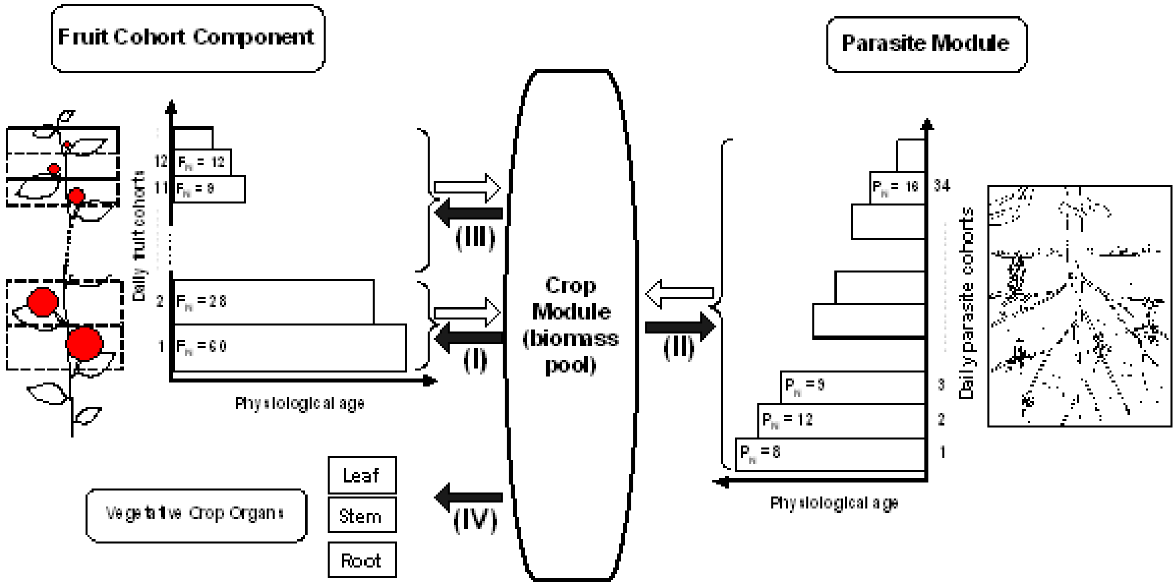

Fig. 1: Schematic representation of the APSIM's modelling components for simulating age classes (cohorts) of crop fruits and parasites; F_N and P_N indicate the number of fruits and parasites in each cohort, respectively; arrows represent carbon demand (open) and supply (closed); roman numerals show the priority order for assimilate partitioning.

The Parasite module also uses a cohort-based approach to simulate age classes of parasites on a daily basis. The number of parasites in each cohort is a function of crop root-length density and parasite seed load. Potential carbon demand of each parasite is calculated based on the developmental-stage dependent maximum growth rate modified by actual temperature. The actual amount of dry matter partitioned into parasites is the minimum of total parasite potential demand and assimilate supply by the host plant assuming that parasites have a sink priority higher than vegetative faba bean organs and younger pods, but lower than the pods in the grain-filling phase (Fig. 1). Parasite infestation, therefore, reduces the rate of pod addition and increases the pod abortion rate.

Results and discussion

For the simulation studies, the fruit cohort component was linked to APSIM's faba bean, parasite, soil water, soil nitrogen, crop residue, and soil temperature modules.

Model parameterisation

The genetic input parameters required by the fruit cohort component were derived from the experimental studies for model parameterisation involving faba bean genotype ILB1814. Comparisons between model simulations and the measured pod numbers indicated that the fruit cohort component was capable of predicting the pod dynamics of faba beans grown under different levels of abiotic and biotic (*O. crenata*) stresses. An example of the model performance against observed faba bean pod dynamics is given in Fig. 2.

