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SIMULATION OF THE GROWTH OF FABA BEANS (VICIA FABA L.) INFESTED WITH BROOMRAPES (OROBANCHE CRENATA FORSK.)

M.J. Kropff and P. Schippers

Department of Theoretical Production Ecology, Agricultural University, P.O.B. 430,6700 AK Wageningen, The Netherlands.

Abstract

An existing simulation model (Grashoff, 1986) for the growth of faba beans under potential conditions and under conditions when water limits crop growth was linked with a preliminary submodel for the growth and development of broomrape (*Orobanche crenata* Forsk.). In the model broomrapes are characterised as organs of the faba bean plants with a strong "sink capacity" for assimilates. Dry matter allocation to the broomrapes is simulated in dependence of the developmental stage of the broomrape. Parameters and rates of processes that determine broomrape growth were estimated from experimental data. Despite its preliminary character the model simulates realistic values for bean seed yield and broomrape dry weight. The potentials of the model and the simulation approach are discussed and directions for future research are indicated.

Introduction

The total root parasite *Orobanche crenata* Forsk. causes considerable damage to legume crops in the Mediterranean area. Heavy broomrape infestations in faba bean crops (*Vicia faba* L.) may result in total yield loss (Pieterse, 1979; Saghir and Dastgheib, 1978). Up to now there is no consistent economic method for broomrape control in faba bean crops.

In most studies on broomrape control the effect of different control measures and methods on final crop yield are compared empirically. Only in a few studies the quantitative relation between broomrape infestation and yield loss was estimated (Mesa-Garcia and Garcia-Torres, 1984). These quantitative relations are needed for estimation of economic thresholds of broomrape control and for forecasting yield losses at certain broomrape infestations. Damage relationships and the effect of control measures vary with the environmental conditions (weather, soil characteristics,irrigation,etc.; cf ter Borg, this volume).

The development of effective broomrape control systems requires a better understanding of the growth of the crop, growth of the parasite and their interaction under different environmental conditions in a quantitative way. Crop growth and its interaction with the parasite can be understood quantitatively with the help of an explanatory simulation model. Such a model integrates the existing knowledge on ecophysiological processes that determine growth of the crop and its interaction with the parasite. A thoroughly validated model may be used to estimate damage relationships and to evaluate theoretically the effect of control measures under different environmental conditions. This approach has been followed succesfully in pest and diseases management systems (Rabbinge and Rijsdijk, 1983).

This paper presents a preliminary simulation model for the growth of a faba bean crop and its interaction with broomrapes in dependence of environmental variables. The paper starts with a discussion of the dynamic simulation approach. It then describes briefly the relations between the elements of the faba bean-broomrape system. Some results of the model are presented and discussed. Finally, the potentials of the model and the approach are discussed and the need for specific research on broomrape-faba bean interaction is indicated.

Systems analysis and dynamic simulation

Dynamic simulation models for crop growth have been developed in the past 20 years. They have proven to be a useful tool in agricultural research and practice for various reasons. In the first place they enable us to integrate knowledge from various disciplines and to make this knowledge operational. Models are instruments with which the current state of knowledge can be evaluated and they help to formulate the right research questions. Once a model is thoroughly validated it may be summarized and can be used for prediction (Penning de Vries, 1982).

Models are relatively simple representations of real systems and contain the most important interacting elements. An example of such a system is a field crop of faba bean in which the dry weights of the organs (leaves, stems, roots and reproductive organs) are the main elements of the system. For the construction of dynamic simulation models a number of steps have to be taken. In the first place the system has to be defined and the elements and the relations between the elements have to be described. The boundaries of the system are chosen in such a way that the system is influenced by its environment, but not the reverse. In the second step the variables, their interrelations and their dependence on environmental conditions are quantified. This quantitative information is expressed in a computer program. The model is evaluated by comparing the simulation results with observations of the real system. When the simulation differs from the observations the model has to be improved on the basis of better insight in the functional relations of the system. After validation of the model sensitivity analysis can be made by changing the value of the parameters in the model to analyse the relative importance of the parameters.

The faba bean-broomrape model

General structure of the model

The model consists of two submodels: a growth model for faba beans and a broomrape submodel. The faba bean model has been constructed by Grashoff (1986), based on the crop growth model developed by Jansen and Gosseye (1986). The model simulates dry matter growth and phenological development of the crop as a function of light, temperature and available soil moisture. In the faba bean growth model two production situations are considered. Growth of the crop is either limited by the amount of incoming light, temperature and crop characteristics (potential production situation) or growth is at least a part of the time limited by available soil moisture (second production situation). Nutrients are assumed to be available in non-limiting amounts and the crop is free of pests, diseases and weeds. In the broomrape submodel growth of the parasite is calculated from the amount of carbohydrates allocated from the faba bean shoot.

