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Wind Dispersal of *Alternaria alternata*, a Cause of Leaf Blight of Cotton

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With 6 figures

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Abstract

Introducing *Alternaria alternata*, the cause of blight disease of cotton plants, into a field of young healthy plants growing in rows cross-wind, yielded disease foci which were spread downwind up to 7 m from the infection sources. Only light disease incidence was found in the remainder of the field. When the disease was introduced into a field of mature cotton plants grown in rows cross-wind, randomly scattered disease foci occurred. In mature plantations where rows were parallel to the average wind direction, only limited size disease foci developed downwind, up to 16 m from the source. These foci did not developed further during the season. The number of air-borne spores of *A. alternata* was significantly increased by the presence of diseased cotton plants, being highest close to the diseased plants. The spores were transferred to a distance of at least 20 m. However, the number of air-borne spores significantly decreased 6 m from the infection source. Periodical trapping of air-borne spores of *A. alternata* in a cotton growing region for 2 years, revealed that their air dispersal is local, probably at the field level. *A. alternata* air-borne spores were also trapped in rather low numbers regardless of the presence of infected cotton plants. However, the number of the air-borne spores trapped was dependent mainly on the average wind direction and on the *Alternaria* blight epidemics occurring in the fields twice a year. It is suggested that *A. alternata* spores are transferred by wind for short distances but are constantly present in small numbers in the atmosphere throughout the whole year. The two peaks recorded for the number of spores present in the air above cotton crops correlate with the annual two outbreaks of *Alternaria* blight epidemics. In addition, both wind and plant row direction affect disease development in the fields.

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Zusammenfassung

Windverbreitung von *Alternaria alternata*, eine Ursache einer Blattfäule bei Baumwolle

Wenn *Alternaria alternata*, die Ursache einer Blattfäule von Baumwollpflanzen, in einem Feld eingeführt worden war, wo junge, gesunde Pflanzen in Reihen im Seitenwind wuchsen, entwickelten sich Krankheitsherde, die sich bis zu 7 m von der Infektionsquelle in Windrichtung ausdehnten. Im Feld wurde sonst nur ein leichter Krankheitsbefall festgestellt. Unter ähnlichen Bedingungen, aber mit volt entwickelten Pflanzen, wurden nur vereinzelte, verstreute Krankheitsherde beobachtet. In volt entwickelten Beständen, wo die Pflanzenreihen parallel zu der allgemeinen Windrichtung standen, entwickelten sich Krankheitsherde bis zu 16 m von der Infektionsquelle in Windrichtung. Diese Krankheitsherde entwickelten sich während der Saison nicht weiter. Die Anzahl der in der Luft vorhandenen Sporen von *A. alternata* wurde durch das Vorhandensein von erkrankten Pflanzen signifikant erhöht, and die höchste Anzahl an Sporen wurde in unmittelbarer Nähe von erkrankten Pflanzen ermittelt. Die Sporen wurden mindestens 20 m weit von der Quelle verbreitet. Die Anzahl der Sporen verringerte sick jedoch signifikant 6 m von der Quelle. Das unregelmäßige Erfassen des Sporenfluges von *A. alternata* in einem Baumwollanbaugebiet über 2 Jahre zeigte, dal deren Luftverbreitung nur lokal ist, wahrscheinlich innerhalb eines Feldes. *A. alternata*-Sporen wurden auch ohne das Vorhandensein von infizierten Baumwollpflanzen in der Luft erfaßt, obwohl nur in verhältnismäßig niedriger Anzahl. Die Anzahl der in der Luft erfaßten Sporen war jedoch hauptsächlich von der durchschnittlichen Windrichtung and der *Alternaria*-Fäuleepidemien, die in den Feldern zweimal im Jahre vorkommen, abhängig. Es wird vorgeschlagen, daß *A. alternata*-Sporen fiber kurze Strecken mit dem Wind verbreitet werden, sie Bind jedoch in niedriger Anzahl das ganze jahr in der Luft vorhanden. Die zwei Spitzen der Anzahl der in der Luft vorhandenen Sporen korrelierten mit den zweimal im jahre auftretenden *Alternaria*-Fäuleepidemien. Außerdern beeinflußte sowohl die Windals auch die Pflanzenreihenrichtung die Krankheitsentwicklung in den Feldern.

Air-borne spores of many plant pathogens have been attributed as causal agents of epidemics in many crops worldwide (AYLOR 1986, GREGORY 1968, RAO and MALLAIAH 1988). Aerial surveys to predict possible epidemic outbreaks using passive (sticky surfaces, solid medium surface) (ATLURI *et al.* 1988, BANERJEE *et al.* 1987) or active (volumetric) (EVERSMEYER *et al.* 1973, MCCRACKEN 1989) traps are a common practice.

Usually data, relating to air-borne spores in epidemiological studies of plant diseases or in studies of allergies caused by fungal spores, are collected from single traps located at one or several sampling sites in an area, and are considered sufficient to draw reliable conclusions (EVERSMEYER and KRAMER 1987b, GREGORY 1968). A significant amount of data relating to air-borne spores has been accumulated in relation to plant diseases yielding several general conclusions: (i) there are significant variations in trapping air-borne spores of fungi directly related to the biometeorological factors prevailing during sampling time (LONG and KRAMER 1972, LYON *et al.* 1984 b), (ii) there are unique patterns of aerial distribution mainly at the fungal genus level (EVERSMEYER and KRAMER 1987 a, KRAMER and EVERSMEYER 1984, KRAMER *et al.* 1963), (iii) spore dispersal *via* air currents can be considered in terms of air dispersal of small particles (BURROWS 1983, 1988, GREGORY and STEDMAN 1953) regardless of viability (FAULKNER and COLHOUN 1976, WALE and COLHOUN 1979), (iv) wind can be considered as the main factor affecting aerial dispersal of propagules (VOLCANI 1969, WAGGONER 1973) and (v) temperature as well as water, either by precipitation or irrigation, is of utmost importance to the growth of fungi and directly affects the number of

spores produced and released into the air (KRAMER et *al.* 1963, LYON *et al.* 1984 b). The present study has thus concentrated on the effect of wind on aerial distribution and initiation of disease epidemics of *A. alternata*, one of the causal agents of *Alternaria* blight of cotton.

