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Use of Ecophysiological Models for Crop-Weed Interference: The Critical Period of Weed Interference[1]

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Abstract. **The performance of a mechanistic simulation model of crop-weed competition was tested with data on the critical period of weed competition in sugarbeets and both seeded and transplanted tomatoes. In general, there was good agreement between simulated and observed yields for different periods of weed interference in each crop. The model was then used to evaluate the influence of weed density, weed height, and weather conditions on timing of the critical period. Simulations suggested that the greater the weed density, the shorter the period of time that the crop could tolerate early-season competition, and the longer the period of time that the crop must be kept weed free to prevent yield losses. Simulations also suggested that the length of time that a crop can tolerate early-season weed competition is related more to the availability of soil moisture, or possibly essential nutrients, than to light limitations. Nomenclature: Sugarbeet, *Beta vulgaris* L. 'Monohil'; tomato, *Lycopersicon esculentum* L. 'TH318' and 'Springset'.**

Additional index words. **Simulation, interference, sugarbeet, tomato, redroot pigweed, *Amaranthus retroflexus* L. #[3] AMARE, lambsquarters, *Chenopodium album* L. #[3] CHEAL.**

INTRODUCTION

Dynamic, mechanistic simulation models of weed-crop competition have been developed by Spitters and co-workers (6, 7, 10, 11). These models are extensions of a general simulation model for crop growth in monoculture (9, 17) to mixtures of crop and weed species in which growth-limiting resources are distributed among the species according to underlying physiological processes. Simulation models can be used as research tools to investigate the various factors that affect weed-crop competition, and to make predictions about crop yield losses which can then be tested in the field. An application of a mechanistic model to the relationship between weed density, the relative time of weed emergence, and crop yield losses has been described in an earlier paper (7). Here we use the model to explore the relationship between duration and timing of weed competition and crop yield losses.

The influence of length of time that weeds are present in a crop on the magnitude of crop yield losses has generally been analyzed in the context of the critical period of weed competition (8). This period represents the time interval between two separately measured components: the maximum weed-infested period, or the length of time that weeds that emerge with the crop can remain before they begin to interfere with crop growth; and the minimum weed-free period, or the length of time a crop must be free of weeds after planting in order to prevent yield losses. These components are experimentally determined by measuring crop yield loss as a function of successive times of weed removal or weed emergence, respectively.

Dawson (4) has suggested the use of period thresholds in integrated weed management systems to predict when, rather than if, weeds must be controlled to prevent yield losses. Economic period thresholds could also be calculated, indicating the length of time that a crop could tolerate weed competition before yield loss exceeded the cost of control. Early-season thresholds would denote the beginning of the critical period, and late-season thresholds the end. These two points are usually determined by applying multiple comparison tests to the data. Cousens (3) has pointed out the statistical problems associated with interpretation of such analyses and has suggested using fitted response curves instead. Such an approach would allow more precise estimation of yield losses but still suffers from problems associated with empirical relationships. The length of time that a crop can tolerate weed competition, and therefore the parameters of the response curves, will vary with crop and weed species, weed density, and environmental conditions. The use of a simulation model allows one to examine how such factors affect length of the critical period.

Objectives of the present study were to compare the performance of a simulation model with independent field data on the critical period of weed competition in tomatoes and sugarbeets, and to use the model to evaluate the influence of weed density, weed height, and weather conditions on the length of the critical period.

MATERIALS AND METHODS

The model. The structure of the simulation model has been described in detail previously (7, 10, 11). The model simulates dry matter growth of the crop and weed species from emergence through crop maturity as a function of radiation, temperature, rainfall, and species characteristics with a time step of 1 d.

The model was parameterized for competition between sugarbeets and lambsquarters, and tomatoes (seeded and

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[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

transplanted) and a mixed weed population of lambsquarters and pigweed. Physiological data used to parameterize the model for each crop and weed species were derived from the literature or independent experiments (1, 2, 6, 7, 12, 13, 16). Simulations were initialized with starting plant weight and leaf area at the time of emergence or transplanting. Daily weather data (maximum and minimum temperatures, rainfall, and total global radiation) recorded at each site were input to the model, as were crop and weed densities and dates of emergence or transplanting.

