

Alternaria diseases of potatoes: epidemiology and management under Israeli conditions

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SUMMARY

Potatoes are grown in Israel in two main seasons. For the autumn crop, potatoes are planted in late August to early September and harvested during December and January. For the spring crop, potatoes are planted in late January to February and harvested during May to July. Two *Alternaria* species infect potato plants in Israel: *A. solani*, the causal agent of early blight and *A. alternata*, the causal agent of necrotic lesions. Nevertheless, the most destructive pathogen is *Phytophthora infestans*, the causal agent of late blight. Analysis of disease progress curves revealed that early blight is more important in the autumn than in the spring season. Results of field experiments suggested that *A. solani* intensifies towards the end of the season, in mature plants and that the yield was reduced and application of fungicides was profitable in the autumn but not in the spring seasons. Based on these experiments we developed an integrated strategy for management of both early and late blights. The strategy was evaluated in field experiments, under natural infections, and found accurate. In observations carried out in commercial fields it was found that necrotic lesions appear suddenly in large areas, often after heavy rain events and that the phenomenon was more common in crops growing in sandy soils. *Alternaria alternata* was isolated from necrotic lesions and the Koch postulates were completed and proved the pathogenicity of that fungus. Based on these observations it was hypothesized that heavy rains wash the nitrogen fertilizer from the root zone and that necrotic lesions appear in plants suffering from stress imposed by sudden reduction in nitrogen content in the foliage. These hypotheses were tested and it was found that necrotic lesions develop primarily in nitrogen-deficient plants and that applying supplemental N fertilization reduces necrotic lesion severity. Accordingly, it was decided not to recommend fungicide spraying for suppression of necrotic lesions.

KEYWORDS

Alternaria alternata, *A. solani*, disease management, *Solanum tuberosum*

INTRODUCTION

Potatoes are grown in Israel (30° E, 31° N) in several regions. The main area of production (ca. 12,300 ha, 80% of the national cultivated area) is in the northern Negev. The climate there is

semi-arid with mild winters and hot, rainless summers. There are two main seasons for potato production, autumn and spring. For the autumn season crop, potatoes are planted in late August – early September and harvested during December and January; for the spring crop they are planted in late January – February and harvested during late May, June and July. The growing seasons differ markedly in respect to the environment: for the autumn season crop, growth starts when temperatures are high and the days are relatively long, and continues under decreasing temperatures, day length and radiation; for the spring season crop, growth starts when temperatures are relatively low and days are relatively short, and continues under increasing temperature, day length and radiation (Levi *et al.*, 1986).

Early blight (caused by *Alternaria solani*), necrotic lesions (caused by *A. alternata*) and late blight (caused by *Phytophthora infestans*), are the main foliar diseases of potatoes in Israel. Severe epidemics of early blight may restrict potato yields by up to 20-30% and late blight may result in complete destruction of the yield in severe epidemics (Rotem, 1994; Shtienberg *et al.*, 1996). Quantitative estimations on the effects of necrotic lesions on yield are currently not available. In order to suppress the diseases, fungicides are often applied to the foliage. During a typical growing season, potato fields are sprayed with fungicide eight to twelve times. In the current paper we review the experience gained over the years in coping with these potato diseases under the semi-arid conditions prevailing in Israel.

EARLY BLIGHT, CAUSED BY *ALTERNARIA SOLANI*

Observations and epidemiological considerations

The response of potatoes to *A. solani* changes as the host ages. Immature potato plants are relatively resistant to early blight. However, after the initiation of tuberization, susceptibility increases gradually and mature plants are very susceptible to *A. solani* (Pscheidt & Stevenson, 1988; Rotem, 1994). Cultivars differing in genotype resistance usually follow a similar pattern of changes in age-related resistance. Thus, early blight is principally a disease of senescing plants and early sprays had little, if any, effect in overall suppression of *A. solani* (Christ & Mazuga, 1989; Pscheidt & Stevenson, 1988; Shtienberg *et al.*, 1996). Analysis of epidemics of early blight in the autumn and spring seasons in Israel revealed that early blight is more important in the autumn than in the spring season. The variable effects of the disease in the two growing seasons was attributed to the different seasonal patterns of environmental conditions such as temperatures and radiation (Shtienberg *et al.*, 1996). This implies that management of early blight in the autumn is essential and may lead to significant yield increases, but the need for its suppression in the spring season is questionable.