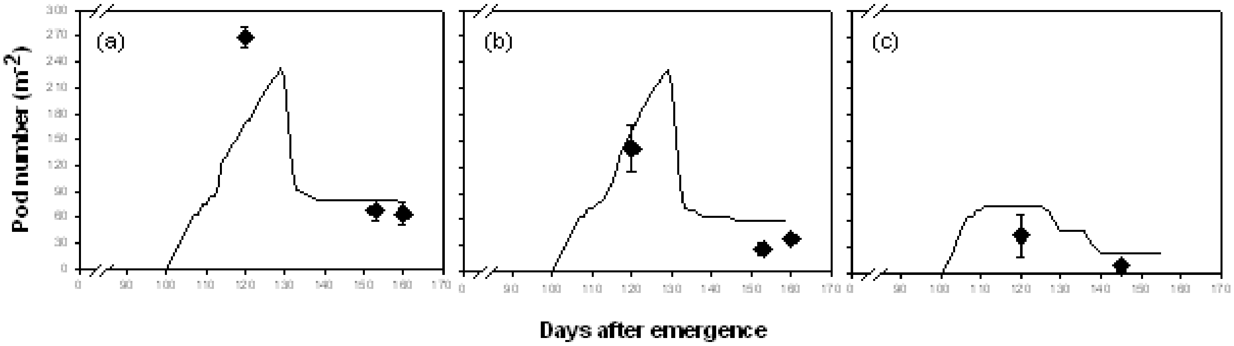

Fig. 2: Simulated (curves) and observed (points) pod dynamics of faba bean grown under rainfed conditions without and with *Orobanche crenata* infestation; a, b and c indicate 0, 50 and 200 parasite seeds kg^{-1} soil; bars are standard errors.

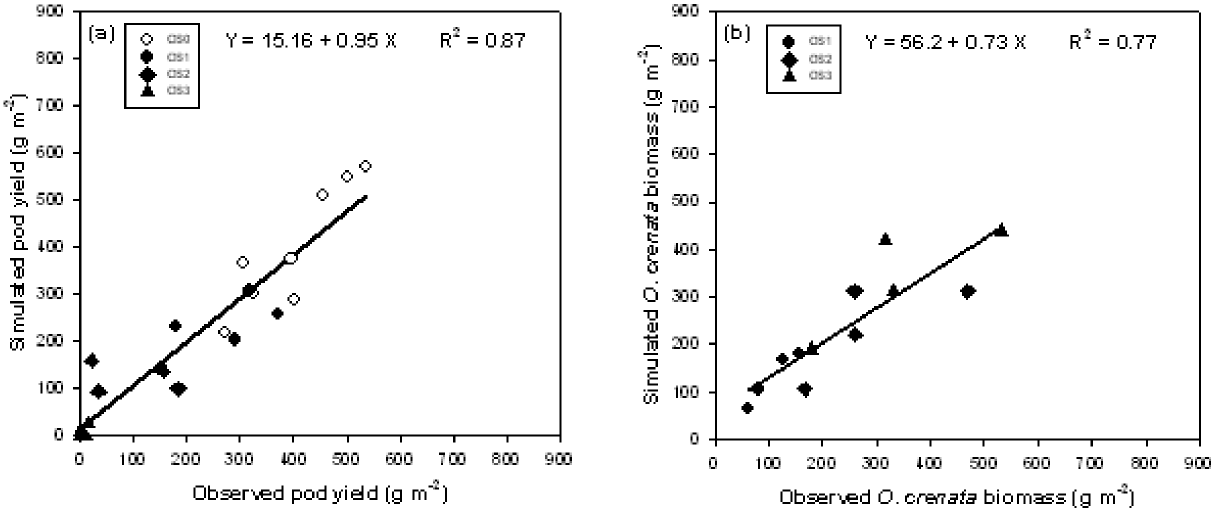

Fig. 3: Comparison of simulated and observed faba bean pod yield (a, RMSE=65.6g m^{-2}) and *Orobanche crenata* biomass (b, RMSE=61.5gm^{-2}) for various parasite seed densities, crop sowing dates and moisture regimes; OS0, OS1, OS2, and OS3 indicate 0, 50, 200, and 600 *O. crenata* seeds kg $^{-1}$ soil, respectively.

The simulated patterns of biomass competition between faba bean pods and parasites agreed well with the observed data. Overall the model was able to explain 87 and 77% of the observed variation in faba bean pod yield and *O. crenata* biomass, respectively (Fig. 3).

