Neth. J. Pl. Path. 92 (1986) 107-113

Three-dimensional representation of downy mildew development in a spinach crop

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Accepted 11 February 1986

Abstract

The development of downy mildew on spinach *(Peronospora farinosa* f. sp. *spinaciae)* was stratified according to leaf layers and represented in three-dimensional computer graphics, in which percentage diseased leaf area was plotted against time for each leaf layer. Distinction was made between a point source and an area source. Inoculations were made at three growth stages of the crop.

More information could be gathered on the course of disease development on the upper leaf layers, for the first true leaf pair sporulates longer and more intensively, masking the disease development on the other leaf layers in this way.

Additional keywords: Peronospora farinosa, computer graphics, epidemic.

Introduction

Three-dimensional representation of experimental results is not new in biological sciences (Massie et al., 1973; Rhebergen, 1985). For three-dimensional visualization the computer has proven to be an adequate aid, especially for picturing the distribution of pathogen concentrations and the development of epidemics in a crop (MacKenzie, 1979).

Three-dimensional pictures of the vertical spread of a pathogen in a crop have as far as known, not yet been made. Frinking and Linders (1986) compared two pathosystems, viz. *Peronospora farinosa* on spinach *(Spinaciae oleracea)* and on common lambsquarters *(Chenopodium album),* a naturally occurring weed. The relation between disease development and weather was discussed and illustrated by two-dimensional graphs.

The present paper gives details on the development of the same *P. farinosa* epidemics in vertical direction, using three-dimensional computer graphics.

Materials and methods

For a description of the experimental field, observations on leaf area (LA) growth, inoculation method (AS = area source inoculation, PS = point source inoculation),

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inoculation time (presence of c = cotyledons, 1 = first pair of leaves, 3 = third pair of leaves), disease assessment method, and environmental data, the reader is referred to an earlier paper (Frinking and Linders, 1986).

Plant development. The spinach plants consisted of a pair of cotyledons and three pairs of true leaves. When cultivated for consumption the plants will be harvested when the third pair of leaves is formed. When the third pair of true leaves is fully expanded, stem elongation begins, followed by flowering and seed setting. During stem elongation some new and small upper leaves develop along the elongated stem under the inflorescence.

The time of appearance of cotyledons and true leaves, of stem elongation, flowering and disease levels per leaf pair were recorded. This made it possible to calculate leaf area (LA) and percentage diseased leaf area (% DLA) for each leaf layer (LL). The development of DLA in time of cotyledons (LLc). first (LL1), second (LL2) and third leaf layer (LL3) and the upper leaves (LLu), were the inputs for a computer-operated plotter.

Results

LA. The development of the leaf area measured per m^2 field area is shown in Fig. 1. LLc reached its maximum leaf area on 15 May (about $0.2.10^4$ cm^2). Hereafter a steady decrease could be observed due to leaf fall and decay. LL1 could be measured from 15 May on. From that date on its LA increased to approximately 2.10^4 cm^2 on 7 June. The first pair of leaves remained, in terms of LA, the most important one. LL2 appeared on 18 May. The LA reached its maximum on the same date as that of LL1 but was smaller. LL3 appeared on 24 May; the LA increased until 12 June to a maximum of 1. 10^4 cm^2. LLu on the elongated stem began to appear on 7 June. These leaves developed simultaneously with flowering. An important increase of its LA started on 21 June after the flowering period.

The development of the percentage diseased leaf area in plots with point source and area source inoculations is shown in Fig. 2a to 2d, and 3a tot 3d.

DLA/PSc: Fig. 2a and 3a. The latency period was 11 days. The percentage DLA of LLc was extremely low, due to the small number of infected plants. A second and third generation were observed on LL1, with maxima of 3% DLA on 27 May and 46% on 21 June, respectively. The second wave also became visible on LL2 and LL3, but it only reached a maximum of 0.2% DLA. The third wave became better visible on LL2, LL3 and LLu, with maxima all on the same date: 21 June. The disease had moved upwards.

