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SIMULATION OF CROP WEED COMPETITION

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1. INTRODUCTION

Weeds reduce crop yield by competition for the growth limiting resources, light, water and nutrients. There are many examples of studies in which quantitative approaches have been developed to describe competition effects (Spitters et al., 1987). In most of these approaches simple mathematical equations are used to describe the relation between plant density and yield. The relation between weed density and crop yield can best be described with a hyperbolic equation (Spitters, 1983, Spitters et al. 1987). Although this hyperbolic equation fits very well to experimental data of additive experiments in which only the weed density is varied, it cannot be used to predict effects of weed competition in specific field situations since many other factors determine the competitiveness of weeds (i.e. relative time of weed emergence, row spacing and weather variables influencing morphology and growth of the species (Zimdahl, 1981). This was illustrated in a study on maize-barnyard grass competition.

A very close fit of the hyperbolic model to experimental data on maize yield at different barnyardgrass densities has been found in two successive years on the same site (Fig. 1) (Kropff et al. 1984, Spitters et al., 1987).

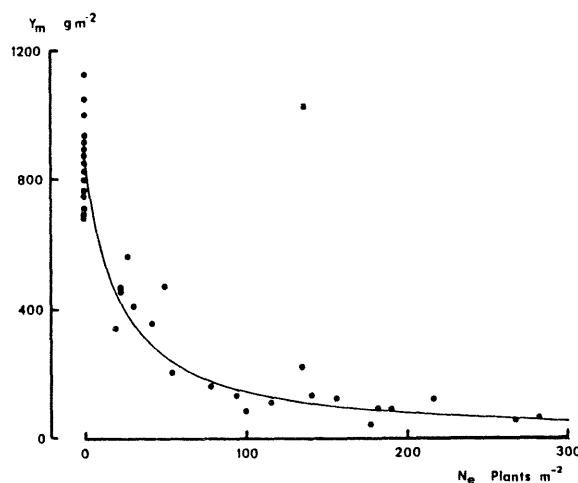


Fig. 1. Maize yield at different weed densities relative to weed-free yield (Kropff et al., 1984).

However, in the first year the maize yield was hardly reduced at high densities of the weeds (8% at 300 barnyardgrass plants m^{-2}), whereas in the second year maize yield was strongly influenced even at low densities of the weeds (50% yield reduction at 21 barnyardgrass plants per m^{-2}). This study indicated that the usefulness of the hyperbolic model is very limited for the derivation of threshold weed densities for weed control advisory systems. The same conclusion holds for experimentally derived so called critical periods (the minimum period of time during which weeds must be suppressed in order to prevent yield losses) (Zimdahl, 1981, Weaver, 1984).

Since many factors determine the outcome of interplant competition, explanatory simulation models may be useful to gain more insight in the crop-weed system and for the derivation of damage relationships. These models are based upon insight in the real processes involved in competition for the growth-limiting resources and the use of the captured resources in plant growth processes. Simulation models for crop-weed competition have been developed and evaluated with field-experimental data on maize-barnyardgrass competition (Kropff et al., 1984, Spitters, 1988, Spitters & Aerts, 1983). Analysis of the data on maize-barnyardgrass competition with simulation models showed that the different yield-density relationships were caused by differences in relative starting position of the weeds and by the severe drought in 1983 (Spitters, 1984, Kropff et al. 1984).

In this study such a model is applied to competition between sugarbeet and fat hen. A short description of the model will be given first, followed by an analysis of model behaviour by comparing the results with a field experiment. For an extensive evaluation of the model with 5 sugarbeet-Chenopodium experiments we refer to Kropff et al., 1988. The sensitivity of model parameters is tested for this specific situation and finally the simulation model was used to predict yield-weed-density relations at different times of weed emergence and critical periods at different weed infestations.

2. DESCRIPTION OF THE MODEL

Simulation models for crop-weed competition at different levels of complexity have been developed recently (Spitters, 1984, Spitters & Aerts, 1983, Spitters, 1988, Spitters & Kropff, 1988). These models are based upon existing models for crop growth (Penning de Vries & Van Laar, 1982, de Wit et al., 1978). The time course of the competition process is simulated by distribution of the growth limiting resources over the species. The growth rates of each of the species is calculated from the amount of acquired resources by each species.

The model applied in this study is derived from the model for maize and barnyard-grass (Spitters & Aerts, 1983) and is parameterized for su-

garbeet and for fat hen. In this paper a short description of the principles of the simulation model is given. For a full description of the underlying principles and algorithms we refer to Spitters (1988) and Spitters & Kropff (1988).