Alternaria blight disease is the most severe leaf disease of cotton plants in Israel (HADAS and JACOBY 1981) and was attributed to the species *A. macrospora* affecting mainly *G. barbadense* plants of cv. Pima and its derivatives (BASHAN 1984, 1986 b, BASHAN and LEVANONY 1987, EBBELS 1980, HADAS and JACOBY 1981). This species has the ability of being transferred within the growing season by various biotic and abiotic vectors (BASHAN 1986 a). Recently, strains belonging to the *A. alternate* complex of species (SIMMONS 1967) caused also *Alternaria* blight in plants of *G. hirsutum* cv. Acala (LEVANONY et *al.* 1988) and of *G. arboreum* (SINGH *et al.* 1984).

Disease outbreaks in Bet-Sheen valley occur annually twice a season: first in the cotyledon and young seedling stage in April-May and second, in September-October late in the cotton growing season, just before the commercial harvest. Although chemically treated by frequent aircraft sprayings, effective disease control or increase in yield is rarely achieved. Moreover, the most effective fungicide (fentin-acetate, formulated product, Bedilan 60 w.p.) is phytotoxic to cotton seedlings (ZACKS 1990). *A. macrospora* can induce symptoms mainly in the cotton species *G. barbadense* (long fiber cotton). *G. hirsutum* (short fibre cotton) cv. Acala is almost resistant to this pathogen. On the other hand, *A. alternata* is capable of infecting both cotton species. However, it has a preference to attack *G. hirsutum* plants. Recently, it was proposed that *A. macrospora* together with *A. alternata* form a disease complex responsible for *Alternaria* blight disease in both cotton species (BASHAN *et al.* 1991).

Spores of *Alternaria* spp. are abundantly dispersed in the atmosphere and are used as a common model in allergic studies (DURHAM 1944, 1946). Abundance of *Alternaria* spores in the air was not correlated with plant vegetation. The spores were detected far from any agricultural zone in the dry desert town of Arad in Israel. This town deliberately maintains a minimal vegetation cover and has severe restrictions on plant species which are allowed to grow there, in order that it may serve as a spa for allergic disease patients (BARKAI-GOLAN et *al.* 1977).

The objectives of this study were to: (i) find out whether *A. alternata* spores are air-borne in the field, (ii) measure the distance these spores are transported by wind, (iii) evaluate the effect of wind and row direction on the rate of spread of *Alternaria* blight disease in the field, and (iv) correlate the relation between presence of infected plants and air-borne spores of *A. alternata* during the entire year.

Materials and Methods

Organisms and growth conditions

Spores of *Alternaria alternata* (Fr.) Keissler were trapped and counted in this study. Cotton plants (*Gossypium barbadense* cv. Pima S-5 and *G. birsutum* cv. Acala SJ-2) were grown in commercial fields under the regular practice employed in cotton cultivation in Israel. No special arrangement of plants or treatment was given to the fields.

Cotton plants designated for artificial inoculation (cv. Pima S-5) were grown from seeds in 5 1 pots in peat : vermiculite : volcanic dust (1 : 1 : 1, v/v/v), 3 plants/pot, in a net house (against bird damage). Plants were fertilized (100 ml/pot) with half-strength Hoagland's nutrient solution every week after germination. At the 3-5 true leaf stage, plants were inoculated with 12000 spores/ml of *A. alternata* strain S-1 (BASHAN et al. 1990) by brushing the leaves with an aqueous spore suspension containing a small amount of fine carborundum (BDH, 300 grid) (BASHAN et al. 1990). Each pot was then covered with a loosely sealed, large, pre-wetted polyethylene bag and incubated in the dark for 16 h at 25 ± 1 °C after which the plants were returned to the net house for an additional 5 days. Each plastic bag was removed daily for a few minutes to improve aeration.

Fungal cultures were grown and maintained on Czapeck (Dox) medium (C.M.I. 1968). Cultures originating from air-borne spores were treated as described later.

Disease severity index

Disease severity was recorded 8 days after inoculation using the following scale: 0 = no symptoms; 1 = 1-3 lesions/leaf; 2 = 4-10 lesions/leaf; 3 = 11-20 1esions/leaf; 4 = 21-301esions/ leaf and 5 = more than 30 lesions/leaf, indicating a heavy infection. The numbers of lesions on all inoculated leaves were counted separately. The mean number of lesions per leaf represents the disease severity per plant.