DLA/ASc: Fig. 2b and 3b. The latency period was the same as in PSc. On the first observation day 8.5% DLA could be noted on LLc and 0.5% DLA on LL1. The first wave reached its maximum on 21 May with 14% DLA on LLc. The second wave became visible on LL1, LL2 and LL3 after 25 May. The epidemic reached its maximum in the different leaf layers between 28 and 31 May with 15% on LL1, 46% on LL2 and 47% on LL3. No third wave was observed. The epidemic declined rapidly. The LLu was no attacked by the simple reason that the upper leaves had not yet appeared.

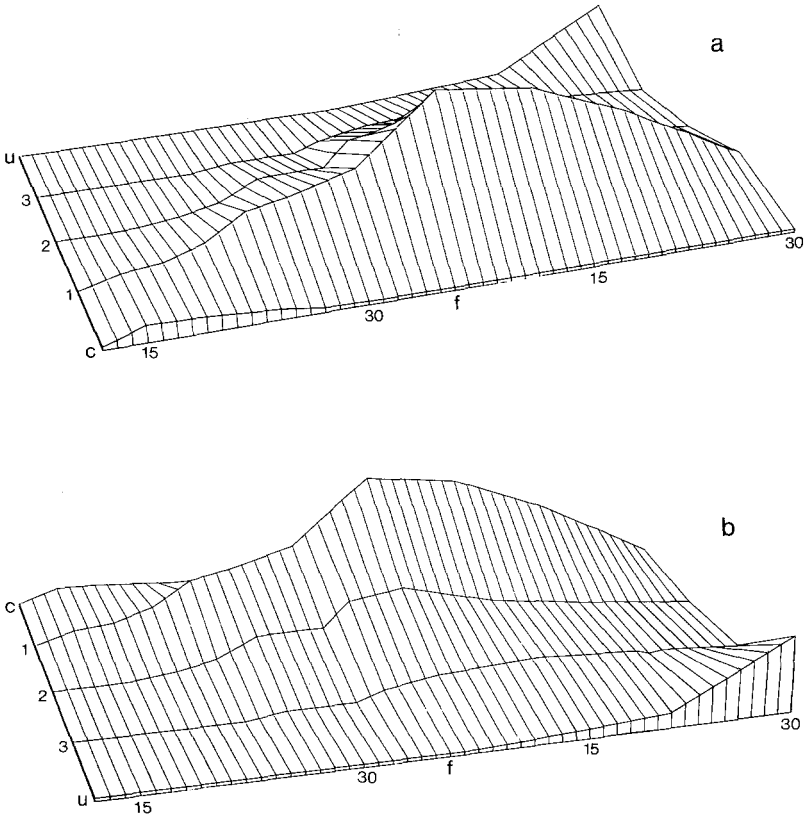


Fig. 1. Three-dimensional representation of the leaf area (LA) development from 12 May till 30 June (X axis) per leaf layer (c = cotyledons, u = upper leaves, 1-2-3 = number of true-leaf pairs). Date f indicates the beginning of the flowering period. Leaf area is a relative measure.

DLA/ASI: Fig. 2c and 3c. The first symptoms of sporulation were observed on 21 May after a latency period of 7 days. The disease appeared at the same time on LLc (83% DLA), LL1 (41% DLA) and LL1 (6% DLA). After a low percentage DLA on LL2 in the beginning, a real wave with a maximum of 31% DLA was observed on this leaf layer on 1 June. This second wave also found expression on LL3 with a similar DLA (32%) on the same date. No attack was seen on LLu.

DLA/AS3: Fig. 2d and 3d. At the time of inoculation, when LL3 was developed, LLc had disappeared. The first sporulation could be observed on 3 June on all leaf layers available on that date. The latency period was 9 days. The percentages DLA were: 14% on LL1, 9% on LL2, and 6% DLA on LL3. These percentages were rather stable on these leaf layers until 14 June. From 14 June on the disease showed a remarkable revival, which ended for LL1 on 21 June with a maximum DLA of 47%. LL2 and LL3 also showed a point of inflexion on the same date, but less pronounced. The first sporulation on LLu appeared on 14 June; it progressed as on LL3.

