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CALCULATION OF APHID DAMAGE IN WINTER WHEAT, USING A SIMULATION MODEL

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ABSTRACT. To study the effect of the English grain aphid, Sitobion avenae *(F.), on dry matter accumulation in winter wheat grains, the influence of aphids on plant physiological parameters was introduced into a simulation model of wheat growth and development. A field experiment was carried out to test the model.*

Simulated yield reduction agrees with field observations. At an aphid pressure of 490 aphid days (number of aphids per ear times duration) and an expected yield of 9377 kg.ha^{-1}, the model predicted a yield reduction of 1241 kg.ha^{-1}. In the field a loss of 994 ± 322 kg.ha^{-1} was measured at an expected yield of 8414 kg.ha^{-1}. The excretion product honeydew causes the major part of the damage by interference with leaf photosynthesis. Aphid damage caused by withdrawal of phloem sap is less important. Total damage increases more than linearly with the expected yield level of a comparable crop without aphids, up to a level of 8000 kg.ha^{-1}. Above this level, the response flattens. The simulation results show that aphid damage is highest during anthesis and decreases during the grain-filling period.

Keywords: simulation, aphid, wheat, damage, yield reduction, production level

INTRODUCTION

During the last decades aphids have become an important cause of yield loss in cereals, probably as a result of changes in crop husbandry: higher sowing densities, earlier sowing, split- and top dressings of nitrogen and increased use of fungicides and herbicides (Rabbinge et al., 1983). In the Netherlands, three aphid species can be found in winter wheat: the English grain aphid, *Sitobion avenae* (F.), the rose grass aphid, *Metapolophium dirhodum* (Wlk.), and the bird cherry oat aphid, *Rhopalosiphum padi* (L.). The first species is probably the most important because of its migration to the ear and because of its usually high density. Owing to their rapid reproduction and their uneconomical turnover of food, aphids take up huge amounts of phloem sap. This is called the primary effect of aphids. Yield losses are caused not only by this suction damage, but also by their excretion product honeydew, which changes the plant physiology. Honeydew blocks the stomata of the leaves, leading to a reduction in gas exchange. This is called the secondary effect of aphids.

Experiments have revealed the complex effects of *S. avenae* on yield loss. There is a low correlation between aphid abundance and yield reduction of winter wheat (Rabbinge & Mantel, 1981). This is probably due to the variation in the secondary effect of aphids on the plant physiology, which is influenced by environmental factors and the condition of the crop. There has been a tendency to use insurance spraying, i.e. spraying schedules without verifying the presence of pests or diseases. This causes an overuse of pesticides, which reduces the net profit per hectare. Economic damage thresholds have been developed for certain pests and

diseases. An economic damage threshold is defined as the pest density or disease severity above which the benefits of chemical treatment exceed the costs. Because of the low correlation between aphid abundance and yield loss, economic damage thresholds are difficult to develop for aphids. Damage relations between aphid density and yield loss in winter wheat have been developed and used (Rabbinge, Sinke & Mantel, 1983) but these relations are highly descriptive and cannot be extrapolated to a typical field situation. Therefore, to quantify the effect of various dynamic reduction processes on growth and development of winter wheat, a simulation approach was adopted, using quantitative data from laboratory studies. The results are used to calculate density thresholds for various crop development stages under various production levels.

SIMULATION MODEL

A simulation model of post-anthesis growth of winter wheat was developed, based on a simulation model of spring wheat (van Keulen & Seligman, in press), which simulates changes in the amount and distribution of carbohydrate and nitrogen during the grain-filling period of wheat. This model has been extended by incorporating a model describing the influence of *S. avenae* on various plant physiological parameters. Simulation of pre-anthesis growth is not necessary in a study of aphid damage, because aphids are present only during anthesis and the grain-filling period. The actual grain yield depends on environmental conditions such as radiation and temperature and on the availability of carbohydrates and nitrogen. The model includes source-sink relations for carbohydrates and nitrogen. The carbohydrate source is built up by the net photosynthesis. The nitrogen source consists of translocatable nitrogen in the plant, which is supplemented by nitrogen uptake from the soil. Carbohydrates and nitrogen are taken up by the grain and by the competing aphids, which together form the sink. Both are characterized by their potential uptake rates. The simulation starts at anthesis (DC 60, Zadoks et al., 1974). The model is initialised with the dry weights and nitrogen fractions of the plant organs at anthesis. Measured aphid densities are used as a forcing function.

