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HERBICIDE APPLICATION IN WINTER WHEAT - EXPERIMENTAL RESULTS ON WEED COMPETITION ANALYSED WITH A MECHANISTIC SIMULATION MODEL

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Summary: In the Netherlands, various experiments were conducted to determine the effect of weeds on the yield of winter wheat in relation to herbicide application. Omission of herbicide application resulted in a significant lower crop yield only when weed densities were extremely high in spring. These results were further analysed using a dynamic model, which simulates competition between weeds and winter wheat on the basis of physiological and morphogenetic processes. The model simulated the observed effects of weeds on crop production relatively well. Further simulation studies showed that weeds that emerge in autumn, may considerably reduce crop yield only when they are able to grow relatively high into the canopy. Weeds that emerge in spring, hardly affect crop yield. Implications for weed control in winter wheat are discussed.

INTRODUCTION

This study aimed to analyse quantitatively the necessity and timing of control of annual broad-leaved weeds in winter wheat in the Netherlands. A series of experiments was conducted to study the effect of autumn and spring herbicide treatments on yield of winter wheat and biomass of surviving weeds. The experimental results were further analysed with a dynamic simulation model, based on physiological and morphogenetic processes (Spitters and Aerts, 1983; Kropff, 1988; Spitters, 1989). By means of this mechanistic model, the observed effects of weeds on yield of winter wheat are explained in terms of relative emergence time, plant height and physiological characteristics of the weeds under Dutch conditions.

MATERIALS AND METHODS

Field experiments

Fourteen field experiments were conducted over four years (1-6 different sites per year, Table 1). The experiments contained a range of herbicides, applied in autumn or in spring (Table 1). The experimental sites of the last three trials were selected for an expected high density of weeds (e.g. Matricaria chamomilla, Alopecurus myosuroides). The other trials represent average Dutch weed densities and growth conditions of the crop (H.F.M. Aarts, pers. comm.). Each experiment was of a ramdomized block design with four replicates. At most sites individual plots measured 40 m x 6 m. The experimental conditions are described in more detail by Lotz, Kropff and Groeneveld (submitted). The pre-emergence herbicides were sprayed within two days after sowing. In spring herbicides were applied at various growth stages of the winter wheat (stages 21-40, after Zadoks, Chang and Konzak, 1974). Each experiment contained a control treatment (no herbicide).

In 1983, at monthly intervals from March until August, the following characteristics were determined at 5-12 quadrats (ranging 0.12-0.25 m^2) at each plot: the number of wheat plants (from June the number of culms) and the mean height, the leaf area and the

Table 1. Site details for a series of experiments on the effect of herbicide application in autumn or spring on yield of winter wheat in the Netherlands.

Year	Trial	Type of herbicide application Autumn	Spring
1982-83	1	1	4 + 5
	2	2	-
	3	1	4 + 5
	4	1	6
	5	3	8
1983-84	1	2	-
	2	1	9
	3	1	7
	4	3	10
	5	3	-
	6	1	6
1984-85	1	-	4
	2	-	4 + 5
1985-86	1	-	11

1 methabenzthiazuron 70% 3 kg/ha
2 linuron/nitrofen 61/222 g/l 8 l/ha
3 linuron/trifluralin 120/240 g/l 4 l/ha
4 bentazon/mecoprop 250/375 g/l 4 l/ha
5 mecoprop 560 g/l 2 l/ha
6 bromoxynil/MCPA/mecoprop 100/150/275 g/l 4 l/ha
7 MCPA 250 g/l 2 l/ha
8 ioxynil/isoproturon/mecoprop 60/300/140 g/l 5 l/ha
9 benazolin/dicamba/MCPA 25/16/193 g/l 4.5 l/ha
10 dichlorprop/MCPA/mecoprop 185/125/125 g/l 5 l/ha
11 isoproturon 500g/l 3 kg/ha
- means no application

above-ground dry weight of these plants; the number of seedlings per weed species and for each weed species, the mean plant height and the developmental stage (vegetative phase, flowering, seed maturing). Specific leaf area and patterns of biomass partitioning of weeds were determined for samples, taken at least twice in the growing season, of the frequently occurring species. In 1983-1986 final grain yields (at 84% dry matter) were determined at one quadrat (ranging 17.25-45 m^2) per plot. Differences in grain yield between herbicide and unsprayed treatments were tested by ANOVA.