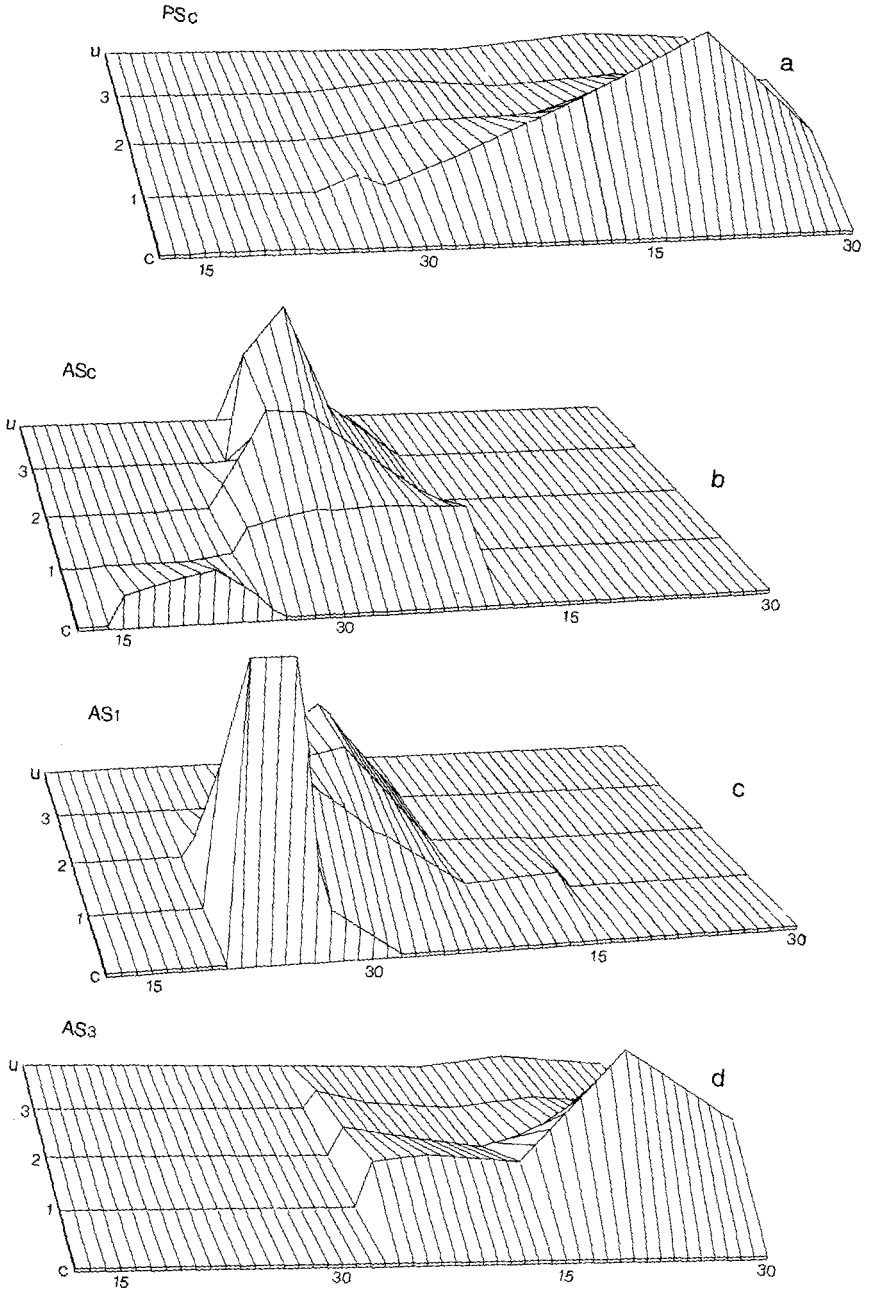