Data used to test the model. Data on the critical period of lambsquarters competition in sugarbeets and a complete account of experimental methods were originally published by Groot and Groeneveld (5). Monohil sugarbeets were grown at the Droevendaal experimental farm, Wageningen, The Netherlands, in 1982 and 1983, at a population of 82 000 plants ha^{-1}. A natural weed infestation dominated by lambsquarters was allowed to develop and remain in the crop for various periods of time, ranging from 20 to 70 d after crop emergence.

Data on the critical period of weed competition in seeded and transplanted tomatoes, and a complete account of experimental methods, were published by Weaver and Tan (14, 15). Experiments were conducted in 1980, 1981, and 1982 at the Agriculture Canada Research Station, Harrow, Ontario, Canada. 'TH 318' tomatoes were seeded to the field in May of 1981 and 1982 at a population of 17 000 plants ha^{-1}. Springset tomatoes were transplanted at the 2-leaf stage from the greenhouse to the field in May of 1980 and 1981, also at a population of 17 000 plants ha^{-1}. Natural weed populations dominated (> 90%) by lambsquarters and pigweed were allowed to grow for various lengths of time in each crop. In one set of treatments, weeds were allowed to grow for 0 to 63 d after planting, after which plots were kept free of weeds until harvest. In another set of treatments, plots were kept free of weeds for 0 to 63 d after planting, and then weeds were allowed to grow until harvest. Tomato yields and weed aboveground dry weights were measured in late August of each year.

Model analyses. Simulation runs were conducted initially for each crop and weed population in monoculture. Simulations of crop-weed competition were then conducted in which the dates of weed emergence or removal were systematically varied. Ability of the model to accurately simulate the effect of duration of weed competition on crop yields was tested by regressing observed against simulated yield loss over all periods of weed infestation for each crop. Ideally, the intercept should not be significantly different from 0, the slope should not be significantly different from 1.0, and the coefficient of determination should be high. The effects of weed density, the maximum height of the weed canopy, and soil moisture availability on the relationship between the duration of weed competition and crop yields were examined by systematically varying each of these model parameters in turn while holding all others constant.

RESULTS AND DISCUSSION

Sugarbeets. Kropff et al. (7) previously validated the model for sugarbeets and lambsquarters grown in monoculture and in full-season competition over a wide range of weed densities, with data collected in 1984, 1985, and 1986 at the same site as in the present paper. The results of simulation runs for various durations of lambsquarters competition and observed data for 1982 and 1983 are shown in Figure 1. There was generally good agreement between simulated and observed yields (Table 1). The model underestimated crop yield losses when weeds were allowed to compete with the crop for longer than 60 d after sowing (45 d after crop emergence) in both years (Figure 1b).