Monitoring air-borne spores of *A. alternate* in the field and greenhouse

A. alternata spores were trapped in the field throughout the year by passively exposing Petri dishes containing Czapeck medium supplemented with 250 mg/1 chloramphenicol (C.M.I. 1968) and 1 mg/1 of the surfactant Triton N-101 (alkylphenylpolyethyleneglycol to prevent overgrowth of the colonies on the medium (MADELIN 1987). Dishes were exposed for 2 h on a flat table mounted 1.5 m above ground level. This height is known to be optimal for trapping air-borne spores of various fungi (LYON *et al.* 1984 a). The table size was 30 x 40 cm and five Petri dishes per sampling time were mounted on each table using soft solid clay. Each dish was vertically oriented to the following wind directions: 90° (east), 180° (south), 270° (west) and 360° (north) and one dish was placed in an horizontal position facing upward. This setup allowed exposure of up to a total of 318 cm^2 of medium surface to the air. The traps were located in the field as described later. Gravity traps of this kind are common in numerous field studies (BANERJEE *et al.* 1987, BARKAI-GOLAN 1958, DURHAM 1946, HYRE 1950, GREGORY 1950, MADELIN 1987).

In the greenhouse (a commercial sealed polyethylene tunnel, 3 m in diameter, 22 m long with no environmental control such as temperature, light, humidity or CO_2, used primarily for growth of winter vegetables in Israel), five highly infected cotton plants (before flowering stage, mean disease severity index of 3.8) were placed on a stand 0.5 m above ground level in front of the greenhouse ventilation system which produced a constant wind of 4 ± 1 m/sec along the longitudal dimension of the greenhouse. Two traps containing five Petri dishes per trap vertically facing the wind direction were exposed, in 1 m intervals for 2 h (a total of 200 Petri dishes/sampling).

After exposure of the medium, lids were returned, sealed with Parafilm, transferred to the laboratory, incubated at 25 ± 2 °C in the dark and spore formation was induced as previously described for *A. macrospora* (BASHAN 1984). Three to 5 days after sampling, each colony which developed was examined under a stereoscopic microscope for the presence of *A. alternata* according to the description of this species by SIMMONS (1967). Results are given as numbers of spores trapped/ 60-300 cm^2 medium surface/2 h. Pathogenicity tests of the trapped air-borne spores were routinely carried out as previously described (BASHAN 1984).

Sites for monitoring *Alternaria* blight disease and *A. alternata* air-borne spores

This study was carried out in Bet-Sheen valley in the North-eastern part of Israel during the years 1983-1987 (see additional geographical detail in Fig. 1). This region is known to have a large area of cotton plantations (approx. 5700 hectare in 1987, mainly of *G. barbadense* cv. Pima S-5 and its derivatives and smaller areas of *G. hirsutum* cv. Acala SJ-2 and its derivatives). The region is semi-arid, hot and dry during the cotton growing season [average temperatures between May and September; max. 36-40 °C (day), min 15-26 °C (night)]. Many nights (160-170) per season have