Simulation of faba bean growth

In this section the essential parts of the crop growth model are described and illustrated in fig. 1. For a full description of the model we refer to Jansen and Gosseye, 1986, van Keulen, 1975 and van Keulen et al., 1982.

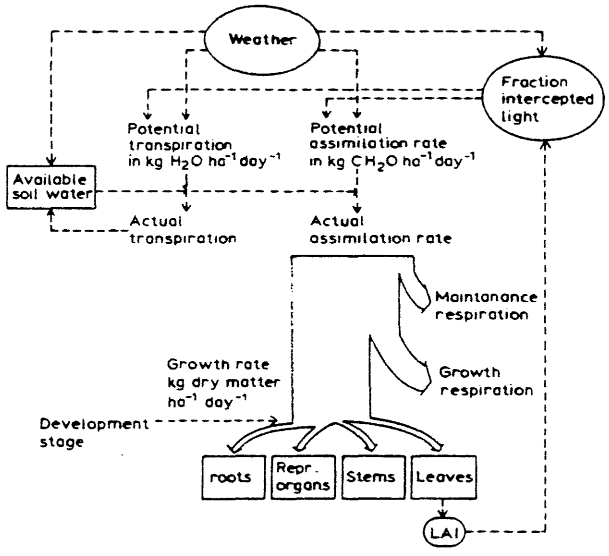

Figure 1. General structure of the faba bean model.

Potential growth of the crop

When crop growth is not limited by water and nutrients and when the crop is free of pests, diseases and weeds, growth is determined by the available light, temperature and some crop characteristics. Daily gross CO_2-assimilation of the canopy is computed from the input variables daily incoming radiation and average daily temperature.

The incoming radiation is partly absorbed by the leaves and partly lost by reflection or transmission to the bare soil. From the leaf area and some crop characteristics the absorbed amount of light is calculated. Daily gross CO_2-assimilation is calculated from the absorbed amount of photosynthetically active radiation. The basis for this calculation is the photosynthesis-light-response of single leaves. The computed gross CO_2 assimilation is expressed in carbohydrates (CH_2O).

A part of the carbohydrates produced is lost by respiration processes for maintenance and growth. Maintenance respiration is necessary to maintain ion gradients across cell walls and for protein-turnover and is assumed to be proportional with the biomass. Temperature effects on maintenance respiration are accounted for with a Q10 value of 2. Growth respiration is the loss of carbohydrates (in the form of CO_2 and H_2O) as a result of conversion of carbohydrates into structural biomass. The efficiency of this conversion only depends on the chemical composition of the dry matter formed. On the average 0.7 gram structural dry matter is formed from 1 gram carbohydrates.

Dry matter is distributed in dependence of the physiological age of the crop which is characterised with the phenological development stage of the crop. Developmental rate is only dependent on average daily temperature in this situation. The leaf area is computed by multiplying the dry weight of the leaves with the specific leaf area which is dependent on developmental stage. The leaf area determines the fraction of light which is absorbed by the canopy and with that the assimilation rate. This part of the model is derived from the summary model SUCROS (van Keulen et al., 1982).

Growth of the crop when limited by water

In the second production situation water limits crop growth. In a water balance submodel the distribution of water over the different soil layers is simulated because it determines the amount of water which is available for the crop (the amount of water above wilting point). Water is lost by drainage and evapotranspiration. Input of soil water is a result of irrigation and rainfall.

Potential transpiration and evaporation from the soil are calculated with the methods proposed by van Keulen, 1975, based upon the Penman formula for evaporation of water from a free water surface. The driving forces for these processes are the incoming radiation, the vapour pressure deficit of the air and windspeed. Transpiration rates depend further on canopy architecture and the stomatal resistance for water vapour diffusion.

At low soil moisture content the actual transpiration rate is lower than the potential transpiration rate due to closure of stomata. The reduction of the potential transpiration rate is simulated in dependence of soil moisture content in the rooted zone.