2.1. SIMULATION OF CROP GROWTH IN MONOCULTURE

General structure

The model simulates potential dry matter growth and phenological development of a crop as a function of incoming daily radiation temperature and some crop characteristics (Fig. 2). In this potential production situation it is assumed that water and nutrients are available in non-limiting amounts and the crop is assumed to be free of pests, diseases and weeds.

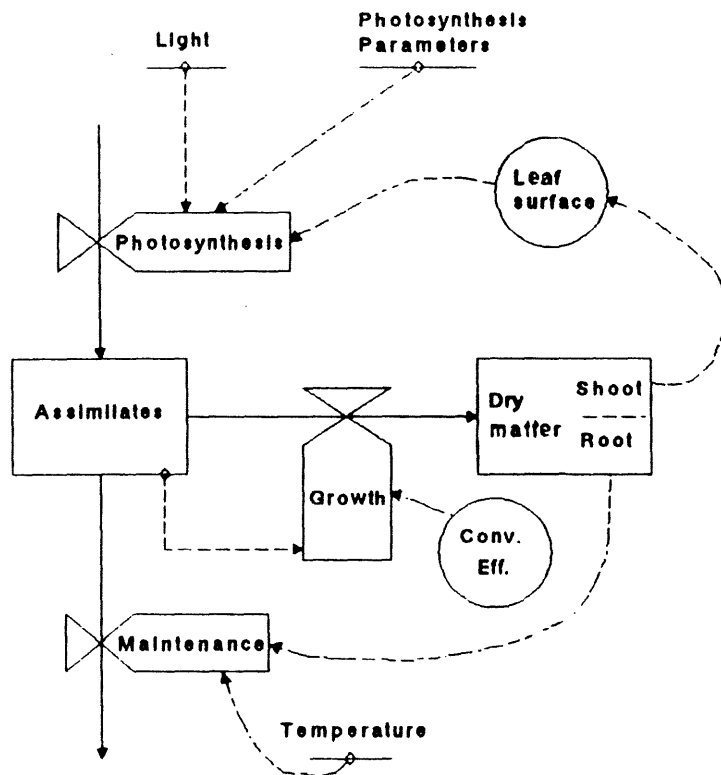


Fig. 2 Relational diagram of the carbon balance processes determining crop growth. Rectangles represent state variables; valves: rate variables Underlined: driving variables; flow of material; --- flow of information.

Simulation of crop growth

The starting point for calculation of gross canopy assimilation is the light penetration profile in a crop canopy which can be described as an exponential function of leaf area:

$$I_h = I_0 \exp(-k \text{ LAI}_h) \quad (1)$$

where I_h is the visible irradiance ($\text{J m}^{-2} \text{ s}^{-1}$) at a certain depth in the canopy; I_0 is the incoming average visible radiation (400-700 nm) corrected for 8% reflection; LAI_h is the leaf area index ($\text{m}^2 \text{ leaf} / \text{m}^2 \text{ ground}$) calculated from the top of the canopy downwards and k is the light extinction coefficient (-) which depends on canopy architecture. The derivative of Eq. 1 gives the absorbed amount of visible irradiation per unit leaf area at a certain depth in the canopy:

$$I_{\text{abs},h} = -\frac{dI_h}{d\text{LAI}_h} = k \cdot I_0 \cdot \exp(-k \cdot \text{LAI}_h) \quad (2)$$

From the CO_2 -assimilation light response of individual leaves and the amount of absorbed radiation the rate of CO_2 -assimilation is calculated for a number of leaf layers. Integration over canopy LAI and time gives the daily CO_2 -assimilation of the canopy.

The computed gross CO_2 assimilation is expressed in carbohydrates which are converted into structural biomass by subtracting losses due to respiration for maintenance and growth processes. Respiration for maintenance of ion gradients across cell wall and protein turnover is assumed to be proportional to the biomass of the standing crop ($Q_{10}=2$). Respiration for growth is a result of conversion of carbohydrates into structural biomass. The efficiency of conversion is only dependent on the chemical composition of the biomass.

The dry matter formed is distributed over the plant organs with empirically derived distribution functions in dependence of developmental stage of the crop. Developmental rate is calculated as a function of temperature. Leaf area is assumed to be a function of leaf dry weight with an empirically derived parameter: the specific leaf area (SLA), which is a function of developmental stage.

Since leaf area growth early in the growing season when the $\text{LAI} < 0.75$ is not limited by carbohydrate supply but is driven by temperature, leaf area development in this period is simulated with a temperature dependent relative leaf area growth rate.