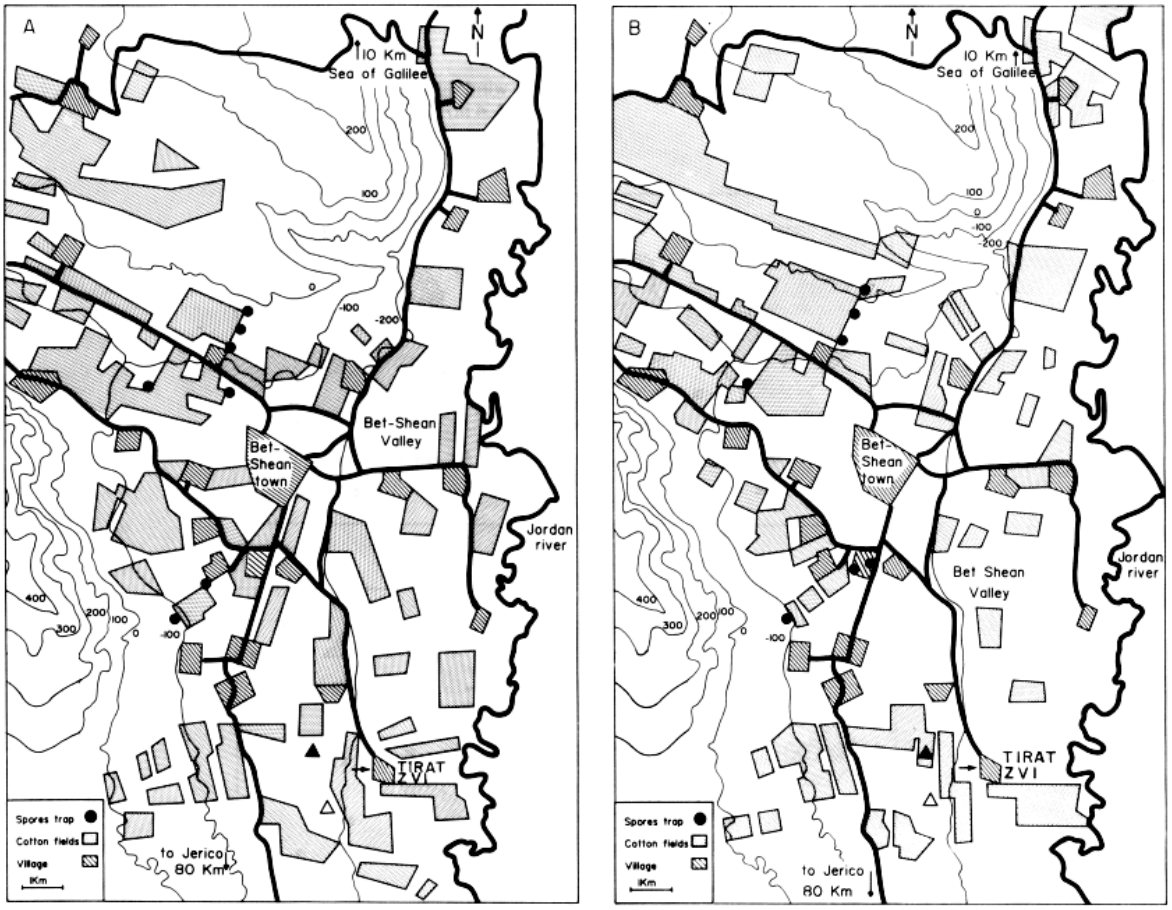
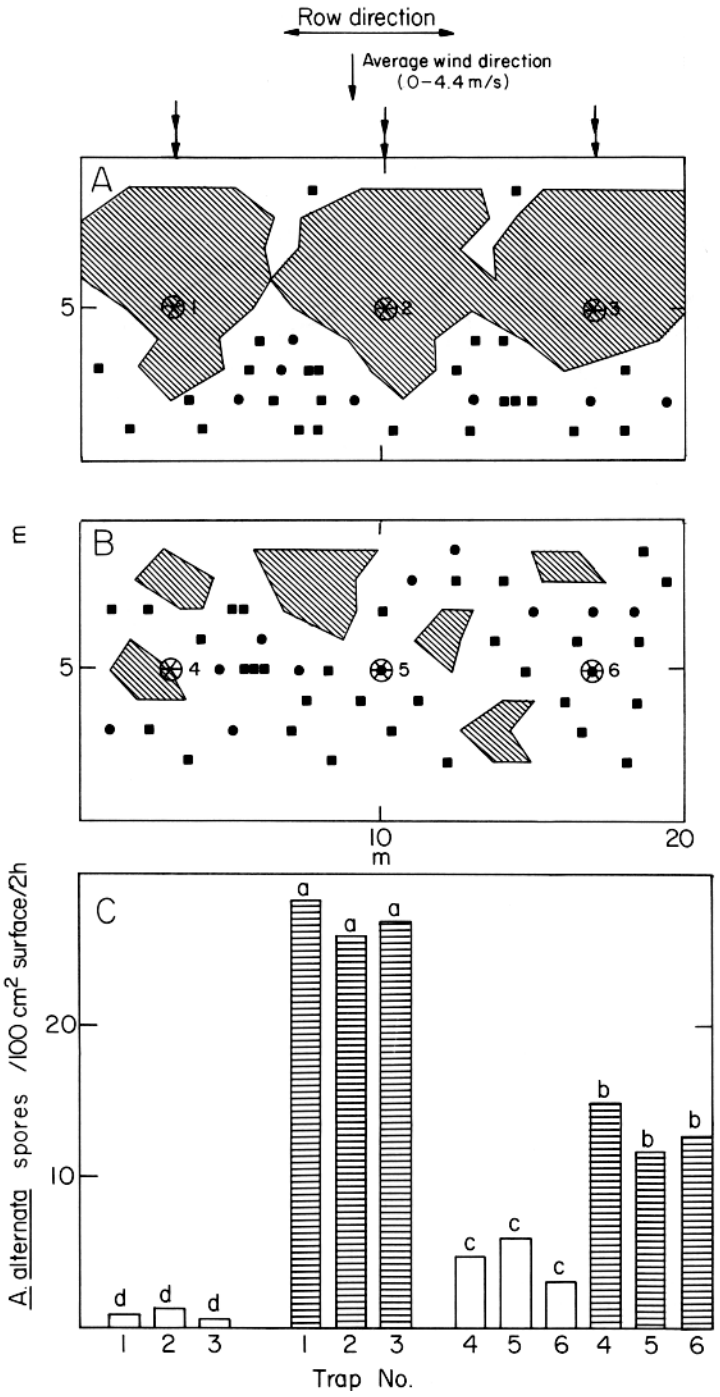


Fig. 1. Location of *A. alternata* spore traps in the western entrance of Bet-Shean valley in 1986 (A) and 1987 (B). Thick lines represent paved roads and thin lines the ground altitude above and below sea level (in m). Arrow indicates the location of the meteorological station of Tirat-Zvi. ▲ -site a in 1984. Δ-,site b in 1995.. (for additional infotmation see Material and Methods section).

dew. There is no rain during the entire growing season season (except in May, < 5 mm rain, (NIR, 1989).All cotton fields are irrigated by sprinklers or by drip irrigation. The meteorological station of Tirat-Zvi is operated continuously by the Meteorological Service of Israel since 1950. This station provided the meteorological data presented in this study. One of the meteorological characteristics of this valley is constant strong west and north-west winds (wind direction 270-320°, 5-11 m/s between 10.00 and 18.00 hours. Over 70 % of all winds in the valley are blown from these directions) during the entire cotton growing season. During other hours of the day or night, the air is more calm (1-5 m/sec) with random patterns, i.e., wind changing direction frequently. All field sampling of *A. alternata* air-borne spores was performed between 11.00 and 15.00 hours. During this period, plant leaves were dry and there was a strong west wind (NIR 1989).