Late blight may develop in both growing seasons but epidemics are more likely to occur and are more severe in the spring, due to the prevalence of more conducive weather. Often, the disease does not develop at all in a certain season or in certain fields but due to its destructive potential growers apply fungicides as a precocious measure. Since adequate control efficacy depends on timely initiation of fungicide sprays (*i.e.*, before the disease had infected the crop) spraying is initiated soon after emergence and continues, in 7-10 days intervals, until vine kill.

Conceptual model for early and late blights management

Results of previous studies enabled us to develop concepts for integration of genotype resistance, age-related resistance and fungicide in the management of *A. solani* and *P. infestans*. An attempt was made to develop an effective, reliable and cost-effective solution for changing environment and under uncertain conditions. The basic principles are as follows: late blight is the

most important disease and the crop has to be protected before the pathogen had invaded the field; thus, sprays are applied in a prophylactic manner as an insurance measure. The frequency of sprays is dependent on the response of the cultivar to *P. infestans* and on the season: sprays are applied less frequent to moderately resistant cultivars and in the autumn. To quantify the general risk a specific field is facing, three "risk" categories were defined. Risk category "A" implied that late blight was not observed at all in the region; risk category "B" implies that late blight was observed in the region but not in the field and risk category "C" implies that symptoms were observed in the specific field. A regional system has to be developed to notify growers on the current situation of the disease in the region. The type of fungicide to be applied and the frequency of sprays are determined according to the current risk category. In general, protectant fungicides at half rate are to be applied under risk category A and protectant fungicides at full rate are to be applied at risk category B. Under risk category C, protectant fungicides are to be applied if conditions are unfavorable to *P. infestans* and systemic fungicides are to be applied when environmental conditions are highly favorable to *P. infestans* (i.e., cool, rainy weather).

Early blight is to be considered specifically only in the autumn season employing the concepts presented in Figure 1. Application of fungicides is not needed in plants at the vegetative stage because they are relatively resistant. Accordingly, spraying should be initiated only when host response to *Alternaria* shifts towards increasing susceptibility, i.e., at the initiation of the reproductive stage (Shtienberg *et al.*, 1989). The frequency of subsequent sprays should be determined according to the genotype resistance of the cultivar to *A. solani* and the efficacy of the fungicide, in relation to changes in age-related resistance. Accordingly, protectant fungicides should be applied initially at relatively long intervals, which will shorten as the crop ages. Towards the end of the season, more effective control, by means of a systemic fungicide, is recommended. The maturity class of the cultivar and its genotype resistance to *A. solani* should be considered as well by adjusting the frequency of spraying according to the changes in host response to the pathogen (Figure 1). Towards the end of the autumn season, if late blight alert B or C is issued, a systemic fungicide used against early blight is to be mixed with a full rate of a fungicide against late blight (protectant or systemic). In the spring season, the environment promotes host growth and the production of new leaves precludes a significant reduction in yield and management of early blight should not be considered specifically. The protectant sprays applied against late blight in the spring season are sufficient for adequate suppression of early blight.