Water stress influences developmental rate, photosynthetic capacity and leaf dying rate of the crop. The water balance submodel is coupled to the growth submodel by reducing assimilation rate with the same factor as the potential transpiration rate (Tact/Tpot). This is based on the assumption that stomatal closure due to waterstress reduces transpiration and CO_2 assimilation with the same factor. This part of the model is based on the model ARID CROP (van Keulen, 1975).

Different parts of the model have been tested for several crops under various environmental conditions. The faba-bean model was validated with field experiments of several years at different irrigation levels by Grashoff (1986). It simulated the time course of crop growth and soil water content well enough for many purposes. The model overestimated the final production at high irrigation levels, probably because a field crop in that situation is never free of diseases, as is assumed in the model (Grashoff, 1986).

Simulation of growth and development of broomrape

A simple model for the growth and development of broomrapes and their interaction with the crop is constructed. Only interactions concerning the carbon-balance of the parasite host system are included.

Phenological development

Phenological development of the broomrape is simulated in dependence of temperature according to data of Schmitt (1981): At an accumulated temperature of 51 degree-days from emergence of faba bean the seeds germinate induced by root exudates of the faba bean, and connect the vascular tissues of the host roots. At 878 degree-days from emergence of faba bean a bud is formed from the tubercle (a bulb shaped organ formed on the place where the connection is made). The bud produces a florescence (spike) which emerges and maturity is reached at 1661 degree-days from emergence of faba bean.

Host-parasite interaction

A broomrape is an 'extra strong sink' for carbohydrates by maintaining a very low sucrose concentration in its tissue (Whitney, 1972). The fraction of carbohydrates which is allocated to the broomrapes is dependent on the developmental stage of the broomrape and broomrape density. The relation between the fraction of carbohydrates which is allocated to the broomrapes at a broomrape density of 1 spike per faba bean plant (f_{br}) and development stage of the broomrape, is estimated from unpublished data of M. Bogers and S. ter Borg (fig. 2).

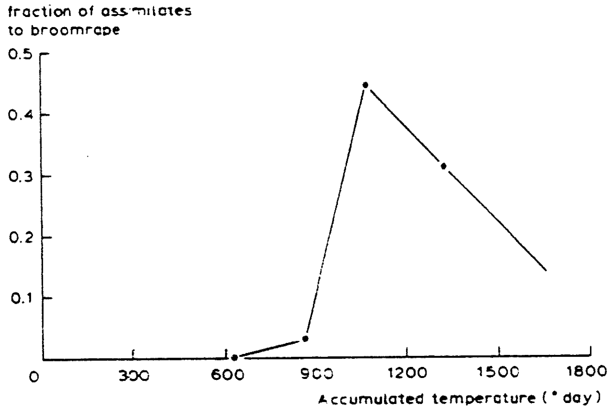

Figure 2. The fraction of carbohydrates allocated to the broomrape at a density of 1 broomrape per <u>Vicia</u> <u>faba</u> plant in dependence of accumulated temperature from faba bean emergence (calculated from data of Bogers/ ter Borg, variety Giza 402).

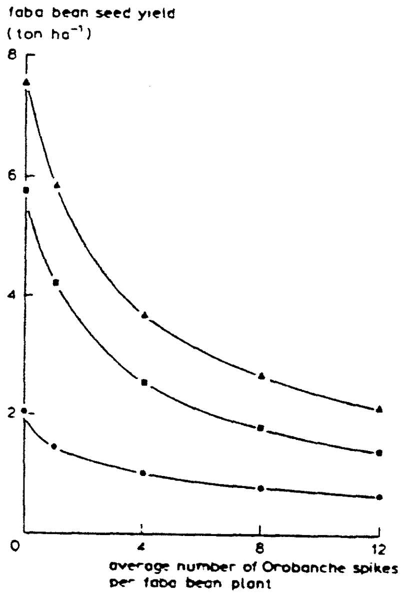

Figure 4. Simulated final seed yield of faba bean at three irrigation levels (no irrigation ● ; 10 mm water per 10 days ■ ; 10 mm water per day ▲) at different average broomrape densities.

The simulated dry weight of the broomrapes seems realistic when compared with literature data (table 1). These results indicate that the effect of broomrapes on faba beans may be explained from carbohydrate allocation to the broomrapes. However, this cannot be concluded until model performance is evaluated with complete data sets from field experiments in which faba bean dry weights and broomrape dry weights are measured simultaneously in the course of time.

