Assessing the short and long term effects of parasitic weed infestation on the productivity of faba bean in the Mediterranean region: Simulation studies using APSIM

Jan Grenz[1], A.M. Manschadi[2], Peter DeVoil[2], Holger Meinke[2] and Joachim Sauerborn[1]

[1] University of Hohenheim (380), 70593 Stuttgart, Germany (jangrenz@uni-hohenheim.de)
[2] APSRU, Queensland Department of Primary Industries & Fisheries, PO Box 102, Toowoomba, Qld 4350, Australia

Abstract

Legume production in the Mediterranean countries suffers considerable damage from infestation with the parasitic weed *Orobanche crenata*. Characteristics of *O. crenata* infestation include host specificity, complex host-parasite interaction and a persistent soil seed bank. Hence durable control of the parasite can only be achieved through a combination of control approaches in an integrated strategy. The time-consuming evaluation of potential control strategies may be accelerated by use of an ecophysiological model of host-parasite interactions. A mechanistic modelling capability for simulating the interaction between host plants and parasites has been implemented within the Agricultural Production Systems Simulator (APSIM) and parameterised for the association faba bean - *O. crenata*.

This paper reports on the addition of a model for predicting *O. crenata* seed bank dynamics to the APSIM framework. Parasite seed production in the model is proportional to parasite biomass. Seeds are added to the soil seed bank and redistributed vertically by tillage. The probability of seed germination responds to host root-length density. Loss of viability in buried seeds is a function of soil moisture content.

Short and long term simulation studies were performed for two contrasting Mediterranean environments to test the functionality and reliability of the model. APSIM proved capable of realistically estimating the response of the host-parasite association to environment, infestation level and management measures including shifted sowing date and hand-weeding. The model can contribute to development and evaluation of potential *O. crenata* control strategies in the target environments.

Media summary

A model for simulating seed bank dynamics was added to APSIM. Short and long term faba bean-parasitic weed interactions could be realistically predicted.

Key words

Orobanche crenata, parasite, integrated control, seed bank, modelling, population dynamics model

Introduction

The root-parasitic weed *Orobanche crenata* Forsk.(crenate broomrape) can inflict devastating yield losses on faba bean, lentil, pea and other crops in its native distribution area around the Mediterranean. Each parasite produces dozens of capsules each containing thousands of seeds that can survive in the soil for more than 10 years. Being adapted to Mediterranean climate, the species has the potential to become a noxious neophyte in environments with similar climatic conditions, including South and Western Australia.

Many attempts have been made to devise control methods against *Orobanche* spp., but due to complex interactions between host and parasite, no single measure has proven effective and practicable. Developing an integrated management system combining various control options, such as delayed sowing and optimised weeding schedule, is considered the most promising approach to sustainable control of *O. crenata*. Experimental evaluation of integrated strategies would require considerable time and labour, yet only render site-specific solutions. The use of an ecophysiological model may help overcome these constraints. A mechanistic competition model of faba bean – *O. crenata* interactions was developed within the framework of the Agricultural Production Systems Simulator (APSIM) (Keating et al., 2003) as a module (Manschadi et al., 2003). The Parasite module was parameterised with experimental data from Syria and displayed a very good ability to reproduce growth and development of faba bean and its parasite *O. crenata* in an evaluation with independent data from Turkey (see Manschadi et al. this vol.).

This paper reports on the (i) addition of a model for predicting *O. crenata* seed bank dynamics to APSIM, (ii) application of APSIM to determine optimum sowing windows for faba bean with and without *O. crenata* infestation, and (iii) quantification of the long term effects of pedoclimatic conditions and weeding schedules on *O. crenata* seed bank at two contrasting Mediterranean sites.

Material and methods

Database on O. crenata seed bank dynamics

Data on reproduction and seed longevity of *O. crenata* were collected from literature and field trials conducted in Turkey in 2000-01 and 2001-02. Measured parameters included parasite capsule and seed number, generative and vegetative biomass, and seed viability. The seed production of *O. crenata* was linearly correlated with parasite biomass (Figure 1). Capsules on average contained 3,394 seeds, 65% of which were viable at plant maturity. Based on literature reports, seeds were estimated to remain viable in the soil for 10 to 15 years, depending on soil temperature and soil moisture.