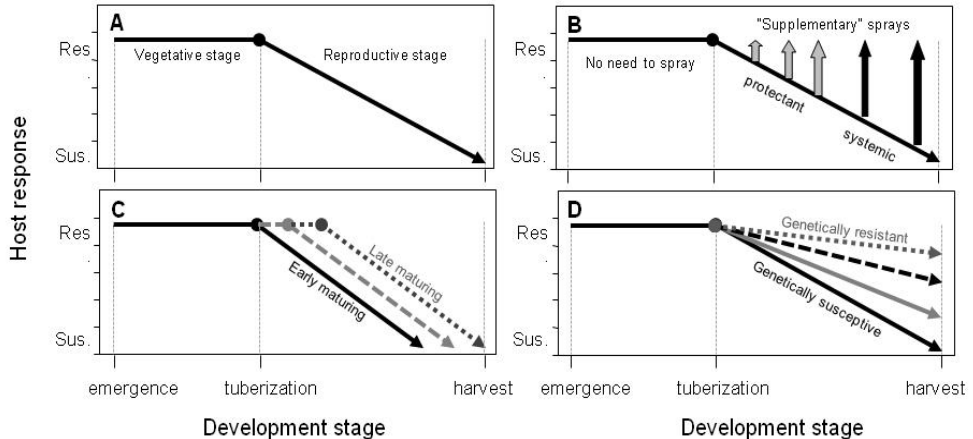


Figure 1. Graphical presentation of components of the conceptual model for integration of control measures for suppression of *Alternaria solani*, the causal agent of early blight in potatoes. **A.** Changes of host response over time (i.e., age related resistance); **B.** The need for applying supplementary fungicidal sprays to compensate changes in host resistance over time; **C.** Effects of maturity class of the cultivar; **D.** Effects of genotype resistance. Host response: Res. = resistant; Sus: susceptible

Experimental results

The conceptual mode described above was evaluated in seven experiments conducted in the northern Negev region of Israel; 4 experiments were carried out in the autumn season and 3 in the spring season. All experiments were carried out in commercial fields so that the results would reflect the complexity and uncertainty prevailing in normal situations. In this report results recorded in one autumn-season experiment and in one spring-season experiment are presented but those recorded in the other experiments were similar. Susceptible cultivars were used in the experiments, Mondial in the autumn experiment and Alpha in the spring experiment. Plots consisted of four 7-m long rows and were separated from each other by fallow areas approximately 1 m wide. Fungicides (in 260-300 L water/ha) were applied by means of a motorized back-sprayer at a pressure of 275 kPa with cone-jet X6 nozzles. In each trial one protectant and one systemic fungicide (for each pathogen) were used. The protectant fungicide was mancozeb and the systemic fungicides were tebuconazole (Folicur) and cymoxanil+mancozeb (Mancur; CM). The following five treatments were included in all trials: (i) untreated control; (ii) management of both early and late blights by protectant fungicides (application of mancozeb on a 7-day schedule); (iii) optimal management of early blight (application of tebuconazole on a 10-14 day schedule); (iv) optimal management of late blight (application of CM on a 10-14-day schedule); and (v) application of protectant and systemic fungicides according to the concepts of the integrated management strategy. In treatments iii spraying was initiated after observing the first early blight symptoms in the plots; in the other treatments, prophylactic sprays were applied. Two individuals assessed disease severity visually independently and the average scores were computed. Assessments were made every 7-14 days from the appearance of disease symptoms until the end of the season. Since it was not always possible in the field to distinguish between symptoms induced by *A. solani* or *P. infestans*, their combined intensity was assessed. Thus, disease severity records reflect the intensity of both pathogens and towards the end of the season also the natural senescence of the crop. Severity

records were used to calculate the Area Under the Disease Progress Curve (AUDPC) for each of the treatments. Results were subjected to statistical analysis and where F values showed significant differences, Fisher's protected LSD Test was applied at $P = 0.05$.

In the autumn experiment early blight was observed 40 days after emergence; late blight was observed in the region (risk category B) about three weeks after emergence and in the field (risk category C) about 7 weeks later. By the end of the season, plots treated only with tebuconazole and plots treated only with CM were significantly more diseased than plots that were treated against both pathogens (the integration treatment). Presumably, the higher disease severity resulted from inadequate suppression of *P. infestans* and *A. solani*, respectively, in this plots. AUDPC values in the fungicide treated plots differed significantly from the value recorded in untreated plots (Figure 2).