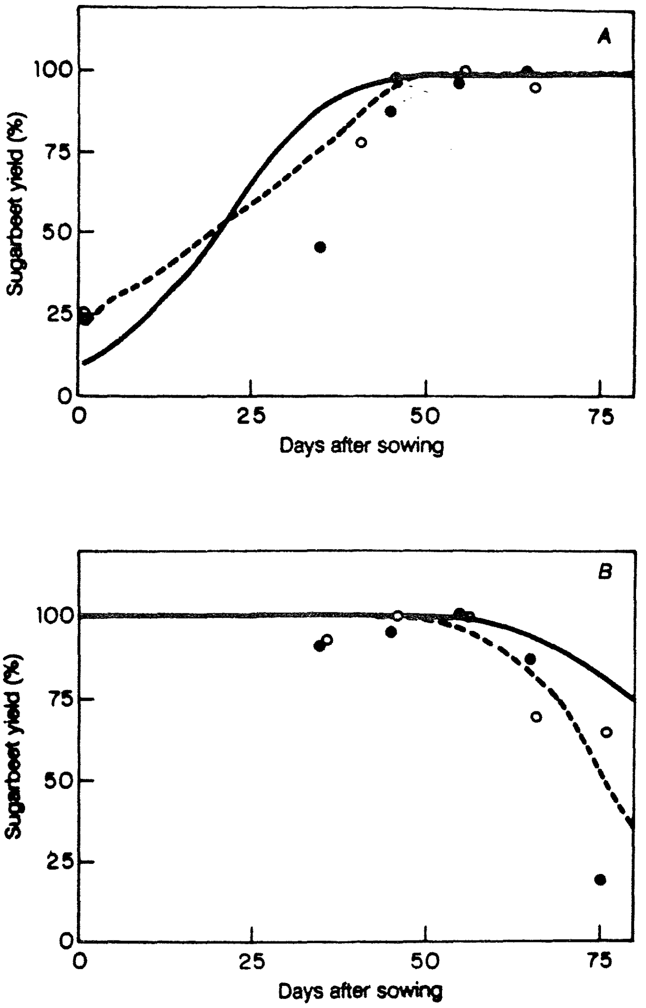

Figure 1. Simulated and observed sugarbeet yields for 1982 (——, ○) and 1983 (– – –, ●) with different weed-free (a) or weed-infested periods (b). Yields are presented as percentages of the weed-free controls.

Tomatoes. The model accurately simulated the increase in dry matter of both weed and tomato populations grown in monoculture, for both methods of crop establishment, during the 1981 season (Figure 2). Data on growth of transplanted tomatoes and weeds during 1980 were similar to those in 1981 and are not presented (14). Observations on the increase in dry matter of seeded tomatoes during the 1982 season were not available.

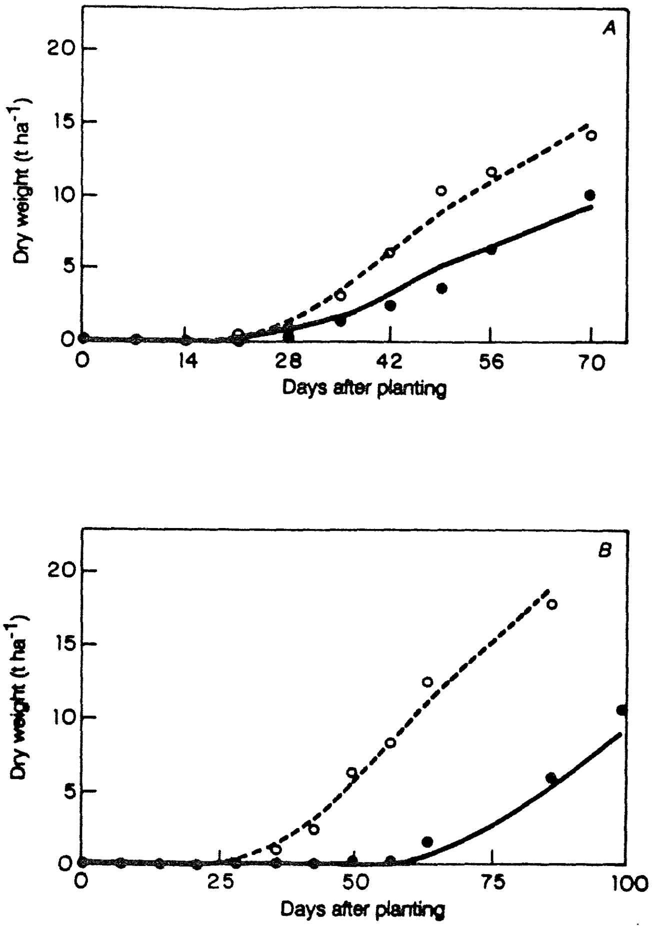

Figure 2. Simulated and observed aboveground dry weights of tomatoes (——, •) and weeds (– – –, o) during the 1981 growing season for transplanted (a) and seeded (b) tomatoes.