Site a (Fig. 1 A, B and Fig. 2 A, B) was located 2 km west of Tirat-Zvi. the cotton cultivar was Pima S-5 and plant rows were cross-wind. Each of two plots (area 200 m^2) was located in the centre of a 70 hectare commercial cotton field. In each of these areas on the wide side of each plot, three m from its side and in the centre (10 m from its side); (double arrows in Fig. 2 A), five highly infected cotton plants (before flowering stage) were placed creating artificial disease sources. In one plot (Fig. 2 A), these plants were placed in position at an early growth stage (up to six true leaves), and in the other plot (Fig 2 B), plants were placed in position at a mature growth stage (flowering plus young bolls,


Row direction
Average wind direction
(0–4.4 m/s)
A
1
2
3
5
m
B
4
5
6
5
10
20
m
C
A. alternata spores /100 cm² surface/2h
20
10
a
a
a
b
b
b
c
c
c
d
d
d
1 2 3 1 2 3 4 5 6 4 5 6
Trap No.

plant height 80-120 cm). Three spore traps were located downwind in each plot and were operated twice; 5 h after placing the inoculated plants in position and 2 weeks later. The traps were mounted at two heights, 20 cm above ground level (plot A) and 100 cm (plot B) (both heights were lower than the plant canopy). Two weeks after inoculation the plots were examined for disease incidence of *Alternaria*-blight. A plant was considered diseased if at least one of its leaves showed a disease severity index of 3.0. All plants in a plot (approx. 1700 plants) were evaluated during 2 consecutive days. No special agrotechnical treatment had been given to the plot.

Site b (Fig. 1 A, B and Fig. 3 A) was located 2 km south-west of Tirat-Zvi. The cotton cultivar was Pima S-5 and rows were roughly parallel to the average wind direction allowing the wind to penetrate into the canopy of the mature cotton plants. The plot was 1200 m^2 and was located on one side of a 110 hectare commercial cotton field which showed no visible symptoms of *Alternaria* blight. The plot was examined routinely throughout the season for the first appearance of *Alternaria* blight symptoms. Six natural disease foci were detected and marked late in the season (August). Each focus contained 2-3 infected mature plants having both flowers and immature bolls. In order to enhance disease development in these plants each focus was sprayed daily in the evening for 6 days, with tap water until run-off. In addition, a large open water container was placed in each disease focus and a large transparent polyethylene sheet was placed over the upper canopy of the plants. It was impossible to seal the plants in an artificial humid chamber because they were already too large, about 120 cm height, and had dense foliage. This procedure yielded severe symptom production in 4 foci. At the other two foci disease did not developed further. Seven days later, the plastic sheets and the water containers were removed and the water spraying arrested. No additional treatment had been given to the plot and all the plants in the plot (approx. 9700 plants) were evaluated for disease incidence during 3 consecutive days. Twelve spore traps (3 per disease focus, 4 m between each trap) were mounted downwind 6 m from the focus, after removal of the plastic sheet, 150 cm above ground level, i.e., above the plant canopy. Each trap was operated twice, 5 h after the removal of the plastic sheet and 4 weeks later when the plants were also examined for *Alternaria* blight incidence. Diseased plants were monitored as described above. Sites a and b were sampled during the 1984 and 1985 seasons.

Site c, (Figs 5 and 6)*:* Seven spore samplers (35 Petri dishes/sampling; constructed identically as the above spore samplers) were scattered along the western entrance of the Bet-Shean valley between the lower-Galilee foothills in the north to the Gilboa mountains in the south, a distance of 8.5 km. This setup covered the entire valley entrance (Fig. 1 A, B). The traps were operated at 2 week intervals throughout the years 1986 and 1987.

Statistical analysis

Data from all the Petri dishes mounted on the same trap or data collected over all sampling from one wind direction were combined and subjected to Fischer's Least Significant Difference (LSD) analysis at $P \leq 0.05$. Bars represent SE.

Results

The effect of wind and plant row direction in the field on spread of *Alternaria* blight disease and on trapping of *A. alternata* spores

Monitoring of *Alternaria* blight infected plants in a commercial plot after creating three artificial disease sources revealed three local epidemics down-wind, when cotton plants were at the first stages of growth (Fig. 2 A, hatched

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Fig. 2. The effect of wind and row direction in the field (site a) on spread of *Alternaria* blight disease and on *A. alternata* air-borne spores which originated from diseased plants two weeks after inoculation. A – young cotton plants. B - mature cotton plants. ▨ - area which contained more than three diseased plants/m row; ● - site contained two diseased plants; ■ - site for a single diseased plant; ⊛ - location of spore traps; ↓ - location of the artificial disease source (disease severity index > 3). C – number of *A. alternata* air-borne spores; □ - 5 h after placing inoculated plants in the field and ▤ - 14 days later. Columns followed by a different letter differ significantly at $P < 0.05$ by LSD analysis