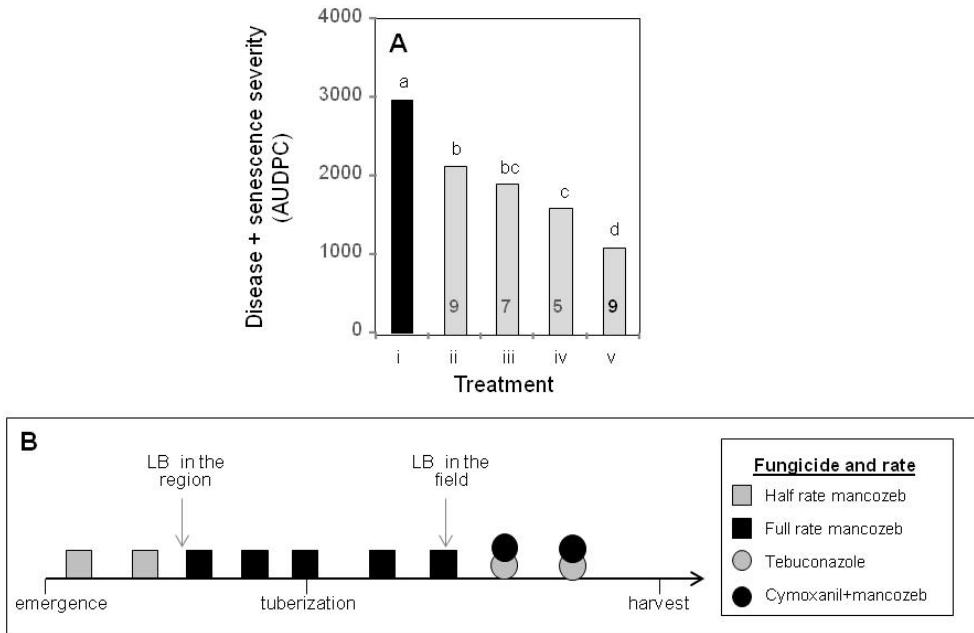


Figure 2. Evaluation of the integrated management strategy in a field experiment carried out in the autumn season. The following five treatments were included in the trials: (i) untreated control; (ii) mancozeb; (iii) tebuconazole; (iv) cymoxanil+mancozeb (CM); and (v) the integrated management strategy. **A.** Effects of the treatments on the AUDPC. The number of sprays applied in each treatment is indicated within the bars; **B.** Timing of spraying in the integrated management treatment. Values of bars accompanied by different letters differ significantly as determined by the LSD test at $P < 0.05$

In the spring experiment late blight was more destructive than early blight (although both diseases prevailed in the experiment). Both pathogens were adequately suppressed in the CM treatment and also in the integrated management treatment. This control was achieved in spite of the fact that only 2 CM sprays were applied in the integration treatment, as compare to 5

sprays in the CM treatment. Disease control (presumably late blight) in the tebuconazole treatment was inadequate as reflected by the higher AUDPC values (Figure 3).

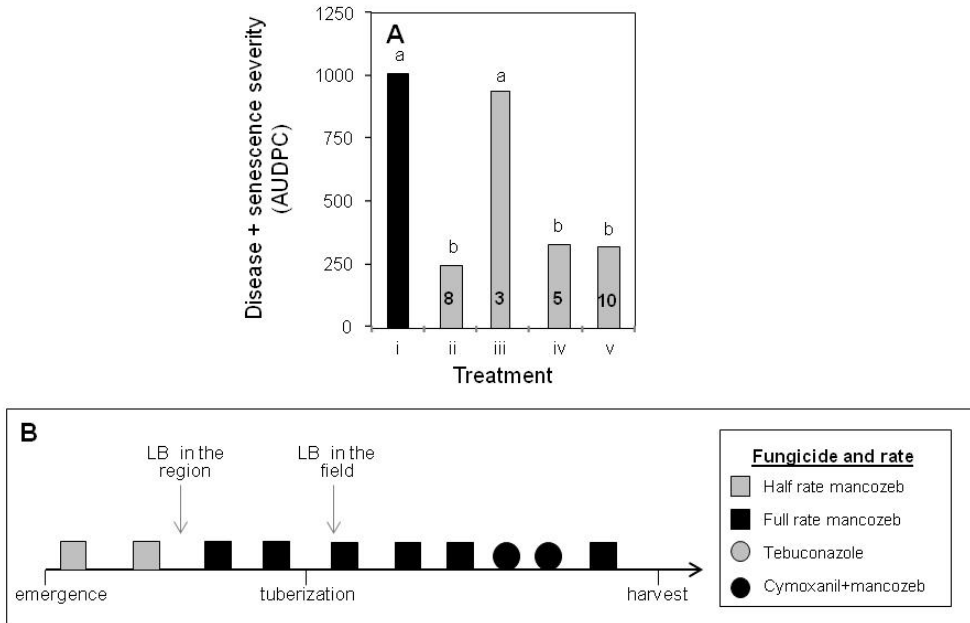


Figure 3. Evaluation of the integrated management strategy in a field experiment carried out in the spring season. The following five treatments were included in the trials: (i) untreated control; (ii) mancozeb; (iii) tebuconazole; (iv) cymoxanil+mancozeb (CM)); and (v) the integrated management strategy. **A.** Effects of the treatments on the AUDPC. The number of sprays applied in each treatment is indicated within the bars; **B.** Timing of spraying in the integrated management treatment. Values of bars accompanied by different letters differ significantly as determined by the LSD test at $P < 0.05$