In the model, primary damage is converted into a withdrawal of carbohydrates and nitrogen. The potential suction rate of aphids has been calculated in experiments, and is dependent on the weight of the aphid and on the wheat development stage: after anthesis, the suction rate declines as the crop matures (Rabbinge & Coster, 1984). In the model, this rate has been introduced as a forcing function, and forms the basis of primary damage simulation. In this way, the total carbohydrate and nitrogen demand of aphids are calculated. These demands are compared with the carbohydrate and nitrogen demand of the grain and with the carbohydrate and nitrogen supply of the plant to calculate the rate of carbohydrate and nitrogen accumulation by the aphids. Carbohydrate uptake by the aphids results in an accelerated depletion of the reserves. Less carbohydrates can be taken up by the grain. Nitrogen uptake by the aphids results in an increase of nitrogen translocation from the leaves. This leads to a lower nitrogen fraction in the leaves, which reduces the photosynthesis rate per unit leaf area and stimulates leave senescence.

In the model, secondary damage by honeydew on ear and leaves is converted into a reduction of the maximum gross photosynthesis (AMAX) and of the light use efficiency (EFFE), as has been shown in experiments (Rabbinge et al., 1981). Honeydew also stimulates growth of yeasts and fungi on the leaves, but this is thought not to damage the crop (Rabbinge et al., 1984) and is therefore not taken into account in the simulation model. The potential honeydew production rate of aphids has been measured in experiments and is dependent on the aphid weight and the wheat development stage: after anthesis, the honeydew production rate declines as the crop matures (Rabbinge & Coster, 1984). The actual honeydew production rate is a fraction of this potential rate, and depends on the rate of carbohydrate accumulation by the aphids compared to their carbohydrate demand.

The potential rate is reached when the carbohydrate supply is not limiting. It is assumed in the model that honeydew covers the ears and upper surface of the leaves, and that, like the light distribution in the crop, honeydew interception decreases exponentionally with the leaf area from the top of the crop. Because photosynthesis also decreases with crop depth (i.e. the upper leaves are photosynthetically more active than the lower leaves), the crop has been divided into layers in the model. In this way, the fraction of the leaf area covered with honeydew, and the AMAX and EFFE reduction, which are functions of this fraction (Rabbinge et al., 1981) are calculated for each leaf layer separately. The total photosynthesis rate is obtained by summing the rates of each layer.

FIELD EXPERIMENT

A field experiment was carried out at the experimental farm 'De Eest' in Nagele, Noord-Oost Polder in 1984 to test the model. The experiment consisted of four treatments in six replicates: control of aphids by a selective aphicide (250 g pirimicarb in 600 l water per hectare) from development stages DC 71 (at the onset of the aphid infestation), DC 75 and DC 77, and an untreated control. Aphid numbers were recorded at weekly intervals, the method and sample size depending on the density (Ward et al., 1985). Growth analysis of the crop was carried out weekly on 50 randomly chosen culms per replicate.

RESULTS AND DISCUSSION

Aphid damage (at harvest) of 1241 kg ha^{-1} is simulated at an aphid pressure of 490 aphid days and an expected yield of 9377 kg ha^{-1}. (The "expected yield" is the yield of a comparable crop without aphids under the same conditions). In the field, a yield reduction of 994 ± 322 kg ha^{-1} has been found at an expected yield of 8414 kg ha^{-1} (Figure 1).

