Effects of Sprinkler Irrigation at Various Times of the Day on Development of Potato Late Blight

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ABSTRACT

The effect of overhead sprinkling applied at various times of day on development of *Phytophthora infestans* on potatoes depended on seasonal weather conditions and density of stand. Under conditions highly favorable or submarginal for blight, the time of sprinkling had little effect. Under marginal conditions, overhead sprinkling encouraged blight, and morning irrigation had a greater effect than did midday or evening irrigation.

The blight-promoting effects of morning sprinkling are related to the fact that, in Israel, the sporangia of *P. infestans* are dispersed in the morning and die under the usually adverse conditions occurring later in the day.

An empirical and arbitrary macroclimatic value useful for indicating conditions governing potato blight has been found in the sum of the daily deficits of relative humidity and of the daily levels of total global radiation. Phytopathology 60:839-843.

Under semi-desert conditions, watering by overhead sprinkling rather than by furrow irrigation favored development of *Phytophthora infestans* (Mont.) deBy. on winter potatoes (*Solanum tuberosum* L.) (4). The relation of disease development in different regions and seasons to sprinkling performed at various times of day has not been previously demonstrated.

MATERIALS AND METHODS.—In 1967 and 1968, five field experiments were performed in the moderately humid coastal plain of Israel, in fall, spring, and summer. Two further experiments were performed in spring under the more arid conditions of the Negev region. In both areas there were fairly frequent hot and dry spells during the experimental periods; in four of the experiments, almost no rain fell. The plots, planted with potatoes of the Up-to-Date variety, did not receive fungicidal treatments. It was at first feared that sprinkling a small plot might affect blight development in neighboring plots by altering the micrometeorological conditions. Therefore, in 1967, each sprinkler treatment was applied to a single plot of 2-7 dunams (1 du = 1,000 m^2). Since the above apprehension proved unfounded, each treatment in 1968 was applied to two or three replicate plots of 18 × 18 m each.

Irrigation was by rotating sprinklers which covered an area of 12 m diam and released 15 m^3 water/du per hr when operated for 3.5 hr. After planting, the entire field was sprinkled uniformly until the plants were deemed ready for inoculation, about 6 weeks after planting. At this time, plants in the coastal plain had grown to a height of 30-40 cm with foliage dense enough to form a continuous canopy in spring and summer, somewhat less dense in fall. In the Negev, the plants at time of inoculation were 20-30 cm high, and foliage did not yet cover the space between the rows. Directly after inoculation, irrigations were applied at various times of day. Unless otherwise stated, subsequent sprinkling was repeated at weekly intervals.

The source of inoculum was an isolate of *P. infestans* from potato, belonging to race 0. Five-mm discs of filter paper were immersed in a suspension of zoospores, then applied to 3-10 leaves of each plant. The plants were kept for 24 hr in moist chambers, then for 2 days in growth chambers at 20 C. On the evening of the 3rd day after inoculation, these plants, with lesions ready for sporulation on each inoculated leaf, were placed in the field. As dew formed during the following night, sporulation took place, and differential irrigation was begun the next morning. In 1967, 6-8 such pots containing inoculated plants were distributed over the large plots; in 1968, a single pot was placed in the center of each 18 × 18-m plot.

The incidence of blight was assessed by making periodic counts of lesions formed on all plants within an area of 100 m^2 around the potted plant which served as an inoculum source. Infected plant organs were graded as follows: 1, leaflet with one lesion only; 2, leaflet with more than one lesion; 3, infected petiole; and 5, infected stem. As the number of leaves per plant varied with seasonal conditions, the sum of disease indices per treatment could not serve for accurate comparisons among the various experiments. Consequently, the sum of indices which, in each experiment, coincided with death of plants, was considered as 100%; the indices for each treatment plot were converted to appropriate percentages.

Conditions prevailing in the field were recorded by screened hygrothermographs and Taylor dew recorders, placed at plant level in various plots. Data from standard screens and from radiation recorders were taken from a nearby meteorological center. In two experiments, leaf temp, at four points/treatment, was measured by thermocouple clips connected to a multipoint recorder.