2.2. SIMULATION OF CROP WEED MIXTURES

In a mixture of crop and weeds the canopy is divided in a number of horizontal leaf layers. Per leaf layer the amount of absorbed radiation is calculated as in a monoculture. A parabolic leaf area distribution over the height of the plants is assumed. The amount of absorbed radiation of the species in a certain canopy layer is distributed over the species according to their share in leaf area, weighted with their extinction coefficient for light:

$$f_{\text{abs},i} = \frac{k_i \text{ LAI}_i}{\sum k \text{ LAI}} \quad (3)$$

where $f_{\text{abs},i}$ is the fraction of light absorbed by species i . Integration of assimilation rates over the leaf layers and over time gives the daily assimilation rate of the species. Dry matter growth is calculated for each species as in monoculture. Plant height is described with an empirically derived function of developmental stage.

3. MODEL EVALUATION

Most parts of the model have been evaluated and validated thoroughly (Penning de Vries & Van Laar, 1982). Different versions of the competition model have been tested with many field experiments (Kropff et al., 1984, Kropff et al., 1988, Spitters, 1984, Spitters & Aerts, 1983). In this study the model was applied to competition between sugarbeets and fat hen (*Chenopodium album*, L.). A full analysis of 5 field experiments with these species with a model for competition for light and water will be given by Kropff et al., 1988. The 1985 experiment was conducted at a potential production situation and will be discussed here.

In 1985 growth of sugarbeet (*Beta vulgaris*, L. cv. monohil) and fat hen (*Chenopodium album*, L.) was measured in monocultures and mixtures by frequent harvesting. The field experiment was carried out on a sandy soil in Wageningen. Sugarbeets were grown at 30*30 cm and fat hen plants were equally distributed between the sugarbeet plants. In this experiment fat hen was grown at 5.5 plants m^{-2} in mixture and at 11 plants m^{-2} in monoculture. Sugarbeets emerged at day 129 and fat hen at day 139. (Day numbers counted from the 1st of January onwards).

Model inputs

Model inputs were the measured weather variables from a nearby station (daily maximum and minimum temperature and daily total global radiation) and dates of crop and weed emergence. Data on species characteristics were derived from literature and from own experiments. Input species characteristics were:

- developmental rate in dependence of temperature
- dry matter distribution functions
- death rate of green leaves
- specific leaf area
- initial leaf area
- relative growth rate of leaf area in early growth
- light extinction coefficient
- parameters of the CO₂-assimilation light response curve.

Model performance

In the first simulation runs the leaf area was input in the model to check the simulation of carbon balance processes. A very close fit was found for growth of the species in monoculture and mixture. This indicates that apart from leaf area development, processes which determine growth of species in mixture are well understood.

Extrapolation to other situations is only valid when the model correctly simulates dry matter growth without input of measured data on leaf area progression. The simulation results of the model version including simulation of leaf area are presented in Fig. 3. The model simulates dry

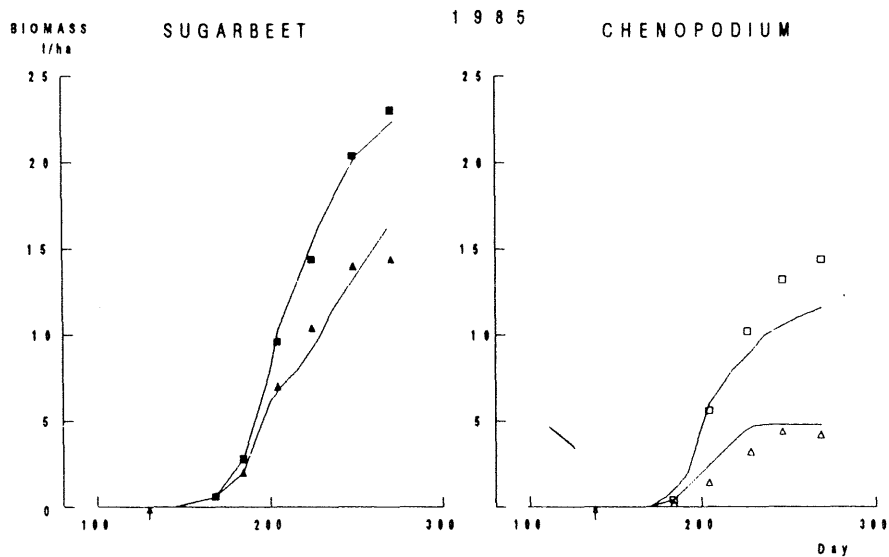


Fig. 3 Simulated (—) and observed time course of above-ground biomass in 1985 of sugarbeet and *Chenopodium album* in monocultures (squares) and mixtures (triangles).

matter growth of sugarbeets both in monoculture and mixture very well for the 1985 situation. Growth of fat hen was underestimated at the end of the season for the monoculture. A slight overestimation was found in mixture. The model used by Kropff et al. (1988) included a water balance and was able to explain extreme differences in competition effects of fat hen on sugarbeet yield between 5 experiments (in which the yield loss ranged from 0-95%). The periods between crop and weed emergence and weed density were the main factors causing differences in competitive effects of fat hen on sugarbeets.