NECROTIC LESIONS, CAUSED BY *ALTERNARIA ALTERNATA*

Observations and epidemiological considerations

Observations in commercial fields in the northern Negev reveal that, occasionally, brown spots develop on the lower side of potato leaves. The spots are scattered on the leaves in large numbers (Figure 4). In accordance to the symptoms the phenomenon was called "necrotic lesions". The fungus *A. alternata* was consistently isolated from these spots and its pathogenicity was confirmed by completing the Koch's postulates (Droby *et al.*, 1984). In their study, Droby *et al.* (1984) found that the fungus infects the leaf by direct penetration and *via* stomata. Young plants, at the 10-12 leaf stage, were less susceptible than adult plants; a differential susceptibility of the leaves was observed in which the middle leaves of the plant showed the highest disease incidence at any given growth stage. They also reported that susceptibility varied according to the cultivar and the quantity of sprinkler irrigation. Observations in commercial fields, under natural conditions revealed that necrotic lesions appear suddenly in

large areas, often after heavy rain events (> 50 mm rain). Furthermore, the phenomenon is more common in crops growing in sandy soils. Application of fungicides against *Alternaria* slightly reduced the intensity of necrotic lesions but control efficacy was relatively low (D. Shtienberg; *unpublished results*). Based on these observations it was hypothesized that necrotic lesions appear in plants suffering from stress imposed by sudden reduction in nitrogen content in the foliage and that heavy rains, or large quantities of over-head irrigation, wash the nitrogen fertilizer from the root zone.



Figure 4. Potato leaves severely infected by necrotic lesions, caused by *Alternaria alternata*

Experimental results

The hypothesis that deficit in nitrogen fertilizer predispose the development of necrotic lesions was examined in a set of field experiments in 2003 to 2005 (Shtienberg *et al.*, 2006). In these experiments the quantitative interaction between various N rates and rain quantities were used. Nitrogen was applied *via* the irrigation system (fertigation) as done in commercial production at rates varying from 0 to 250 kg/ha; "rain" was mimicked by over-head irrigation system at a rate equivalent to 60 mm occurring once (33 or 45 days after planting) or twice (33 and 45 days after planting). To minimize the possibility that "real rain" will fall and mask our treatments, the experiment was carried out in the spring season at a location where rains are infrequent. It was found that necrotic lesions severity was governed by nitrogen rate and by the timing and number of mimicked-rain events. Necrotic lesions severity was the highest in plants that were not fertilized with nitrogen at all (0 fertilization treatment) and were exposed to mimicked-rain twice; the lowest necrotic lesions severity was observed in plants that were fertilized at with high nitrogen rate (245 kg nitrogen/ha) which were not exposed to mimicked-rain at all (Figure 5). Nitrogen content was determined in leaf petioles sampled from the experimental plots. It was found that necrotic lesion severity was significantly related to nitrogen contents in the petioles (Figure 6). The experiment was repeated once with similar results.