An attempt was made to interpret the effects of sprinkling applied at various times of the day in various regions and seasons by comparing the prevailing conditions of dew, relative humidity (R.H.), and temperature. None of these parameters was found to be satisfactory. Suitable criteria were found only when climatic variables, presumed to affect the viability of dispersed sporangia, were compared.

In Israel, *P. infestans* disperses its sporangia at the time dew begins to dry up, which is usually about 3 hr after sunrise. In relation to viability, this is the beginning of a critical period which ends with dewfall at sunset. Its length is thus expressed by the number of day-hr minus three. During this time, the viability of sporangia is adversely affected by high temperatures, low R.H. (2), and radiation. For the analysis of conditions for survival of dispersed sporangia, temp values were expressed as the number of day-hr minus three, multiplied by the mean temperature for these hr. Relative humidities were calculated similarly, expressed in deficits below 100%, and termed "RHD". Total global radiation (TGR) was calculated in g-cal/cm² for the same daily period.

Various combinations of the above three values were considered in relation to the seasonal incidence levels of blight, as determined in the field experiments. The

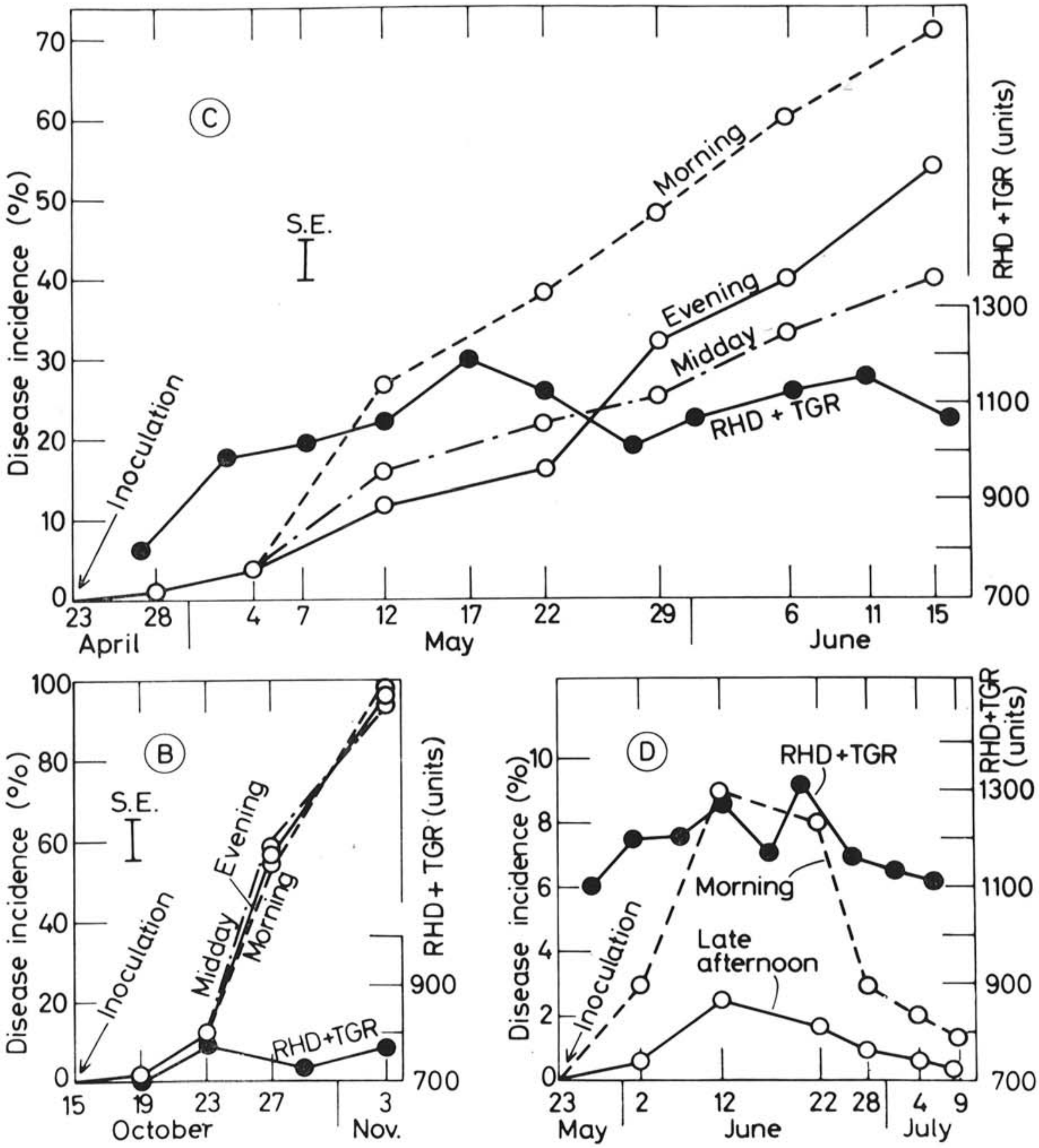

Fig. 1. Late blight development on potatoes sprinkled at various times of the day. **B)** Experiment B in fall 1968; **C)** experiment C in spring 1968; **D)** experiment D in summer 1967. RHD = relative humidity deficit; TGR = total global radiation.

best correlation was obtained by adding RHD values to those for radiation; this total is henceforth designated as RHD + TGR. Any combination that included temp data was less descriptive.

RESULTS.—Effects of sprinkling at various times of the day in various seasons and regions on blight development:

Autumn.—Autumn experiments were carried out only in the coastal plain, on potatoes sown in August.

In experiment A, a single 7-dunam plot was inoculated on 10 October 1967, at seven points. Beginning with the next day, a few days' spell of early rain so saturated the soil that only one irrigation could thereafter be made.