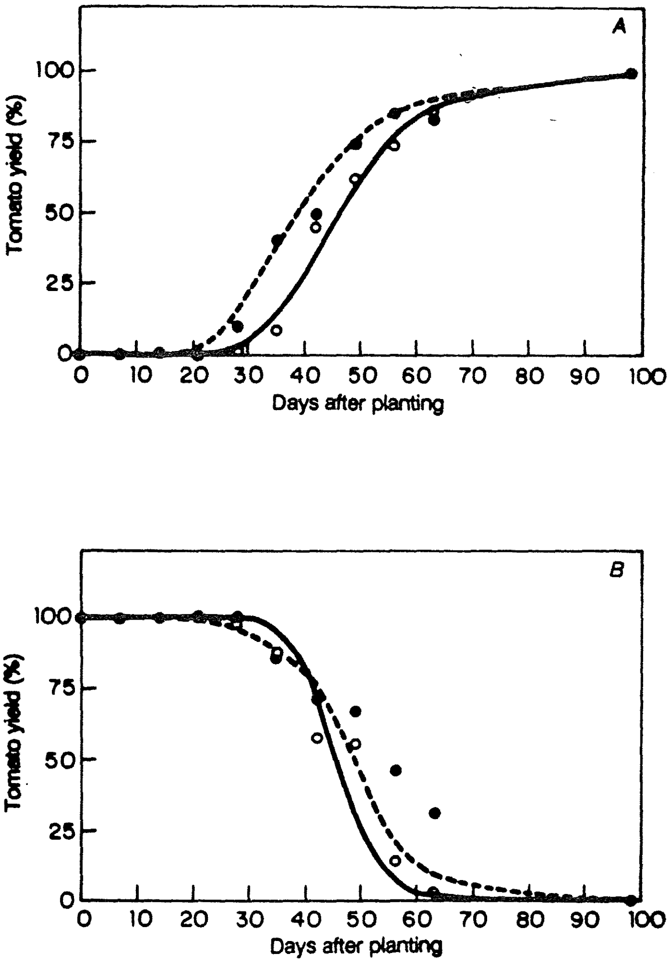

Figure 3. Simulated and observed yields of seeded tomatoes for 1981 (——, o) and 1982 (– – –, •) with different weed-free (a) or weed-infested periods (b). Yields are presented as percentages of the weed-free controls.

There was generally good agreement between simulated and observed crop yields resulting from various durations of weed competition in seeded tomatoes in 1981 and 1982 (Figure 3, Table 1). The model overestimated crop yield losses when weeds remained in the crop for longer than 50 d after seeding (40 d after emergence) in 1982 (Figure 3b).

Results of the simulations for transplanted tomatoes also closely matched the observed data for various periods of delayed weed emergence in both 1980 and 1981 (Figure 4a). However, the slope of the regression of observed against simulated yield losses was significantly less than 1.0 (Table 1). The model underestimated crop yield losses when weeds were allowed to compete with the crop for longer than 20 d after transplanting in both years (Figure 4b).

Model analyses. The reason for underestimation of yield losses in both sugarbeets and transplanted tomatoes resulting from delayed weed removal may lie in a mistaken assumption that nutrients were not limiting. Rainfall was above average during these experiments, and there may have been a high demand for nitrogen. The competing weeds, lambsquarters and pigweed, are reported to be strong accumulators of nitrogen and phosphate (2, 13). Removal of essential nutrients from the soil by weeds early in the season could result in permanent damage to the crop (4) which the model has not accounted for. This hypothesis would have to be tested in the field, with treatments varying in both nutrient supply and duration of weed competition.

Table 1. Summary of regression analyses of observed against simulated yield losses for each crop over all durations of weed competition and years.

Crop	df	Intercept[a]	Slope[b]	R^2	P
Sugarbeet	19	−0.2	0.92	0.81	<0.001
Tomato (seeded)	43	3.5*	0.93	0.94	<0.001
Tomato (transplanted)	23	1.3	0.77*	0.79	<0.001

[a] Intercept values that are significantly different from 0 are indicated by *, $P < 0.05$.

[b] Slope values that are significantly different from 1.0 are indicated by *, $P < 0.05$.