4. DISCUSSION

Crop and weed characteristics determining competition effects

The importance of species characteristics can be studied with a sensitivity analysis. The relative sensitivity of the model output to changes in the value of the most important characteristics is expressed as the percentage yield-increase divided by the relative change in the value of the species characteristic. From Table 1 it appears that simulated yield of sugarbeets is much more sensitive to the value of species characteristics in mixture than in monoculture.

Table 1 Relative sensitivity of the simulated sugarbeet yield for some species characteristics for a monocrop and a mixture with 5.5 fat hen plants per m^{-2} . The relative effect of an increment of a single sugarbeet-characteristic is expressed as the relative change in yield divided by the relative parameter increase.

species characteristic	relative sensitivity in monocrop	relative sensitivity in mixture
specific leaf area	0.3	1.1
light extinction coefficient	0.1	0.8
maximum leaf photosynthesis	0.3	0.6
height	0.0	0.6
leaf area in early growth	0.1	0.2

Simulation of yield density relationships and critical periods

The validity of the model (Kropff et al., 1988) makes it possible to use the model for prediction of the effect of relative date of weed emergence and weed density in these situations. Crop-yield weed-density relations have been generated for different dates of weed emergence in the 1985 situation (Fig. 4). The shape of the simulated yield density relation is very similar to the experimentally derived hyperbolic relations for maize and

barnyardgrass (Kropff et al., 1984). The strong influence of relative starting position on the yield density relationship is clearly illustrated in Fig. 4.

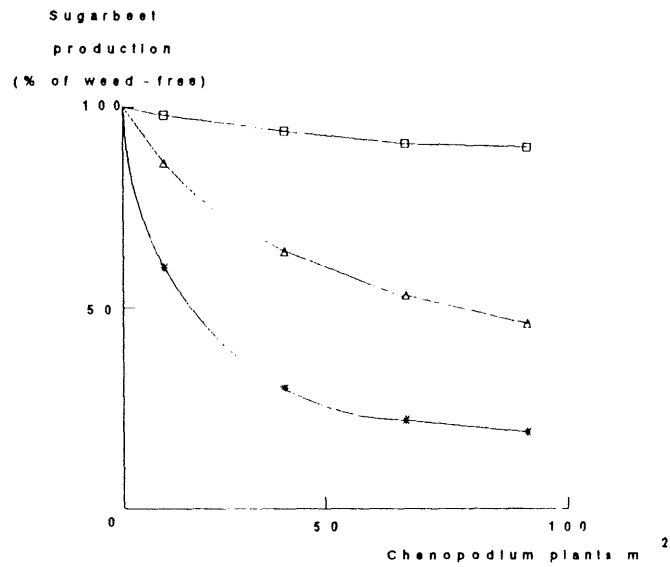


Fig. 4 Simulated relation between sugarbeet yield and weed density at 3 dates of weed emergence (* 10 days after crop emergence; Δ 20 days after crop emergence; \square 30 days after crop emergence).

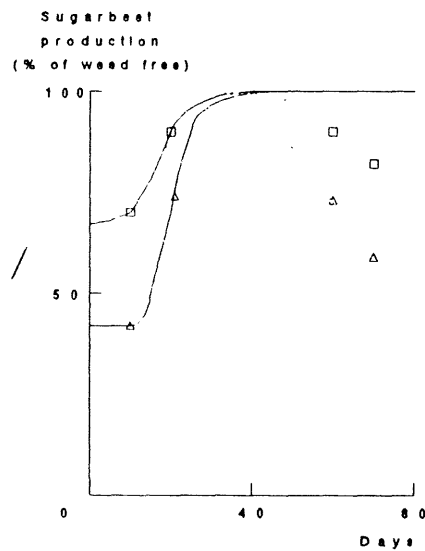


Fig. 5 Simulated relative sugarbeet yield for different durations weed free (—) or weed infested (---) at 2 weed densities (\square 5.5 plants m^{-2} ; Δ 22 plants m^{-2}).

In a second simulation experiment the critical period for weed removal in sugarbeets was simulated at different weed densities.

The results are presented in Fig. 5 and show the typical response curves of relative yield and period weed-free as is found in field experiments. The quantitative values are in close agreement with experimentally derived critical periods for sugarbeets (de Groot, pers. comm.).

5. CONCLUDING REMARKS

An advantage of the presented approach is that imaginary experiments can be performed when the model is thoroughly validated by comparing model output with experimental data. Such imaginary experiments can be used for orienting research i.e. the derivation of alternative damage relationships based upon relative leaf area of weed and crop some weeks after crop emergence; the effect of control measures on damage relationships. Labour and cost intensive field experimental work can be directed to test well defined hypotheses.

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