In experiment B, inoculation was performed on 16 October 1968, in each of three replicate plots/treatment. Subsequent sprinklings were given in the morning, at midday, or in the evening, at biweekly intervals. One additional plot was saturated by irrigation before it was inoculated, and did not receive further irrigation. No rain fell during the period of this experiment.

In both experiments, the pattern of blight development was typical of that observed during fall seasons in commercial fields. In experiment B, traces of infection were detected on all plots 4 days after introduction of the inoculum. Spread of the disease was rapid and uniform in all plots, including the one that received no sprinkling. Thus, 12 days after inoculation, mean blight percentages on plots sprinkled in the morning, at midday, and in the evening, were 52, 58, and 54, respectively (standard error 6.8), and almost all the foliage had dried up within 1 more week. The RHD + TGR values for this season ranged from 695 to 763 (Fig. 1-B), which are far below the values for other seasons. Under these conditions, sprinkling, regardless of the time of its application, had no effect on the rate of blight development.

Spring.—In spring, experiment C was sown early in March in the coastal plain, and experiments E and F were sown in February in the semi-Desert Negev.

In experiment C, two replicate plots/treatment were inoculated on 23 April 1968. A number of rainy days followed, and this resulted in the simultaneous onset of disease on all plots. However, blight subsequently developed with much greater intensity on the plots sprinkled in the morning (Fig. 1-C). When sprinkled in the evening, the rate of blight development was at first below and later above that of plots sprinkled at midday. At the last assessment (15 June), the blight percentage on plots sprinkled in the morning, at midday, and in the evening was 70, 40, and 54, respectively, and differences between replicates of the same treatment were negligible (S.E. 5.2). The RHD + TGR values amounted to 814 just after inoculation, rose to a peak of 1,159, and ranged subsequently from 1,008 to 1,156. The highest values were recorded during a hot and dry spell in mid-May. This did not seem to interfere with the progressive appearance of blight symptoms. However, when samples of 100 blighted leaves from each irrigation treatment were placed in moist chambers, many of the lesions failed to produce spores. The percentage of dead, nonsporulating lesions