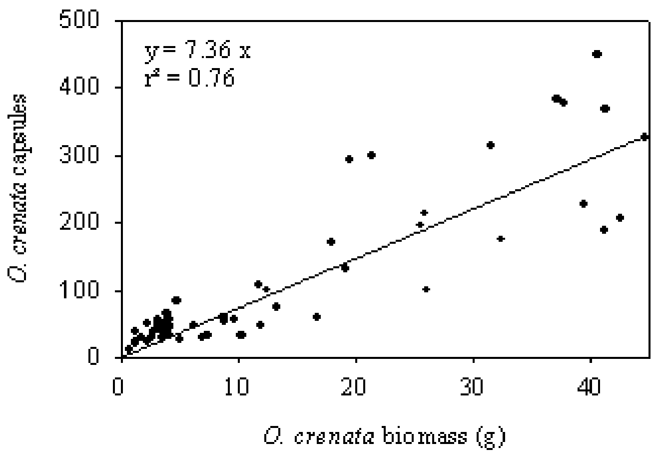

Figure 1. Relationship between biomass (g) and capsule number of an individual *O. crenata* infesting faba bean.

Seed bank dynamics model

In the model, seed population is vertically organised in depth classes, and algorithms are event-based, thus seed number per unit area in each layer is updated at the occurrence of events, such as faba bean sowing, emergence, flowering and maturity.

The production of viable *O. crenata* seeds is the product of parasite biomass at maturity, a factor relating biomass to capsule number, average seed number per capsule and seed viability. After a defined thermal time has elapsed since parasite emergence, capsules progressively split open, and seeds are added to the soil surface class. Tillage redistributes seeds among depth classes. The probability of seeds being stimulated to germinate is a function of host rooting density and becomes 100% at a root-length density of 2.5 mm mm^{-3}. Stimulated seeds are removed from the seed bank. Buried seeds continuously lose viability. Seed decay is a function of soil moisture content, with a higher survival rate in dry soil (Kebreab & Murdoch, 2001). The decay curve was parameterised to reproduce seed bank dynamics found in Mediterranean environments, where average annual viability loss is between 40% and 50% (Schnell et al., 1996). Hand weeding is simulated by removing all emerged parasites and allowing for subsequent regrowth.

Simulation experiments

For the simulation studies, APSIM was configured with the parasite, faba bean, soil water, soil nitrogen, crop residue and soil temperature modules to predict dynamics of soil water, nitrogen and temperature, as well as phenology and growth of faba bean and *O. crenata* at a daily time step. In all virtual experiments, faba bean genotype ILB 1814 was sown 5 cm deep at a rate of 20 m^{-2} with a row distance of 50 cm, and fertilised with urea corresponding to 20 kg N ha^{-1} and irrigated with 30 mm at sowing.

Single season: effects of parasite infestation and sowing date

Faba bean crops grown in fields non-infested or infested with 200 viable *O. crenata* seeds kg^{-1} soil were simulated. Seven sowing dates from 22-October until 22-January, each representing a two-week sowing window centred around the month's 8^{th} and 22^{nd} day, were tested. Simulations were driven by historical weather records of 20 consecutive growing seasons (1979/1980 – 1999/2000) from Adana (Turkey).

Multi-season: effects of location and weeding schedule

Simulations comprising 20 years were driven by weather records from Tel Hadya (Syria) and Adana (Turkey) with a semi-arid Mediterranean-continental and a humid Mediterranean climate, respectively. Faba bean was sown on 15-November every fifth season. To investigate effects of hand-weeding, simulations were run in which all emerged parasites were removed either at fixed dates (1-Apr, 1-May) or as a function of faba bean phenology (7 , 14 or 21 days after flowering). These schedules were applied to fields with S_i of 2,000 and 30,000 seeds m^{-2} (13 and 200 seeds kg^{-1} soil), and yields compared to those in non-infested fields and infested fields without control.