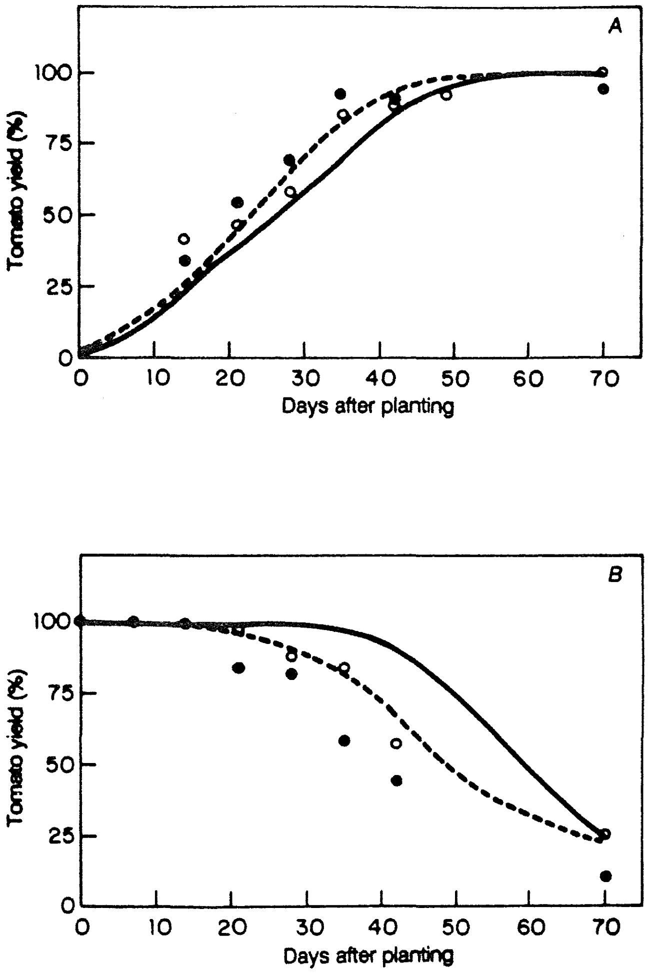

Figure 4. Simulated and observed yields of transplanted tomatoes for 1980 (——, ○) and 1981 (– – –, ●) with different weed-free (a) or weed-infested periods (b). Yields are presented as percentages of the weed-free controls.

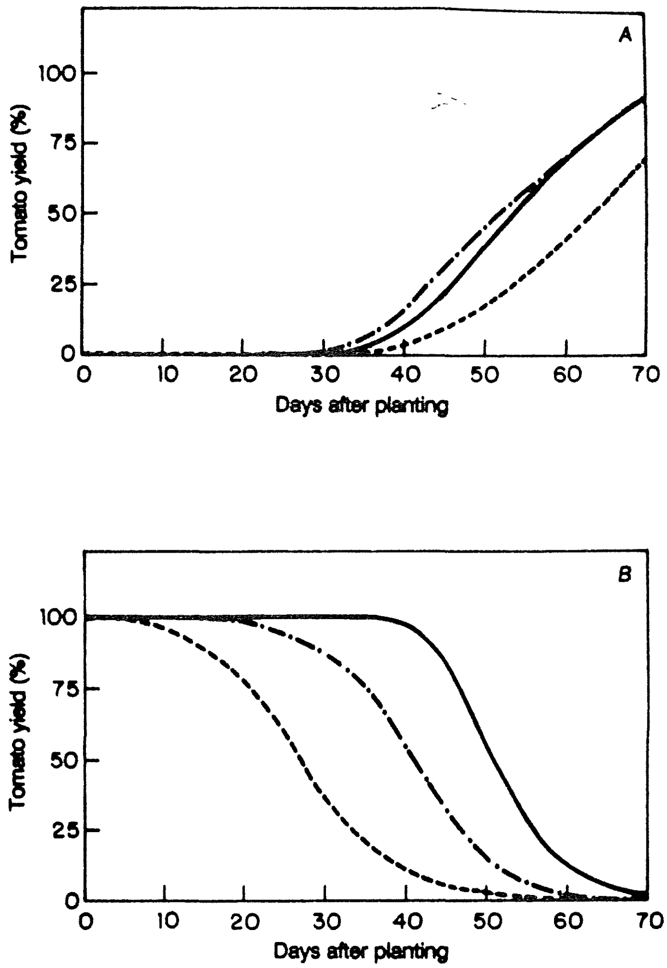

Figure 5. Simulated yields of seeded tomatoes with weather data of 1981 and initial soil moisture content of 100 mm as input (——), weather data of 1982 and initial soil moisture content of 100 mm as input (– – –), and weather data of 1982 and initial soil moisture content of 200 mm as input (–·–) for different weed-free (a) or weed-infested periods (b). Weed densities were 100 plants m^{-2} for all runs.

Effect of water stress on the critical period. The influence of water stress on the two components of the critical period was investigated in greater detail for seeded tomatoes. Rainfall over the growing season in 1981 was 396 mm compared to a long-term average of 280 mm, whereas rainfall in 1982 was only 218 mm (15). Simulation runs were conducted in which the date of planting and weed density were as in 1981, but 1982 weather data were used, and the initial soil moisture content was doubled. All other parameters were left unchanged.