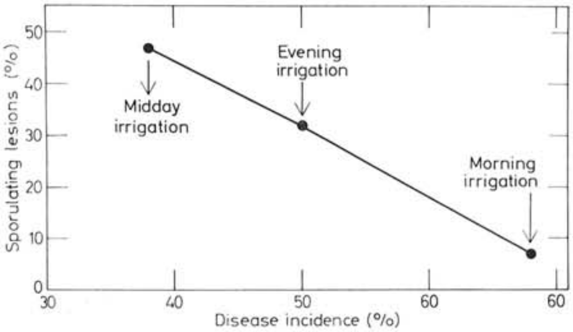

Fig. 2. Sporulating potential of *Phytophthora infestans* on potato leaves collected from plots sprinkled at various times of the day, plotted against disease incidence of the same plots.

was highest in the most severely blighted plots, i.e., those sprinkled in the morning, where the foliage had already become sparse through extensive leaf desiccation (Fig. 2).

In experiment E, inoculated in early April 1967, a rainy spell, uncommon in the Negev in spring, occurred during and after inoculation, interfering with the effects of sprinkling on blight development. Later, as the weather turned normal and dry, the field was affected severely by *Alternaria porri* (Ell.) Neerg. f. sp. *solani* E. & M., which destroyed all plots within 4 weeks, regardless of the time of sprinkling.

In experiment F, two plots of 2 dunams each were inoculated on 2 April 1968. Each plot was inoculated at two points. The night following inoculation was dewy, and the plants serving as inoculum source sporulated copiously. The following day, a single differential sprinkling was given to the two plots in the morning and late afternoon, respectively. Nine days later, blight lesions appeared on two plants next to each of the inoculum plants on the plots sprinkled in the morning, but no infection resulted in the plots sprinkled in the afternoon. Because of a failure in water supply, all further sprinklings had to be applied to the whole field in the afternoon. There was no further blight spread, although the inoculum plants continued to produce sporangia for 7-12 days, as did the infected plants immediately adjacent to them in the plots previously sprinkled in the morning. The RHD + TGR values for the above period ranged from 1069 to 1169, and were thus similar to those associated with continued blight development in spring. However, in contrast to the coastal fields, haulm growth in the plots of experiment F was poor.

Summer.—Two summer experiments were carried out in the coastal plain.

In experiment D, two plots of 2 dunams each were sown in early April and inoculated on 23 May 1967. One plot was then sprinkled in the morning, the other in late afternoon. As shown in Fig. 1-D, the incidence of blight remained low, while the RHD + TGR values were high (1101-1316). The plot sprinkled in the afternoon was very slightly affected (up to 2.5% blight); that sprinkled in the morning developed somewhat more blight (up to 9%).

Experiment G was sown in late April 1968 in two replicate plots/treatment. These plots bordered immediately on plots under identical treatments in the spring experiment C, which served as a source of infection. However, in spite of such permanent presence of inoculum, all plots of experiment G remained free from blight during the 1st month after sowing. As the foliage grew denser, blight began to develop. The pattern of its spread then became related to the irrigation treatments as well as to the amount of inoculum produced in the adjacent old plots. Consequently, results of this experiment, although similar in trend to those of experiment D, were not so clear-cut.

Sprinkling and the splash dispersal of sporangia.—In the course of the spring experiment C, the part played by the splash dispersal of sporangia in the blight development was tested.

Ten healthy, potted potato plants were introduced on 8 May 1967 into each plot, and were left there only while sprinkling was applied in the morning, at midday, or in the evening, respectively. The plants were then removed from the plots, placed in dry growth chambers, and observed for appearance of blight symptoms. Ten additional plants were left in each treatment plot for 1 week following irrigation, and were thereafter kept under similar observation.

Of the plants placed in the field for various periods of sprinkling, only those exposed in the morning developed blight symptoms, but plants exposed for a whole week became infected regardless of the time of sprinkling.