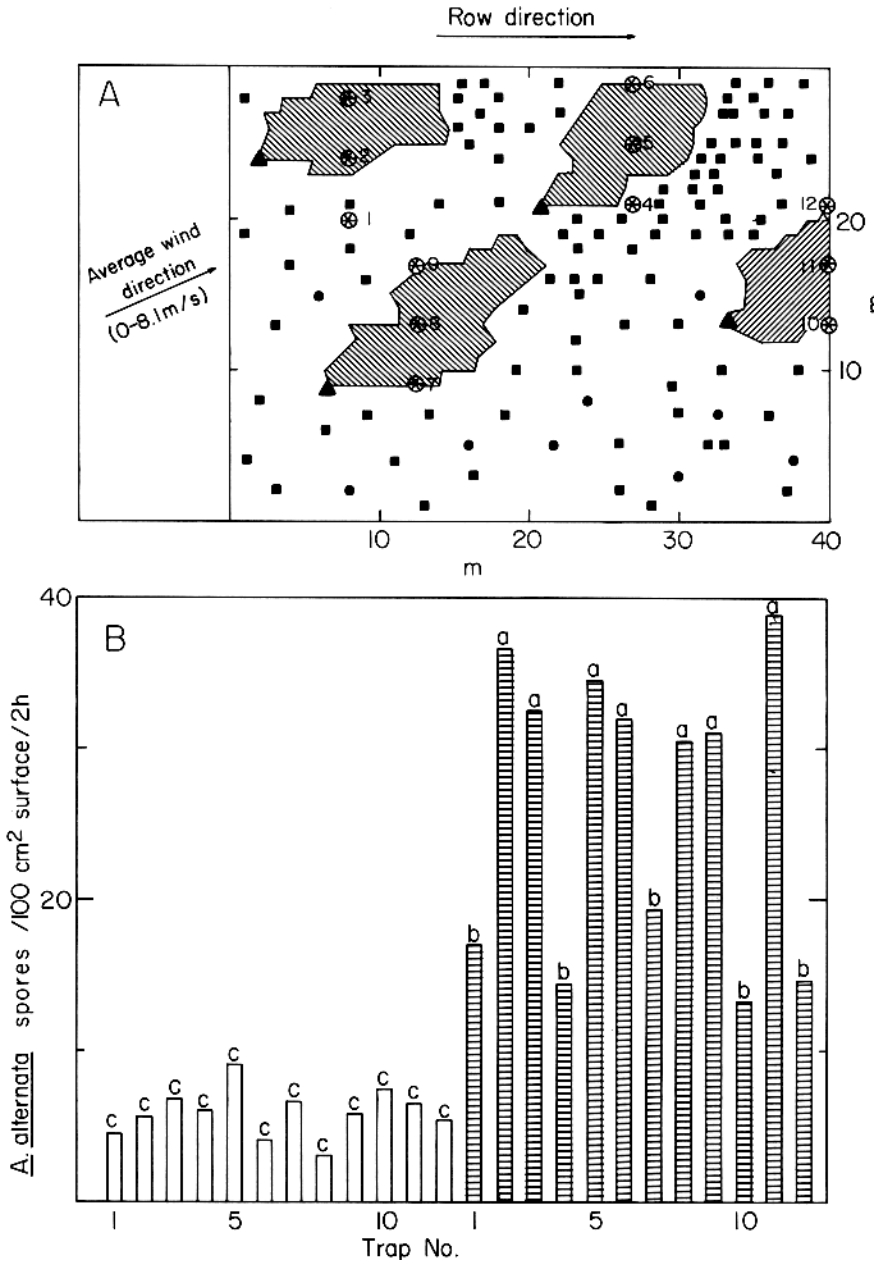

Fig. 3. A -Spread of *Alternaria* blight of cotton from naturally-infected disease foci (in site b) as affected by wind and row direction four weeks after exposure of infected plants. ▨ - area which contained more than three diseased plants/m row; ● - site contained two diseased plants; ■ - site for a single diseased plant; ⊛ - location of spore traps. ▲ - site of the original naturally-infected plants. B- number of *A. alternata* air-borne spores; □ - 5 h after removal of the plastic sheet and of water spraying; ▤ - 4 weeks later. Columns followed by a different letter differ significantly at $P \leq 0.05$ by LSD analysis

areas). Disease incidence further than 7 m from the disease sources was small (Fig. 2 A, ■ and ● symbols). The nearby cotton plot, backward of the disease sources was only slightly diseased (8 plants were visibly infected out of *c.* 12000 plants grown in the plot).

Monitoring disease incidence in mature plants exposed to similar disease sources showed the development of disease foci scattered randomly in the plot without apparent relation to the artificial disease sources (Fig. 2 B, hatched areas). Randomly scattered infected plants were also found in the plot (Fig. 2 B, ■ and ● symbols).

Air-borne spores of *A. alternata* 5 h after exposure of the field to the presence of diseased plants was low (0.6-6 spores/100 cm' medium surface/2 h) (Fig. 2 C, empty columns). Two weeks later, the number of *A. alternata* spores was significantly higher (Fig. 2 C, left hatched columns). A similar trend of spore distribution was detected in mature plants. However, the number of spores detected during disease development in mature plants in the field was significantly lower compared with the number detected in the young stages of cotton growth (compare hatched columns in Fig. 2 C). It should be emphasised that the spore trapping technique employed in this study does not efficiently sample the air-borne spore concentration, but measured only spore deposition on plants.

When the cotton rows in the field were parallel to the average wind direction, local epidemics originated from the disease foci had developed downwind (Fig. 3 hatched areas). Each of these diseased areas was 12-16 m long and 6-8 m wide, 4 weeks after exposing naturally, highly infected plants in the field.

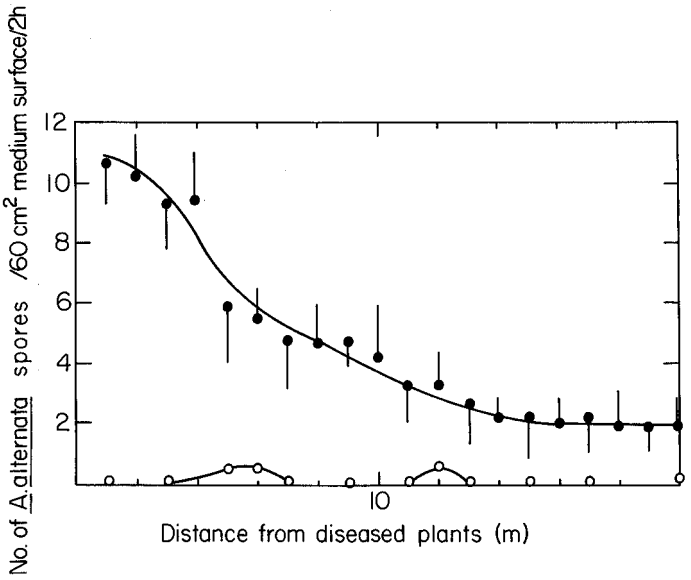

Fig. 4. Transfer of *A. alternata* spores *via* air from diseased plants in the greenhouse. ● - *A. alternata* air-borne spores in the presence of diseased plants; O - *A. alternata* spores in the absence of diseased plants. Bars represent SE