Results and discussion

Single season: effects of parasite infestation and sowing date

Simulated median yields of non-infested faba bean ranged from 493 g m^{-2} in the latest-sown to 812 g m^{-2} in the earliest-sown crops (Figure 2). Field-observed effects of late sowing, such as smaller canopy and reduced pod number and yield, were realistically reproduced. The results confirm the high potential productivity of faba bean at Adana. Infestation with 200 *O. crenata* seeds kg^{-1} soil caused a yield reduction of 88% (averaged across sowing dates), which is in the range of reported values. Delayed sowing significantly improved the yield of infested crops due to faster simulated phenological development of faba bean relative to parasites. This complies with established findings on the mechanisms underlying this traditional method of parasite control (Sauerborn, 1989).

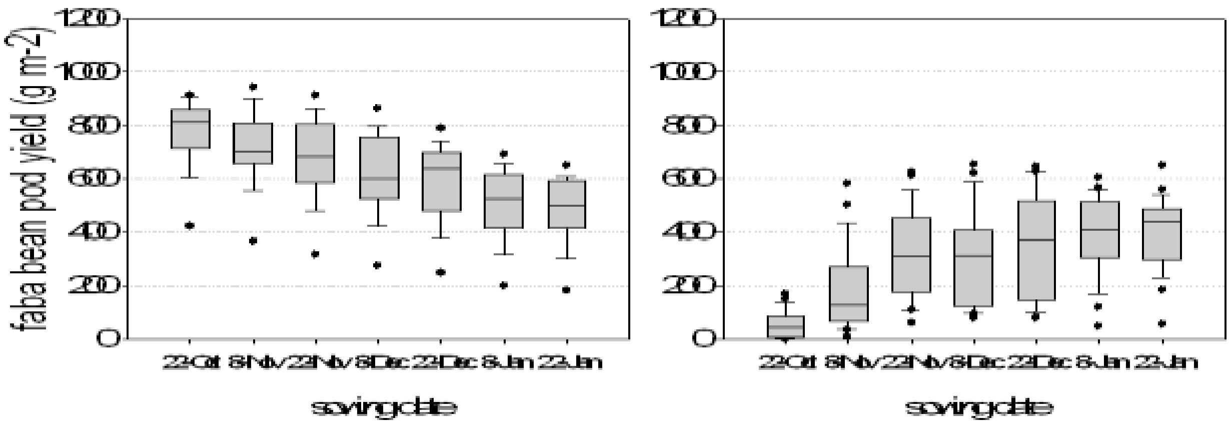

Figure 2. Simulated faba bean pod yield as affected by sowing date and *O. crenata* infestation based on weather records of 20 consecutive growing seasons (1979/1980 – 1999/2000) from Adana (Turkey). Boxes represent the second and third quartiles, lines show median, whiskers mark 10% and 90% quantiles, dots symbolise 5% and 95% quantiles.

Multi-season: effects of location and weeding schedule

Faba bean and *O. crenata* biomass, and consequently *O. crenata* seed production, were markedly higher at Adana than at Tel Hadya (Figure 3). This was a result of milder climate and more abundant rainfall. The *O. crenata* seed bank density increased with time and peaked at approximately 2 and 2.7 million seeds m^{-2} at Tel Hadya and Adana, respectively, which corresponds well with data reported from Spain by Lopez-Granados & Garcia-Torres (1993). Due to higher soil moisture levels, seed decomposition occurred at a higher rate at Adana than at Tel Hadya. The final faba bean crop failed in both locations, indicating that in infested fields, parasite control is required to profitably grow the crop every fifth season.

Simulations including hand-weeding revealed a high potential of this measure to confine parasite infestation. Well-timed weeding once a season reduced predicted average yield losses from 42% (S_i = 2,000 m^{-2}) and 89% (S_i = 30,000 m^{-2}) to 1% and 12%, respectively. Weeding scheduled according to crop phenology was particularly effective at high *O. crenata* infestation densities. The model-recommended optimum time for weeding, which was two weeks after faba bean flowering, corresponded well with recommendations derived from field trials in Syria (ICARDA, 1989).