Effects of sprinkling on leaf and stalk temperature.—Leaf temperature of potatoes sprinkled at various times of the day were measured in the coastal plain in experiment A (26-27 October 1967) and in experiment C (11-12 and 17 May 1968). The data obtained were compared with similar measurements from potatoes not irrigated on the same day, and with temperature readings taken in the standard screens.

In May 1968, with radiation intensities of 1150 g-cal/cm^2 per day, the temp of dry leaves exposed to direct sun radiation exceeded screen temp by up to 6 C; in October 1967, with radiation intensities of 714 g-cal/cm^2 per day, the difference was negligible. Sprinkling lowered leaf temperatures: the hotter and drier the microclimate, the more pronounced became this reduction of temperature. On the morning of a hot May day, the temp of wet leaves exposed to the sun in an irrigated plot was 8 C lower than that of similarly exposed dry leaves, and 4 C lower than the screen temperature. The difference between sprinkled and dry leaves amounted to 10 C with midday sprinkling, and to 6 C with evening sprinkling.

The hotter and drier the weather, the more rapid was the rate at which the decreased temperature of previously sprinkled leaves rose back to the level of dry leaves. This was most marked after morning irrigation which terminated before noon; in plots sprinkled in the evening, leaf-temperatures remained lower long after irrigation.

DISCUSSION.—Under macroclimatic conditions sufficiently favorable to blight, e.g., in the fall season in the coastal plain (experiments A and B), sprinkling does not aggravate late blight development, and the time of day at which it is applied is irrelevant. Similarly, field observations (unreported) showed that, under extremely dry conditions, sprinkling at any time of the day will not promote blight. Generalized assumptions that sprinkling can be expected to favor blight (1) must therefore be modified.

Sprinkling promotes blight chiefly where conditions are suboptimal or marginal for the disease. The effect of sprinkling on disease development is connected with the time of spore dispersal and their survival under given climatic conditions (3). Leaf-surface conditions are more relevant for spore survival than are the conditions of the air. However, when leaf temp tends to exceed the screen measure, standard meteorological data fail to serve for epidemiological analysis.

Since the level of leaf temperature is largely affected by radiation, this parameter (TGR), together with the relative humidity deficit (RHD), may serve as microclimatic indicators. The value obtained by adding RHD and TGR records is, of course, an entirely arbitrary and artificial concept, and no causal connection between these values and blight development is claimed. Nevertheless, it may serve as a workable indicator for the studied phenomena.

Thus, in autumn, with RHD + TGR values generally in the 700-800 range, the morning-dispersed sporangia survive until evening, and infect plants during the next night's dew regardless of sprinkling. In late spring, with RHD + TGR values generally between 1,000 and 1,100, most sporangia fail to survive until the next night's dew. The blight development then is slower and markedly favored by morning, rather than by midday or evening, sprinkling. In summer, with RHD + TGR values constantly above 1,100, and ranging as high as 1,300, conditions for survival of sporangia are inferior, and morning irrigation is by far the most favorable to blight.

As shown by exposing healthy plants for the period of morning irrigation only, the actual 3.5 hr period of sprinkling sufficed for the penetration process. Infection, however, is not restricted to the sprinkling periods, as seen by the infection of all plants left in the infected field for a week. This derives from the ability of some of the morning-dispersed sporangia to remain viable until the dewfall, and/or from early dispersal of some sporangia which completed infection before the dew dried up.

The plant density in the field seems to modify the effects of sprinkling. In experiment G, plants undergoing every kind of irrigation did not contract late blight when young, although the season was favorable and inoculum was abundant. Similarly, sparse foliage at later stages of growth (experiment F) discouraged blight development. These are microclimatic effects on the viability of dispersed sporangia, which are more marked in arid than in temperate climates. It may thus be supposed that with similar RHD + TGR values, but in crops with a different microclimate, the effects of sprinkling on late blight will vary from those described above.

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