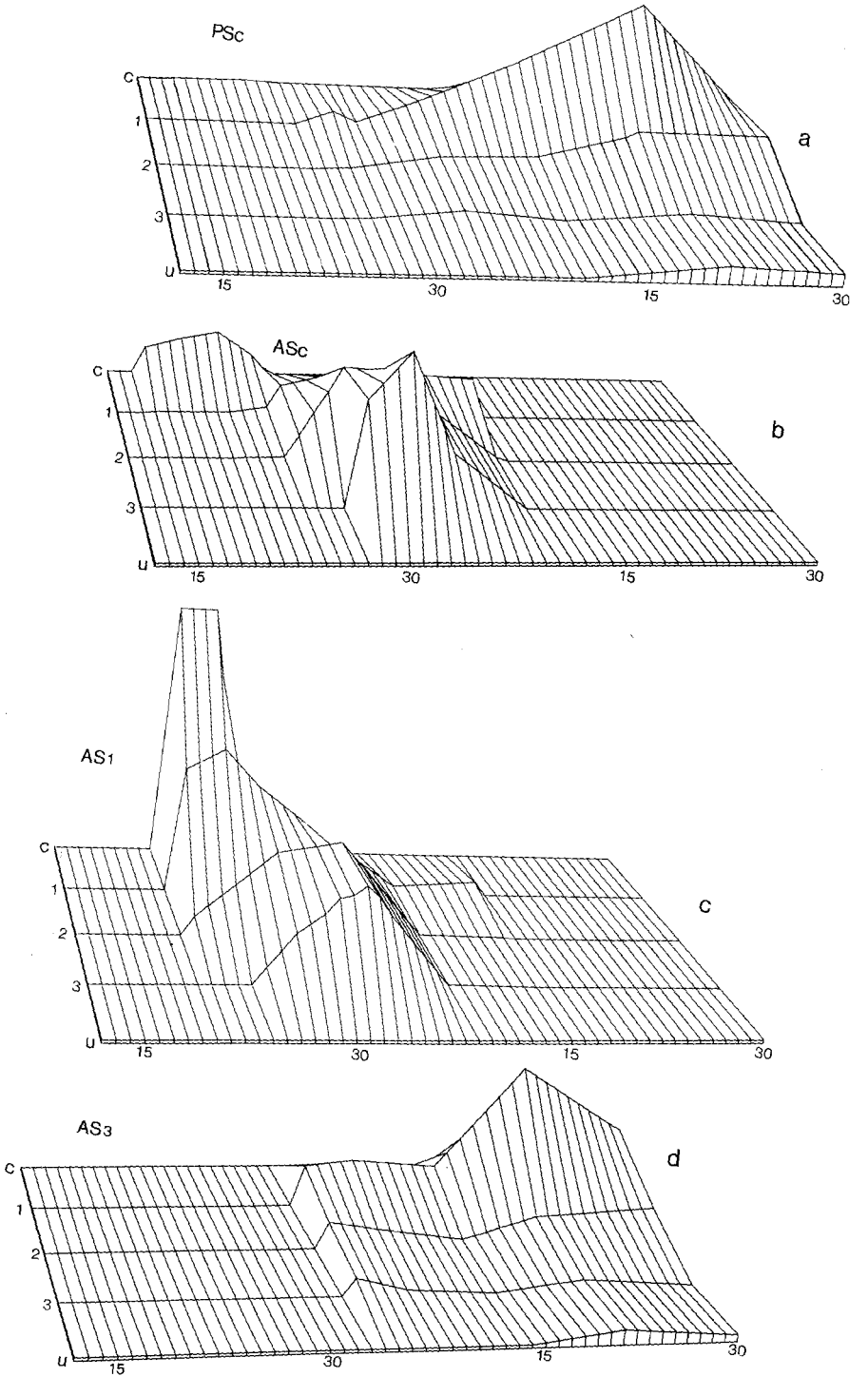