Soil moisture level had a greater influence on the weed-infested curves than on the weed-free curves (Figure 5). The main effect of decreasing available soil moisture, with all other factors constant, was to decrease the length of time that seeded tomatoes could tolerate weed competition early in the growing season (Figure 5b). This would mean an earlier period threshold at which weeds that emerge with the crop must be removed to conserve soil moisture and prevent or minimize yield losses. Examination of observed yield losses of seeded tomatoes (Figure 3) reveals that yield losses in 1982 were generally less than in 1981, despite the lower rainfall. However, weed densities were also lower in 1982 (40 m^{-2}) than in 1981 (100 m^{-2}).

Effect of weed density on the critical period. Simulation runs were conducted for seeded tomatoes, using 1981 weather data, in which weed density was varied from 0.5 to 100 plants m^{-2} while other factors remained constant. Increased weed densities resulted in longer periods of time that tomatoes must be kept weed free late in the season in order to prevent yield losses (Figure 6a) and shorter periods of time that tomatoes could tolerate competition from weeds early in the season (Figure 6b). Weed density had a greater effect on the weed-free curves than on the weed-infested curves. However, changes in soil moisture and weed density are often correlated. In the model, weed emergence is a function of temperature (thermal time) but not of soil moisture, so the

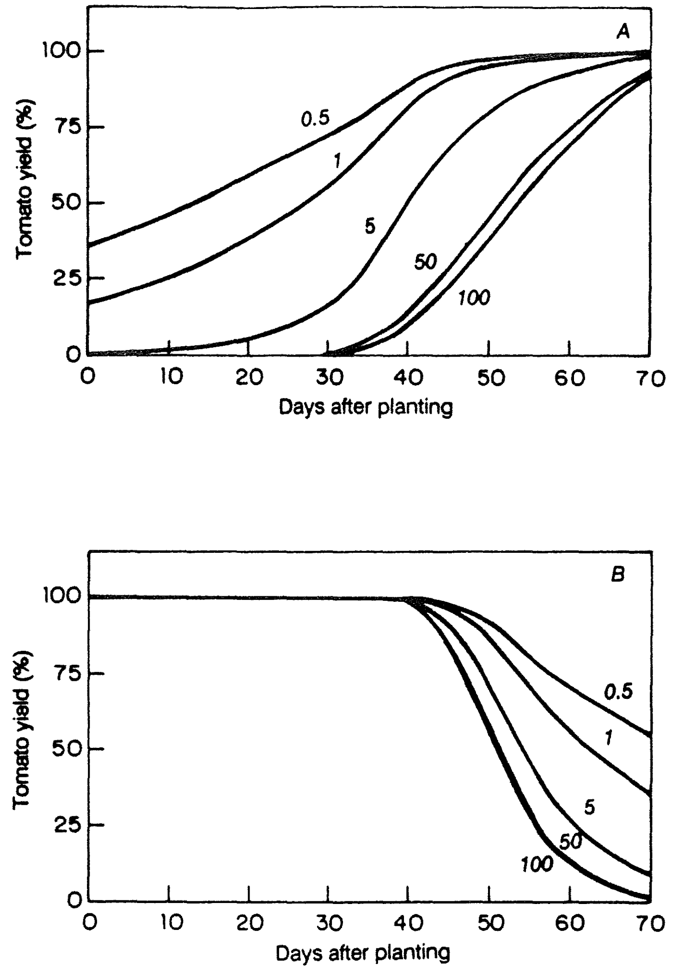

Figure 6. Simulated yields of seeded tomatoes in 1981, with weed densities of 0.5, 1, 5, 50, and 100 plants m^{-2} for different weed-free (a) or weed-infested periods (b).