Simulation analyses
Growth of both crop and weeds was dynamically simulated with a mechanistic model for competition for light and water. In this model the instantaneous CO_2 assimilation rate of each species in the canopy is calculated per leaf layer from the amount of radiation absorbed by the leaves of the species in that leaf layer and the photosynthesis-light response of individual leaves. Daily gross CO_2 assimilation rates of the species are calculated by integration of these instantaneous CO_2 assimilation rates per leaf layer over the height of the canopy and over the day. After substraction of respiration costs, the daily dry matter produced is distributed over the plant organs. When the amount of soil moisture reaches a critical level, a reduced actual transpiration is calculated as a function of soil moisture content and the evaporative demand. In the case of water shortage, the potential CO_2 assimilation rate will be reduced with the same factor as the

Table 2. Effect of herbicides pre-emergence applied in autumn or applied in spring on seed yield of winter wheat. Yield loss is defined as $((yield_{herbicide} - yield_{no\ herbicide})/yield_{herbicide}) \times 100\%$. - means: no observation. (Marginal)significant effects of the factor treatment on seed yield have been indicated between brackets.

Year	Trial	Yield loss (%) autumn application	Yield loss (%) spring application	
1982-83	1	8.7	7.6	
	2	-2.9	-	
	3	1.6	0.9	
	4	-1.9	1.0	
	5	5.1	4.2	(P<0.07)
1983-84	1	-0.1	-	
	2	-0.3	-0.7	
	3	-0.1	0.0	
	4	-1.3	-2.4	
	5	4.4	-	
	6	2.8	4.7	(P<0.06)
1984-85	1	-	39.9	(P<0.01)
	2	-	4.8	
1985-86	1	-	35.7	(P<0.06)

potential transpiration rate. Leaf-area development early in the growing season is simulated on the basis of an experimentally determined temperature-dependent, relative growth rate of leaf area. However, when the canopies closes, leaf-area development is calculated from the dry matter increment of the leaves and an experimentally determined specific leaf area, which is a function of the developmental stage. Spitters and Aerts (1983), Kropff (1988) and Spitters (1989) supplied a detailed presentation of the model structure and its performance.

Model inputs were derived for the five experiments during 1982-83: measured daily weather variables from nearby stations (maximum and minimum temperature, total global radiation, rainfall, humidity and wind speed), dates of crop and weed emergence, and plant density and height. For the weeds, specific leaf area and pattern of biomass partitioning over stems, leaves and reproductive organs were derived from the data determined in the experimental plots, whereas for wheat these characteristics were parameterized after Spitters, Van Keulen and Van Kraailingen (1989). Model inputs, concerning the rates of CO_2 assimilation were also after these authors. Data on soil characteristics were derived from observations at the study sites in later years.

RESULTS

Experiments

In the experiments conducted in 1982-83 and 1983-84, no statistically significant and only two marginal significant (positive) effects of herbicides applied in autumn or spring could be detected on seed yield of winter wheat (Table 2). At least in some blocks, herbicides might have influenced crop growth and development negatively (e.g. in 1982-83 experiment 2 and in 1983-84 experiment 4).

Fig. 1. Comparison of observed and simulated yield loss (total above-ground dry matter production) of winter wheat in five trials (1982-1983). Yield loss has been defined as $(\text{yield}_{\text{herbicide}} - \text{yield}_{\text{no herbicide}})/\text{yield}_{\text{herbicide}} \times 100\%$. Bars present standard errors computed over four blocks. The standard errors of the simulated data are due to differences in weed densities between blocks.

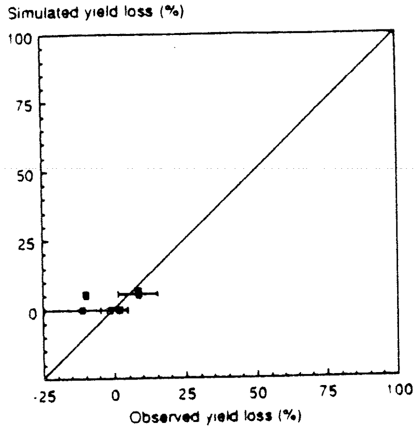
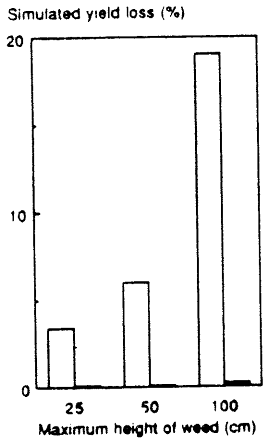


Fig. 2. Simulated yield loss of winter wheat at different times of emergence and maximum heights of weeds. Yield loss was related to the yield in the treatment with autumn-applied herbicides. Weed density was 100 plants m^{-2}. See text for other parameter values. Legend: unshaded bars, weeds emerged in autumn; shaded bars, weeds emerged in spring. (After Lotz, Kropff and Groeneveld, submitted)



In experiment 5 in 1982-83, the most abundant weed in the untreated plots was Galium aparine (mean density at harvest time 72 plants per m^2). In experiment 6 in 1983-84 Polygonum aviculare occurred most frequently (mean density at harvest 9.6 plants per m^2). In the trials of 1984-85 and 1985-86, of which the study sites were selected for their expected high densities of Matricaria chamomilla and Alopecurus myosuroides, one significant and one marginal significant effect of herbicide treatment was found (Table 2). Therefore, the data demonstrate that at rather extreme high weed densities of specific weed species omission of weed control may result in a seriously depressed crop yield.