Model evaluation

The model was tested against experimental data with faba bean genotype ILB1814 from the evaluation studies. While the model predictions of faba bean pod yields were very good, the simulated biomass accumulation of *O. crenata* was less accurate (Fig. 4).

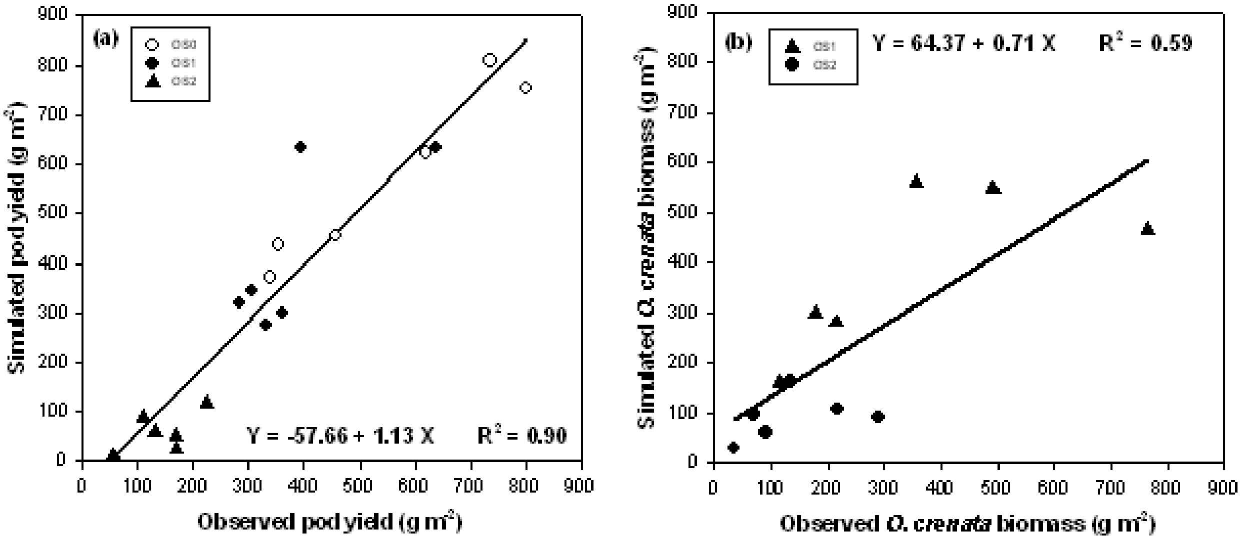

Fig. 4: Simulated and observed faba bean pod yield (a, RMSE=86.8 g m-2) and Orobanche crenata biomass (b, RMSE=129.0 g m-2) in the evaluation studies; OS0, OS1, and OS2 indicate 0, 25, and 200 *O. crenata* seeds kg $^{-1}$ soil, respectively.

Discussion

The fruit cohort component provides a generic modelling approach for simulating pod dynamics and yield formation of legume crops in APSIM. Whereas the final pod numbers and consequently pod yields were simulated satisfactorily, the predicted time course of pod addition and abortion was less accurate (Fig. 2). Pod abortion was modelled by a carbon supply / demand ratio approach, similar to CROPGRO model (Boote et al. 1998), assuming a priority order for assimilates. Studies on the patterns of assimilate partitioning among pods in pea (*Pisum sativum* L.), however, indicate that assimilates are allocated in proportion to potential demand of each pod and there is no priority of some pods over the others (Jeuffroy and Devienne 1995). Implementation of a proportional allocation approach is likely to improve the model performance.

Conclusion

This study has shown that pod yield of faba bean can be simulated using a simple and generic fruit cohort approach. Simulation studies using the same set of genetic input parameters indicated the genericity and capability of the model in predicting a wide range of faba bean pod yields (0 to 800 g m^{-2}) measured under various levels of biotic and abiotic stresses in two contrasting Mediterranean-type environments. With the new modelling capabilities, APSIM can assist in the development and evaluation of integrated *Orobanche* control strategies.

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