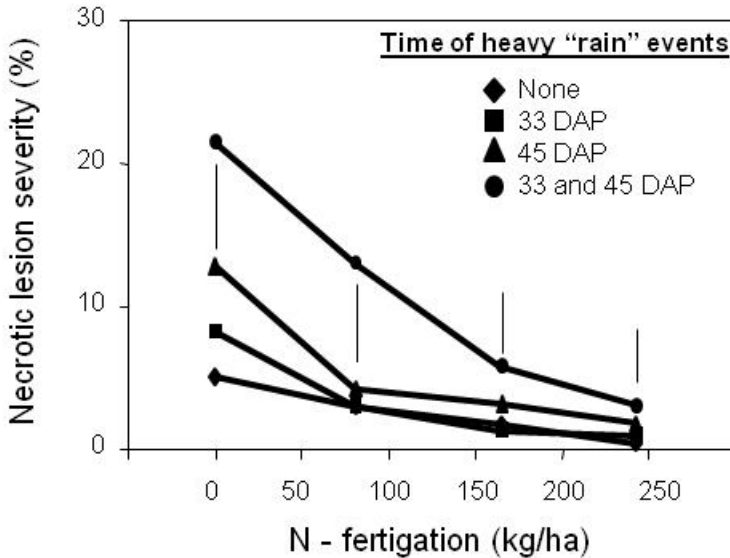


Figure 5. The interacting effects of nitrogen fertilization and the number of heavy "rain" events (mimicked by over-head irrigations) on the severity of necrotic lesions, caused by *Alternaria alternata*, in potato foliage. Vertical lines indicate the LSD at $P = 0.05$. DAP = days after planting

In another set of experiments attempts were made to reduce necrotic lesion severity by application of nitrogen soon after the occurrence of (mimicked) heavy rain event or by application of foliar sprays. Heavy rain event was mimicked over-head irrigation (applied once, at quantity equivalent to 80 mm of rain). After the termination of the mimicked rain, N-fertilizer was applied at a rate of 180 kg N/ha. For the fungicide treatment, tebuconazole was applied 4 times in bi-weekly intervals, starting 3 weeks before the time of mimicked-rain. Thus, two sprays were applied before and two sprays were applied after the occurrence of the mimicked-rain event. Disease severity (*i.e.*, the proportion of the foliage exhibiting disease symptoms) was assessed one month after the simulation of rain. It was found that spraying of fungicides did not affect necrotic lesions severity but application of surplus nitrogen, soon after the occurrence of the mimicked heavy rain event, significantly reduced necrotic lesions severity as compared with the plants that did not receive the surplus fertilization (Figure 7).

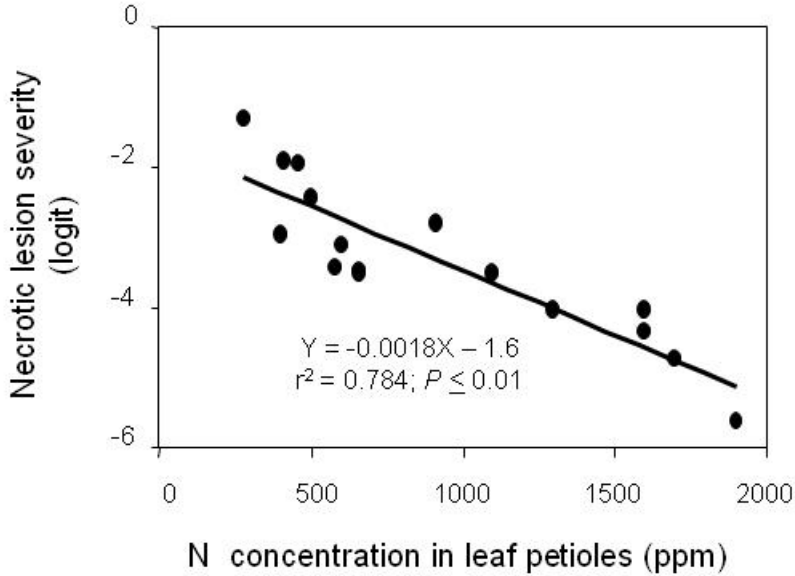


Figure 6. The relationship between N concentration in leaf petioles and severity of necrotic lesions. Necrotic lesion severity is expressed in logit units ($\text{logit} = \ln(X/(100-X))$ where $X = \text{disease severity}$)

Based on our previous observations and on the experiments described herein, it was concluded that necrotic lesions develop primarily in nitrogen- stressed plants. Application of fungicides did not reduce necrotic lesions severity significantly. On the other hand, applying supplemental N fertilization soon after the occurrence of the heavy rain event reduced necrotic lesions severity significantly. As a consequence, to our opinion application of fungicides for the suppression of necrotic lesions is not required; application of supplemental nitrogen soon after the occurrence of heavy rain event may be considered.