The size of these infected areas had not further increased when examined 4 weeks later. Disease incidence in the rest of the plot was low (Fig. 3).

Spore counts from 12 traps located in the plot (at site b) revealed that 5 h after exposure of highly diseased plants, the number of *A. alternata* spores was relatively small and similar in all traps (Fig. 3 B) indicating the number of *A. alternata* spores prevailing naturally in the field. The spore number had significantly increased 4 weeks later (Fig. 3 B). However, traps which were aside of the disease foci (traps 1, 4, 7, 10 and 12) contained significantly fewer spores than traps directly down wind. However, the number of spores trapped was still high (Fig. 3 B).

Transfer distance of A. alternata air-borne spores from diseased plants

In the greenhouse, *A. alternata* spores were transferred *via* air currents for 20 m. However, the number of spores trapped decreased to 50 %, 6 m from the diseased plants (Fig. 4). In the absence of plants showing symptoms of *Alternaria* blight very few spores were randomly trapped (Fig. 4). The variation between the five Petri dishes mounted on each trap was large under the experimental conditions.

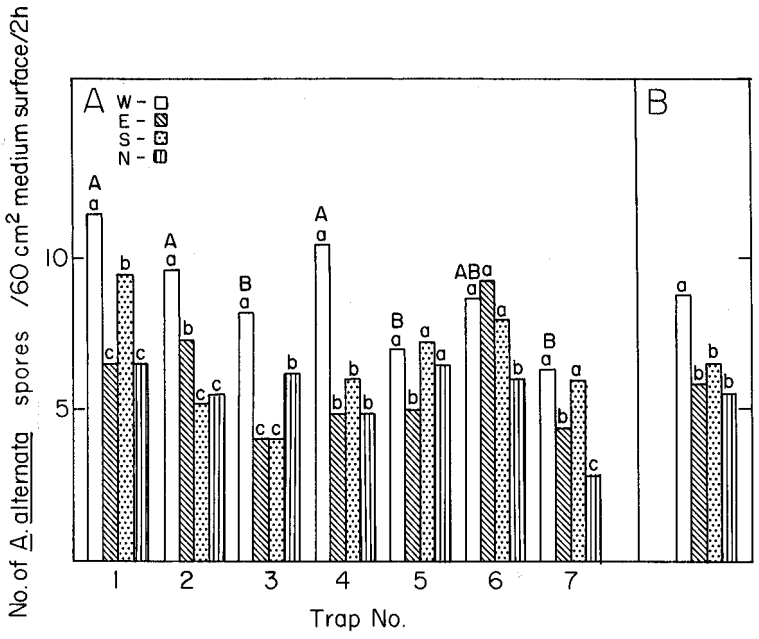

Fig. 5. A - The effect of wind direction on trapping of *A. alternata* air-borne spores in the field (site c) in seven locations during the cotton growing season. Each column represents the mean number of *A. alternata* spores from 7 different samplings performed on each trap. □ -vertical dishes facing the west direction (270°); ▨ - dishes facing the east direction (90°); ⁘ - dishes facing the south direction (180°); ▥ - dishes facing the north direction (360°). Empty columns, representing dishes facing the west direction, followed by a different capital letter differ significantly at $P \leq 0.05$ according to LSD analysis. B - General evaluation of *A. alternate* air-borne spores trapped during the cotton season in relation to the wind direction. In each sub-figure columns for each trap, followed by a different lower case letter differ significantly at $P \leq 0.05$ according to LSD analysis

The effect of wind direction on trapping of *A. alternata* spores in the field in seven locations during the cotton growth season

Seven trapping surveys were conducted between 22. 4. 1987 and 29. 9. 1987 covering the entire cotton growth season in Bet-Shean valley. They were performed at 7 different locations (Fig. 1 B). It was revealed that the wind direction plays an important role in air dispersal of *A. alternata.* In most locations, exposed Petri dishes facing west (the direction of the common local west wind [270-320°]) were more heavily contaminated with *A. alternata* spores than dishes facing in other directions. *A. alternata* air-borne spores were trapped on dishes facing in every direction. However, their numbers greatly varied between traps (Fig. 5 A). General analysis of all the data collected in the 1987 season (245 Petri dishes) revealed that more spores occurred on dishes facing west than others facing in any other direction. Spore numbers did not significantly differ between wind directions other than west (Fig. 5 B).