Figure 2 shows the different damage components simulated by the model, and their relative importance in total aphid damage at an expected yield of 8562 kg.ha^{-1}. Although the aphid infestation started at the end of June (with a population peak at 25 July), the simulated damage did not start until the second half of July. This is due to the reduction of the reserves in the stem at that time, i.e. when the grain growth changes from sink-limited to source-limited.

Primary damage caused by removal of phloem sap forms 37% of the total damage. Carbohydrate and nitrogen withdrawal are of equal importance, with respect to their effects on yield, although the time at which damage occurs is different: when aphids are present, primary damage is caused only by carbohydrate withdrawal. Damage occurs when the reserves in the stem are depleted, this is from about 18 July. The amount of carbohydrates taken up by the aphids is equal to the decrease in carbohydrate uptake by the grains. After the beginning of August, when aphids are no longer present on the crop, withdrawal of nitrogen, which took place a few weeks before, now becomes the important component of primary damage. At this time, the nitrogen demand of the grain exceeds the nitrogen supply, i.e. when the rate becomes source-limited. The extra nitrogen withdrawal of the aphids reduces the nitrogen fraction of the leaves at the end of the grain-filling period, which reduces AMAX.

Secondary damage, caused by AMAX and EFFE reduction resulting from honeydew deposits, is 63% of the total damage. The combination of withdrawal of phloem sap and AMAX reduction causes 51% of the total damage. The remainder is caused by EFFE reduction. Thus the reduction of EFFE caused by honeydew is the most important single component of the total aphid damage, according to this model. This is because EFFE is more sensitive to honeydew than AMAX, as has been shown in laboratory experiments (Rabbinge et al., 1981) and because the simulated growth is more sensitive to EFFE than to AMAX.

Table 1 shows the simulated damage per aphid day (i.e. when one aphid.ear^{-1} is present during one day) as a function of the wheat development stage at an expected yield of 8562 kg.ha^{-1}. The simulated damage per aphid day is highest during anthesis of wheat (5.1 kg ha^{-1} per aphid day between DC 60 and DC 69) and decreases during the grain-filling period (0.8 kg ha^{-1} per aphid day between DC 75 and DC 77). This is caused by a decrease in both primary and secondary damage when aphids are present at later development stages: the potential suction rate of phloem sap and the potential honeydew production rate decrease at later wheat development stages and the period between the start of honeydew production and ripening of the crop (in which honeydew remains on the crop) shortens. In the field, a weighed mean of 2.5 kg ha^{-1} per aphid day has been calculated over the whole period in which aphids are present (between DC 71 and DC 79). The decrease in secondary damage during grain-filling is greater than that in primary damage, so the relative importance of primary damage increases at the end of the grain-filling period (from 24 % at anthesis to 64% at ripening).

According to the simulation model aphid damage increases more than linearly with expected yield, up to a level of 8000 kg ha^{-1} (Figure 3). At a high nitrogen level in the soil, plants take up more nitrogen and photosynthesis is stimulated, leading to a higher nitrogen and carbohydrate content in the crop. As a result, aphids take up more carbohydrates and nitrogen, and thus cause higher primary damage. Because of a longer period in which leaf surface is productive, more green leaf is covered by honeydew and secondary damage is higher. With increasing yield level, the relative effect of primary damage decreases and secondary effects due to honeydew excretion are more important. Beyond an expected yield of 8000 kg ha^{-1}, aphid damage no longer increases more than linearly with yield level and saturation occurs. This is probably because the crop parameters affected by aphids, as mentioned above (e.g. nitrogen fraction, leaf area index, AMAX, EFFE) are now relatively less important in limiting grain growth. These high yield levels are also determined by other crop, soil and meteorological parameters before anthesis, which are not affected by aphids.