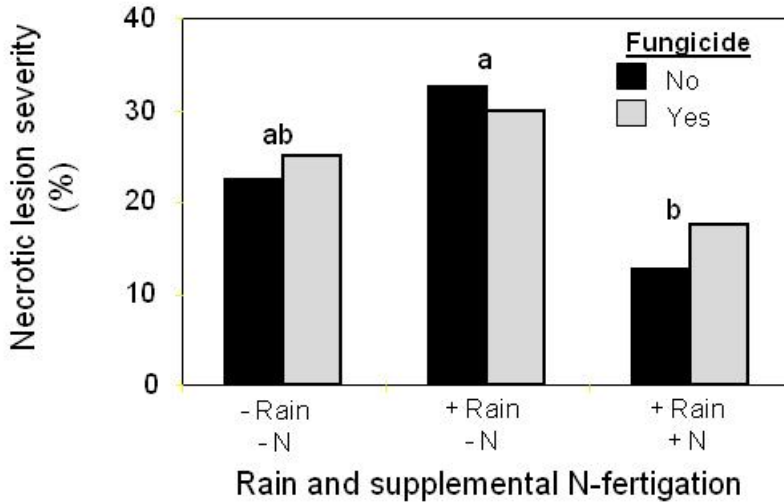


Figure 7. The interactive effects of heavy "rain", supplemental N fertilization and fungicides, on necrotic lesions severity. Rain was mimicked by over head irrigation at quantity equivalent to 80 mm; Nitrogen was implemented after the mimicked rain event in quantity of 180 kg N/ha. Four tebuconazole sprays were applied, two before and two after the mimicked rain event. Effects of spraying were insignificant; Values of bars accompanied by different letters differ significantly as determined by the LSD test at $P < 0.05$

DISCUSSION

Development of more than one pathogen in a certain field is a well-known situation. Potato growers in the northern Negev region of Israel had to combat simultaneously with *A. solani*, *A. alternata* and *P. infestans*. The most important measure employed by growers during the growing season for the suppression of foliar diseases is application of fungicides. Several fungicides of various groups are currently available for the control of each pathogen. However, their efficacy may differ markedly and certain fungicides cannot be used for the suppression of all pathogens. For example, triazole fungicides are highly effective against *Alternaria* but not effective at all against *P. infestans*. On the contrary, if CM is applied against *P. infestans*, only the protectant portion of the product (*i.e.*, mancozeb) is effective against *Alternaria*. The protectant fungicides are effective against all pathogens but their efficacy, in general, is inferior to that of the specific systemic fungicides. Other important factors that should be taken into account are the cost of the fungicides and the ability of the pathogens to develop resistance against the commonly used fungicides. The cost of systemic fungicides applied to a unit area is 2-10 times higher than the cost of the comparable protectant fungicides. The costs, and the need to reduce the number of applications to lower the probability for development of fungal populations resistant to the effective systemic fungicides, motivate growers to apply them as less frequent as possible.

The assumption underlying the concepts of the integration management strategy presented in this study is that the effects of different control measures are complementary and additive. Accordingly, application of one measure may compensate for a decrease in another measure.

Integration of three measures was considered, *viz.*, genotype resistance, age-related resistance and fungicide type and efficacy. Genotype resistance and age-related resistance were considered as measures in which their contribution is more or less predetermined. Fungicides were used as a flexible measure by which it was possible to respond to the situations develops in the field during the growing season.

The relative importance of the pathogens may differ between years, growing seasons and individual fields. Based on our experiments and observations we concluded that in the northern Negev, late blight is the predominant disease and should be managed properly in all crops; early blight should be considered only in the autumn season and necrotic lesions develop sporadically and since it has no significant effects on yield, specific control measures should not be applied for its management. The integrated management strategy presented here provided adequate suppression of the foliar diseases threatening potato production in commercial fields under diverse conditions. It should be noted that the number of sprays applied according to the integrated strategy was not necessarily lower than that applied by the grower's routine program. However, disease suppression was always adequate and calculations of the cost/benefit ratio revealed that the net income, after deduction of spraying expenses was markedly higher in the integrated management treatment than in the other treatments (results not shown). Potato growers in the Negev region implement components of this strategy with considerable success.

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