Presence of *A. alternata* air-borne spores in the field throughout the year

Data of air-borne spores of *A. alternata* were combined. A bimodal distribution pattern was present; one peak between April-June and the other in September-October corresponding to the two epidemics of *Alternaria* blight of

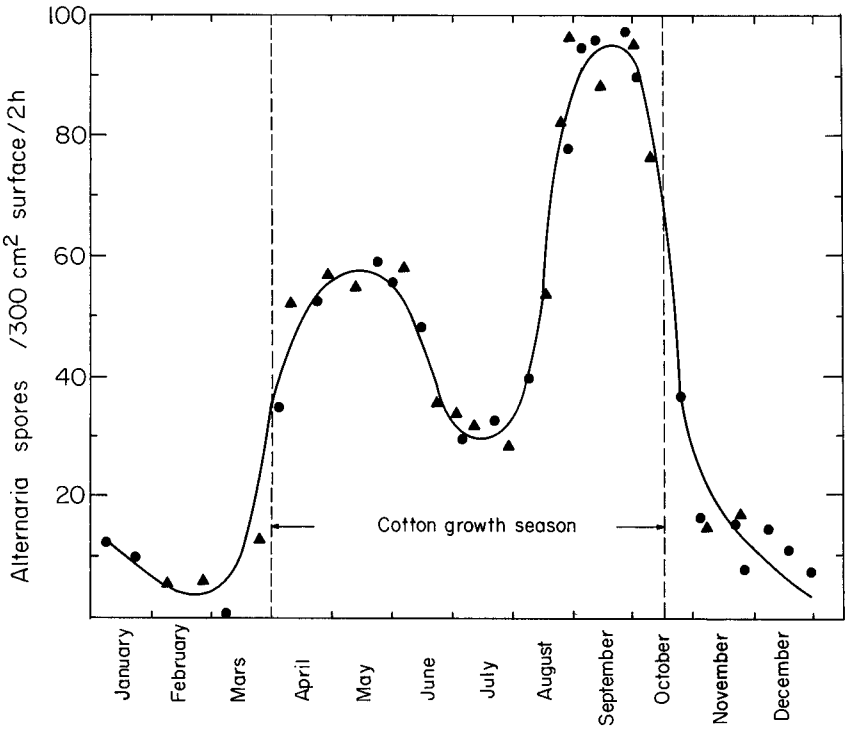

Fig. 6. Distribution pattern of *A. alternata* air-borne spores above cotton fields in Bet-Shean valley during 1986 and 1987. ● - data from sampling in 1986; ▲ - data from sampling in 1987

cotton recorded in each year in the Bet-Shean valley. Air-borne spores of *A. alternata* were trapped in low numbers throughout the rest of the year (Fig. 6).

Discussion

It is well established that *Alternaria* spores, which are usually not identified at the species level, are among of the most common fungal spores trapped worldwide, without any relation to a particular crop (BANERJEE *et al.* 1987, BARKAI-GOLAN *et al.* 1977, DURHAM 1944, 1946, KRAMER *et al.* 1963, LYON *et al.* 1984 a, MADELIN 1987, RAO and MALLAIAH 1988). In the present study it has been shown that *A. alternata* spores are air-borne above infected cotton plants throughout the growing season. Although low numbers of air-borne spores of *A. alternata* were trapped during the entire year, trapping peaks were correlated with the two known disease outbreaks in cotton fields in Israel. Probably off-season *A. alternata* air-borne spores were obtained from wild-beet, the winter carrier of *A. alternata* (BASHAN *et al.* 1990, LEVANONY *et al.* 1988), or the fungus may have a saprophytic ability.

Wind direction and velocity have a crucial effect on dissemination of fungal spores (AYLOR and PARLANCE 1975, WAGGONER 1973). Most release of conidia can be understood in terms of action of wind (AYLOR and DAY 1976). We took advantage of the fact that in Bet-Shean valley, during summer time, there is a permanent strong west wind every afternoon. According to spore counts it was shown that *A. alternata* air-borne spores were trapped downwind from a disease focus in significantly higher numbers compared with those trapped elsewhere. Additional circumstantial evidence implies that *Alternaria* air-borne spores were spread downwind when the plant rows were parallel to the west wind and when the plants were small, thus, the plant foliage did not prevent spore dispersal in the field.

Wind velocities of 1-5 m/sec removed most spores of *Helminthosporium maydis* from an infected leaf (WAGGONER 1973, AYLOR and LUKENS 1974). AYLOR and PARLANCE (1975) suggested that fungal spores in general are blown from the leaves when the wind velocities surrounding the leaf exceeds 5 m/sec. The west wind prevailing during sampling in the present study fitted these values but was sometimes even stronger (up to 8 m/sec), which is a disadvantage for trapping fungal spores (LYON *et al.* 1984b).

Spores are dispersed *via* air currents, from minimal distances within the field to enormous intercontinental distances (AYLOR 1986, BASHAN 1986 a, GREGORY 1968). The present study concentrated mainly on dissemination of *A. alternata* spores within the field as affected by the local wind and the disease source. Although low numbers of *A. alternata* spores were detected up to 20 m from diseased plants, most air-borne spores of *A. alternata* were only transported in the air for a few metres. Disease foci in the presence of the daily strong wind did not spread more than 16 m from the spore source. Great variation in trapping of *A. alternata* air-borne spores in several locations within a cotton growing region, probably reflects the local spore concentration surrounding the trap and not

regional air content. This conclusion was made since it is well known that fungal spores with good air-borne capacity are homogeneously diluted in the air volume and traps located at several sites within the region give the same trend of trapped spores (EVERSMEYER and KRAMER 1987a, b). This had not been the situation with *A. alternata* in this study.

In conclusion, this study demonstrates that viable air-borne spores of *A. alternata* are present in the cotton field. The number of these spores is positively correlated with disease outbreaks in the crop and they can be air transferred for short distances. Wind direction and cultivation row direction have a significant impact on spread of the disease in the field.

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