Table 1. Simulated and observed dry weights of broomrapes at different broomrape densities and production levels (seed yield without broomrapes).

seed yield in ton ha^{-1}	average number of spikes per plant	dry weight broomrape (g/spike)	
2.0	0.5	2.3	simulation results
5.8	0.5	6.8	" "
3.8	0.2	3.6	Nassib et al., 1984
4.1	0.02	6.0	"
4.4	0.1	13.0	"
3.4	0.12	6.7	Zahran, 1982

parameters and functions used in the model are derived from experimental data of the variety Minica, one of the most productive european varieties and may be different for varieties used in the Mediterranean area (Grashoff, pers. comm.) and should be adapted in the model.

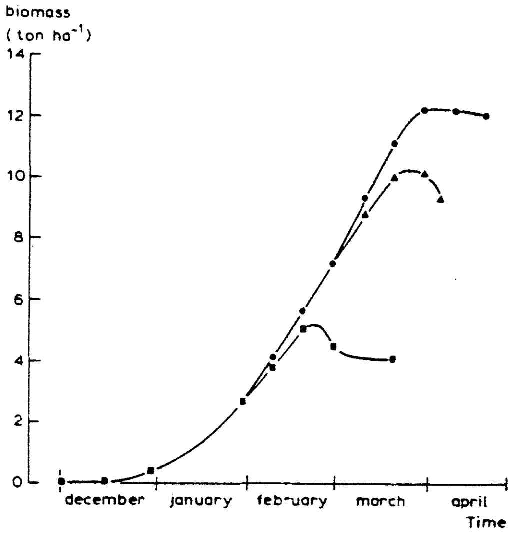

Figure 3. Simulated time course of faba bean growth at three irrigation levels (no irrigation■ ; 10 mm water per 10 days▲ ; 10 mm water per day ●).

Growth of the crop infested with broomrapes

With the faba bean-broomrape model the effect of different broomrape densities on seed yield and broomrape growth is simulated at the three irrigation levels under the same conditions as described earlier. Bud formation of the broomrapes is simulated to be 10 days after the start of seedfilling in the faba beans. Total production of faba beans and broomrapes decreases with broomrape density as a result of leaf area reduction due to broomrape growth. Simulated bean seed yield decreases strongly with broomrape density at all irrigation levels (fig.4).

Absolute seed yield reduction is simulated to be proportional with the production level. At an average value of 5 broomrapes per plant bean seed yield is halved. This simulated reduction in seed yield is realistic when compared with field data of Mesa-Garcia and Garcia-Torres (1984) who reported 50% reduction in seed yield at densities of 2.9-7 spikes per plant. At higher broomrape densities the simulated reduction of faba bean seed yield is not strong enough when compared with the almost linear relation between seed yield and broomrape density found by Mesa-Garcia and Garcia Torres (1984) and Schmitt (1981).

Discussion

Two approaches may be distinguished in modelling crop parasite interactions. First the approach in which the effect of broomrapes on crop growth is quantified within one growing season, which is followed in this paper. A second approach deals with the population dynamics of the parasite. In research on broomrape control the dynamics of the population are important because one broomrape produces many tiny seeds which remain viable for more than 10 years (Pieterse, 1979). These approaches require different types of models, although models on population dynamics need summarized information of the processes in the growing season. This information may be generated with explanatory models which simulate the behaviour of the host parasite system within one growing season.

Despite of the simplicity of the model and the weak parameter estimates simulated bean seed yield, seed yield reduction at low broomrape densities and broomrape dry weights are realistic. However, a thorough evaluation of the model by comparing its results with detailed data from field experiments is necessary. The mechanism of interaction between broomrape and faba bean has to be analysed and the parameter values used in the model have to be verified because they are based upon only a few experimental data.

This study illustrates one of the most important advantages of this approach: The structured approach of systems analysis forces us to formulate precise questions which need quantitative answers from experimental research; i.e. how is broomrape developmental rate related to environmental factors and faba bean development?; which fraction of the carbohydrates from photosynthesis is allocated to the broomrape at the different developmental phases?; how much water is transpired by a spike? ; what is the chemical composition of broomrapes?

Other potentials of this approach appear once the model is validated and explains the behaviour of the system good enough. It is then possible to do sensitivity analyses by changing in turn the values of the parameters to examine their relative importance. This analysis indicates directions for future research. Once the model is validated it is also possible to perform experiments with the model, i.e. to evaluate the effect of control measures.

Although much experimental work can be avoided, it is important to realize that the model is only a simple representation of reality. Observations of the real system remain necessary.

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