Simulation analyses

Simulated yield loss is compared with observed yield loss for the 1982-83 experiments (Fig. 1). In this particular set of experiments, some frequently occurring weeds were Capsella bursa-pastoris, Poa annua, Stellaria media, Polygonum spp., and Galium aparine. Dynamic simulation resulted in relatively small negative effects of weeds on wheat yield. Therefore, it is concluded that simulated yield losses correspond rather well with the lack of significant herbicide-treatment effects in most experiments.

The effect of time of emergence and maximum plant height of the annual broad-leaved weeds on yield loss was analysed with the model using weed-species characteristics corresponding with Chenopodium album and average weather data (Fig. 2). Simulated yield loss appeared to be strongly affected by date of emergence and the parameter for maximum plant height of the weeds. The simulated competition effect of weeds that emerge in autumn was markedly higher than that of weeds that emerge in spring (31 March). Weeds that emerge in autumn and that can grow as high as winter wheat (1m) are expected to reduce yield almost 20 per cent at density of 100 plants m^{-2}, whereas "autumn" weeds with maximum height of 25 cm would reduce the yield about 4 per cent (Fig. 2).

DISCUSSION

Since the two sets of field experiments of 1982-83 and 1983-84 resemble well the growing conditions of winter wheat in the Netherlands, the results suggest that in this country application of herbicides in this crop is only rarely justified on the basis of a depressed yield in the current year. In this respect, the present results agree with results of British research. Evans and Harvey (1978), Orson (1980; 1982) and Wilson (1982) report winter wheat trials in which significant yield responses to herbicide application occurred in half or less of the trials. Mechanistic simulation of crop-weed competition resulted in comparable small effects of weeds on wheat. Subsequent analyses by means of this simulation model, of which the basic model structure is validated also for weed competition in sugarbeet and maize (Spitters and Aerts, 1983; Spitters, 1984; Kropff et al, 1984; Kropff, 1988), demonstrated predicted effects of some single plant characteristics on final wheat yield. Maximum plant height of annual broad-leaved weeds, that emerge in autumn, is expected to considerably influence yield loss. Weeds that grew as high as the crop, have been observed only sporadically in the experiments. Simulated crop yield is less sensitive for the specific leaf area of the weeds (Kropff, 1988).

In contrast to weeds which emerge in autumn, weeds emerging in spring may hardly affect crop yield. This simulation result might explain the corresponding effect of autumn and spring weed control in winter wheat (Orson 1982, Wilson 1982, Table 2). After herbicide treatment in autumn, weeds that emerge in the nearly closed winter wheat stand in (late) spring frequently lack competiveness to reduce crop yield. Therefore, successful autumn and spring treatments would not result in different crop yields.

The present study clearly demonstrates that the dynamic simulation model helps to understand and to explain variation in yield reduction due to weeds. However, in integrated weed management any decrease of intensity of weed control should not only be directed towards avoidance of yield loss in the current year, but also to avoid effects on subsequent crop yields. For this purpose, additional data on the population dynamics of weeds are indispensable.

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L'APPLICATION D'HERBICIDE DANS LE FROMENT D'HIVER LES RÉSULTATS EXPÉRIMENTAUX SUR LA COMPÉTITION DES MAUVAISES HERBES ANALYSÉ PAR UN MODELE DE SIMULATION MÉCANISTIQUE

Résumé: Aux Pays-Bas des expériences diverses on été faites pour déterminer l'effet des mauvaises herbes sur le rendement de froment d'hiver par la variation de l'application des herbicides. L'omission de l'application d'herbicide ne résultait dans un rendement significativement plus basse lors que les densités des mauvaises herbes étaient extrêmement hautes au printemps. Ces résultats étaient analysés davantage par l'utilisation d'un modèle dynamique, qui simule la compétition entre des mauvaises herbes et du froment d'hiver, basé sur des processus physiologiques et morphogénétiques. La modèle simulait relativement bien les effets observés des mauvaises herbes sur la récolte. En plus des études de simulation montraient que les mauvaises herbes qui l'èvent en automne ne puissent que réduire considérablement le rendement si elles puissent croître relativement hautes dans la culture. Les mauvaises herbes qui lèvent au printemps n'affectent pratiquement pas le rendement. Les implications pour la lutte contre les mauvaises herbes dans le froment d'hiver sont discutées.