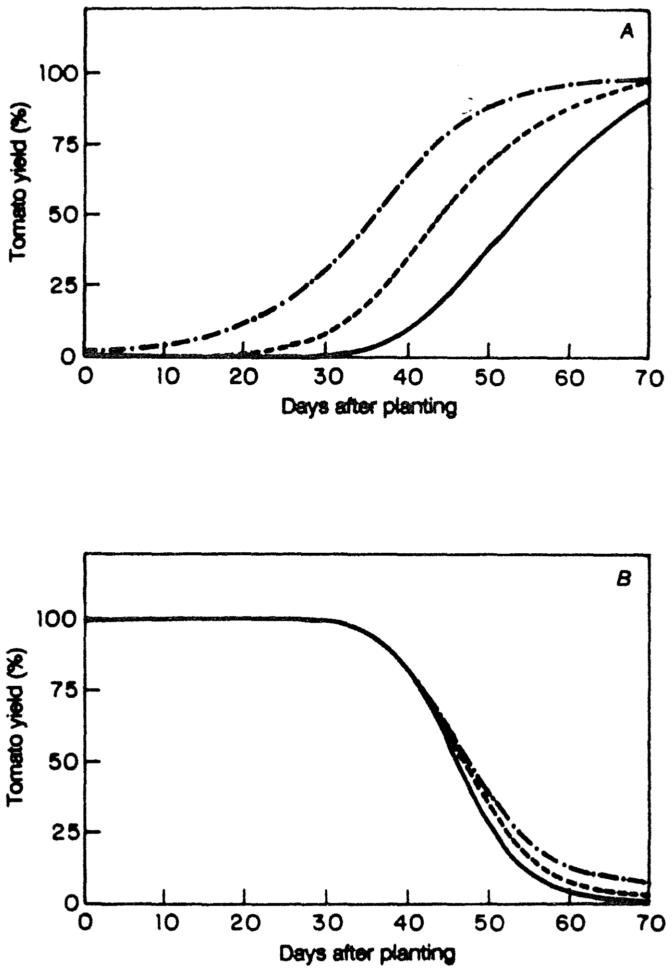

Figure 7. Simulated yields of seeded tomatoes in 1981 for different weed-free (a) or weed-infested periods (b). The maximum height of the weed canopy was 1.2 m (——), 0.6 m (– – –), or 0.3 m (–·–).

model does not accurately reflect the way in which soil moisture deficits would reduce emergence and therefore weed densities as the season progresses.

Effect of weed height on the critical period. Maximum height of the crop canopy was 0.6 m, whereas maximum height of the weed canopy was 1.2 m for seeded tomatoes in 1981. Simulation runs were conducted in which maximum height of the weed canopy was reduced to 0.6 and 0.3 m, while the height of the crop and other factors were left unchanged. Decreasing the maximum height of the weed canopy resulted in shorter periods of time that the tomatoes had to be kept weed free to prevent yield losses (Figure 7). Weed height had little effect on the early-period threshold, i.e. the length of time that the crop could tolerate weed competition, suggesting that competition for light was not important in the early phases of growth. In the model, weed height is a function of plant development but does not vary with soil moisture or density. A better understanding of the way in which these factors interact would lead to improvements in the model and a greater understanding of the complexities of competition.

These simulations, using a relatively simple model, suggest that the length of time that a crop can tolerate early-season weed competition is related more to the availability of soil moisture, or possibly essential nutrients, than to light limitations. Therefore, the greater the probability that these factors will be in short supply the earlier weeds must be controlled. Competition for light is more important in late-season competition, and the length of time that a crop must be kept weed free will depend upon the rate of height and leaf area development of the weeds in relation to the crop. A comparison of the period thresholds for seeded and transplanted tomatoes in 1981 would bear out these conclusions. The early-season thresholds were very similar for the two methods of crop establishment: 28 to 35 d, or approximately 180 degree days (base 10 C), after planting or seeding. The late-season thresholds differed by approximately 28 d (42 d after planting for transplants as opposed to 70 d after seeding), or about 230 degree days, which is approximately the difference in development time between the two crops.

Simulation models can be useful tools for understanding interactions between crop yield losses and weed density, duration of weed competition, and resource availability and for generating hypotheses which can then be tested in the field. Such an approach allows one to focus on critical experiments, rather than attempting to conduct tests under all possible environmental conditions and interactions, which would require unlimited time and resources. A dynamic simulation model permits the estimation of potential crop yield losses as a continuous function of duration of weed competition, rather than at the discrete time periods inherent in experimental designs. Furthermore, models that are weather driven and based on physiological processes can have more general applicability than empirical models, which have parameter values tied to particular experimental circumstances.

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