Sensitivity analysis of the model shows that aphid damage is sensitive to the weight of an aphid, the coverage of honeydew on a wheat leaf, the potential honeydew production rate and the potential suction rate of phloem sap. In general, aphid damage is more sensitive to the parameters influencing both primary and secondary damage (aphid weight), than to parameters influencing only secondary damage (honeydew coverage and the potential honeydew production rate) or only primary damage (potential suction rate of phloem sap).

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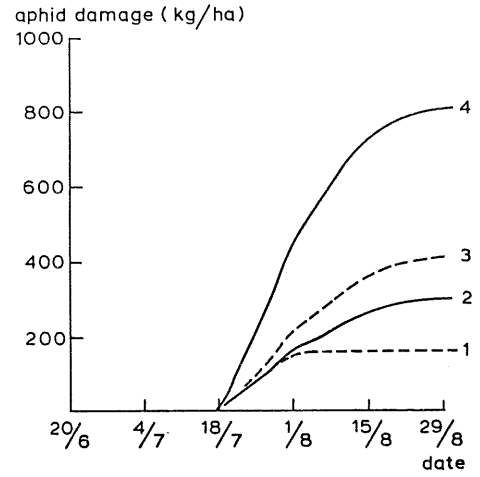


Fig.2: Simulated damage components (kg ha^{-1}) at an aphid pressure of 490 aphid days and an expected yield level of 8500 kg ha^{-1} as a function of time.

1. carbohydrate withdrawal
2. carbohydrate and nitrogen withdrawal
3. carbohydrate and nitrogen withdrawal + AMAX reduction
4. carbohydrate and nitrogen withdrawal + AMAX and EFFE reduction

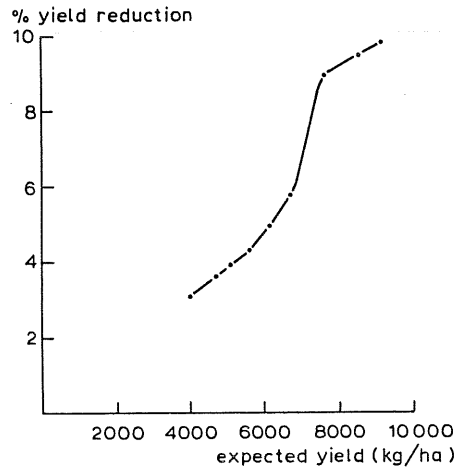
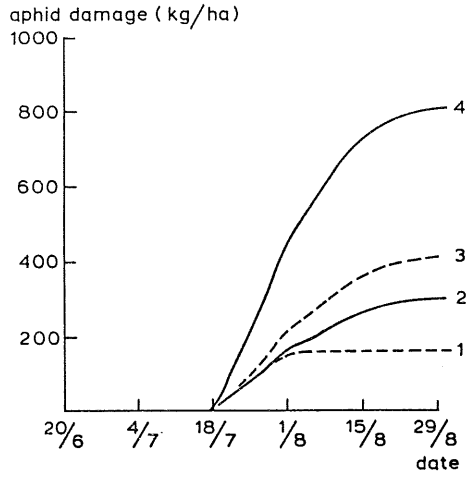


Fig.3: Percentage yield reduction at an aphid pressure of 490 aphid days as a function of the expected yield level.



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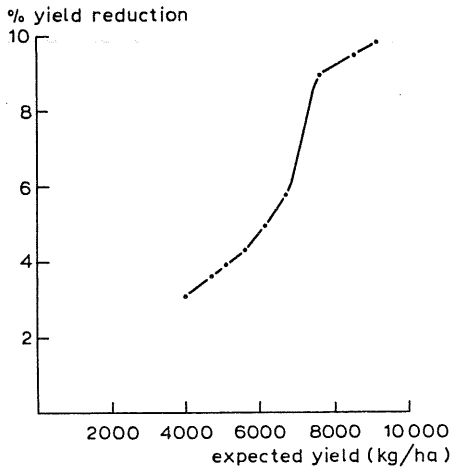

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