Fig. 2 and 3 (opposite page). Three-dimensional representation of percentage diseased leaf area (DLA) from 12 May till 30 June (X axis) per leaf layer (c = cotyledons, u = upper leaves, 1-2-3 = number of true-leaf pairs). Differences between Figures a to d are the method and time (presence of leaf layer indicated) of inoculation (PS = point source, AS = area source). Difference between Figures 2 and 3 is the inverse representation of the sequence of the leaf layers.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Discussion

The experiments were already discussed using two-dimensional graphs (Frinking and Linders, 1986). These graphs represent the development of the percentage DLA with time for all leaf layers together. In these graphical representations, phenomena such as the development of new infections on upper and smaller leaves are masked by the development of the disease on lower leaf layers with higher LA and DLA values. Stratification of the data according to leaf layers can supply more information on the progress of the disease within the crop.

One example is the difference in behaviour of the disease on LL1 as compared with LL2 and LL3. This is shown in the AS3 plots (Figs 2 and 3). The first sporulation was seen here on 3 June on LL1, LL2 and LL3, all with about the same percentage DLA. On LL2 and LL3 the disease did not develop but nearly vanished. LL1 showed an important second sporulation wave with a culmination on 21 June. On the two-dimensional graph (Frinking and Linders, 1986) one cannot see that this second wave was nearly exclusively due to LL1. Neither can one see that the disease stabilized on LL1 for 11 days. The decrease of the disease during this period shown by the two-dimensional graph was caused by the decrease of percentage DLA on LL2 and LL3. The fungus on LL1 can, in general, reach high levels of infection throughout the season. On LL2 and LL3 high levels of infection can only be attained when leaves are young. The effect may be due to a decrease of susceptibility with increasing age, as is the case for sugar beet in relation to *P. farinosa* f. sp. *betae* (Weltzien and Mey, pers. commun.). The effect is not seen on LL1 for either of two reasons. Firstly, LL1 leaves keep growing during most of the experimental period, unlike LL2 and LL3 leaves. Secondly, it can be assumed that LL1, situated on the plant close to the soil, lives in a moister micro-climate than LL2 and LL3. Another example of the usefulness of stratification is given by the PSc. plots. The two-dimensional graph (Frinking and Linders, 1986) shows four dates (15 and 27 May, 3 and 21 June) where the curves go downward at least temporarily. On which leaf layers these declines took place, cannot be seen. The three-dimensional graphs (Figs 2 and 3) give a better impression of disease development in the crop. Only a few seedlings were inoculated in the center of the crop. So the percentage DLA was low and the disease was at the LLc level only (13 May). Meanwhile LL1 developed. Not the cotyledons of neighbouring plants, but LL1 of the same and neighbouring plants played an important role in further development. The disease did not spread in horizontal but in vertical direction (27 May), due to the disappearance of cotyledons and a long latency period. A second wave could not develop on LLc. The third remarkable date (3 June) was determined by developments on LL2 and LL3. A few days before, during a period of sporulation on LL1, the leaves of LL2 and LL3 began to develop. The disease moved upwards, but LL2 nor LL3 were attacked seriously in comparison with LL1. Closing of the canopy by LL2 and LL3 prevented a rapid spread in upward direction. The disease spread horizontally rather than vertically during the growth period of LA2 and LA3 (21 June). The examples show that vertical stratification of disease progress data contributes to a better analysis of epidemic processes. Stratification of fungal development in a crop can be represented by three-dimensional computer graphics.

Acknowledgements

The authors are indebted to Ir M.J. van Hulst an Ir H.W.J. van Roermund for gathering the data of the experiments, and to Professor J.C. Zadoks for critically reading the manuscript.

Samenvatting

Drie-dimensionale weergave van de ontwikkeling van valse meeldauw in een spinaziegewas

De ontwikkeling van valse meeldauw op spinazie *(Peronospora farinosa* f. sp. *spinaciae)* werd geanalyseerd aan de hand van drie-dimensionale grafische voorstellingen, waarbij percentage ziek bladoppervlak per bladetage werd uitgezet tegen tijd. Onderscheid werd gemaakt tussen de ontwikkeling vanuit een puntbron en vanuit een oppervlaktebron, bij inoculatie in drie groeistadia van het gewas.

Het bleek dat hierbij meer informatie kon worden verkregen over het verloop van de ziekte-ontwikkeling op de bovenste bladetages, omdat het eerste echte bladpaar langduriger en heviger sporuleert, en zo de ziekte-ontwikkeling op de overige bladetages maskeert.

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Book review

G.M. Hoffmann, F. Nienhaus, F. Schönbeck, H.C. Weltzien & H. Wilbert, 1985. Lehrbuch der Phytomedizin. Second edition. Paul Parey, Berlin and Hamburg. In German, with 253 figures (of which 36 in colour) and 62 tables, 488 pp. Price hardback: DM 124.

This is a thoroughly revised and updated edition af a textbook on plant pathology and crop protection, of which the first edition appeared in 1976. The authors are German scientists who have won their spurs in various subdisciplines of plant pathology. There are six chapters.