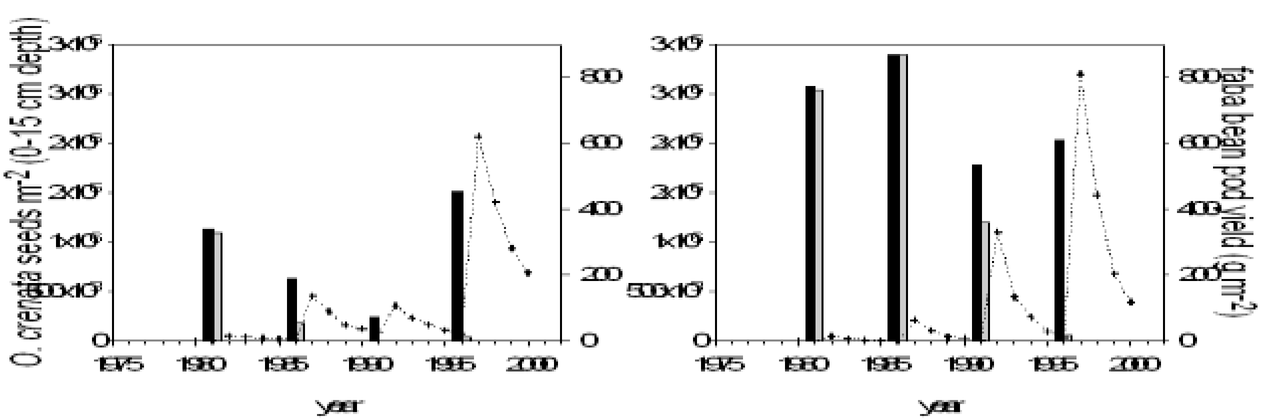

Figure 3. Simulated faba bean pod yield and population dynamics of *O. crenata* over 20 consecutive growing seasons (1979/1980 – 1999/2000) at two contrasting Mediterranean sites. Black bars represent pod yield of non-infested faba bean, grey bars pod yield of faba bean initially infested with 2,000 *O. crenata* seeds m^{-2}, the line shows parasite seed bank dynamics.

Conclusion

In this study, the cropping systems model APSIM proved capable of predicting development and growth of faba bean with and without *O. crenata* infestation under Mediterranean conditions. Both mechanisms and quantitative outcomes of host-parasite-environment interactions were simulated in accordance with established findings. The newly-added capability for calculating seed bank dynamics proved functional and rendered realistic results. The functionality and flexibility displayed by APSIM make it a potentially useful tool for the assessment of short and long term consequences of *O. crenata* control strategies.

References

International Center for Agricultural Research in the Dry Areas, ICARDA (1989). Annual report of the Food Legume Improvement Program. Aleppo, Syria.

Keating BA, PS Carberry et al. (2003). An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267-288.

Kebreab E and Murdoch AJ (1999). Effect of temperature and humidity on the longevity of Orobanche seeds. Weed Research 39, 199-211.

Lopez-Granados F and Garcia-Torres L (1993). Seed bank and other demographic parameters of broomrape (Orobanche crenata Forsk.) populations in faba bean (Vicia faba L.). Weed Research 33, 319-327.

Manschadi AM, Wang E, Robertson MJ, Meinke H and Sauerborn J (2003). Development of a parasite module in APSIM - Case study: the parasitic weed *Orobanche crenata* infesting faba bean. Proceedings of the 11th Australian Agronomy Conference, Geelong, Victoria, (Australian Society of Agronomy). http://www.regional.org.au/au/asa/2003/c/18/manschadi.htm

Sauerborn J (1989). The influence of temperature on germination and attachment of the parasitic weed Orobanche spp. on lentil and sunflower. Angewandte Botanik 63, 543-550.

Schnell H, Kunisch M, Saxena MC and Sauerborn J (1996). Simulation of the seed bank dynamics of Orobanche crenata Forsk. in some crop rotations in northern Syria. Experimental Agriculture 32, 395-403.