Infrared Thermometry for Determination of Root Rot Severity in Beans

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ABSTRACT

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Bean plants were grown in soil infested with root rotting fungi (*Fusarium*, *Pythium*, and *Rhizoctonia*) and in pasteurized soil. Differences between leaf and air temperatures taken with an infrared thermometer between 1400 and 1500 hours on sunny days showed that green leaves of diseased beans were warmer than those of healthy ones even if the soil moisture was maintained at field capacity. Depending on the severity of root rot, leaves of diseased plants appeared to be either normal or slightly less turgid. Increases in root rot severity correlated closely with increases in leaf temperature ($P \leq 0.01$). This was most apparent at early stages of plant growth (one or two trifoliate leaves). Diseased plants grown under water stress had much higher leaf-air temperature differentials than healthy ones. If plants were stressed almost to the wilting point and water was added to return the soil to field capacity, decreases in leaf temperatures of healthy plants were larger than those of diseased plants. In diseased plants, decreases in leaf temperatures subsequent to watering were inversely related to the severity of root rot. Thus, leaf temperatures could be used not only to detect the presence of root rots but also to monitor disease severity in individual plants in soil without visually examining the roots. This technique can be used to screen segregating progeny from crosses of resistant and susceptible cultivars.

Additional key words: *Phaseolus vulgaris*.

Bean (*Phaseolus vulgaris* L.) root rots (caused mainly by *Fusarium solani* (Mart.) Appel & Wr., *Rhizoctonia solani* Kühn, and *Pythium ultimum* Trow (9)) cause variable yield losses depending on the amount of root loss and severity of vascular damage. Severely affected plants wilt and die; less severely affected plants, however, show stunting and/or temporary wilting on warm sunny afternoons.

Recent research results have shown that some bean cultivars are resistant or highly tolerant to this disease complex (3,6,11). At the Agriculture Canada Research Station in Harrow, a breeding program has been developed to transfer resistance characteristics to commercially desirable white bean cultivars by crossing, backcrossing, and subsequent progeny selection.

During progeny selection, it is imperative to differentiate resistant plants from susceptible ones in a segregating population. In the past, plants were grown in naturally or artificially infested soils and rated for the severity of root rot by visual inspection of the root systems, which usually involved removing plants from soil. The disadvantages of that are: removal of plants from the soil damages the roots and disturbs the root system habitat so that (except for small seedlings) replanting is not feasible, and each plant can be examined only once so that disease progress in the same plant cannot be assessed. These limitations make selection of resistant progenies and their use in subsequent crossing difficult. Therefore, an assay method that can estimate root rot severity in situ would facilitate screening progeny of crosses for root rot resistance.

The method that we tested is based upon the fact that water absorption in root rot-affected plants tends to lag behind transpiration, which reduces leaf water potentials, stomatal conductance, and transpirational cooling. These effects lead to elevated leaf temperatures (4,5,8). Diseased plants show varying degrees of temporary wilting in the warm afternoons even when soil moisture is adequate for normal plant growth. However, the plants recover and regain turgidity during the night. This diurnal wilting develops because of insufficient uptake of water to compensate for the loss of water due to transpiration in warm afternoons (7,17). The degree of wilting is usually correlated with the severity of root rot (1). It can be postulated that an increased leaf-air temperature difference is directly related to the root rot severity because plants with more severe root rot have both reduced water uptake and reduced transpiration. Consequently, the rate of heat dissipation is reduced and higher leaf temperatures result. This phenomenon can be accentuated under conditions of soil moisture stress or increased air temperature (4,5,7,8,12).

Infrared thermometry has been used to detect plant water stress conditions by monitoring leaf temperatures (16,19). Advances in infrared thermometry technology has led to the availability of hand-held, infrared thermometers with small aperture angles. This device can provide an instant reading of leaf temperature as well as leaf-air temperature differentials to the nearest 0.1 C (13).

This paper reports the results of a comparative study of conventional visual scoring and infrared thermometry to determine the severity of root rot in individual bean plants.

MATERIALS AND METHODS

Four bean cultivars with known reactions to the root-rotting pathogen complex (*F. solani, P. ultimum,* and *R. solani*) (2,10,15,18) were used. Paired tolerant and susceptible cultivars with similar plant type and growth habit were compared to evaluate the correlation between leaf-air temperature differences and severity of root rot. These pairs were: the tolerant PI 165.435 and the susceptible Seafarer, and the tolerant Wisconsin 46 and the susceptible Kentwood are similar. For each experiment, 832 25-cm-diameter pots were used, 416 of which were filled with sterile soil and the other 416 with naturally infested soil obtained from a nursery heavily infested with root-rotting fungi (i.e., *F. solani, P. ultimum,* and *R. solani*). For each cultivar, four seeds were sown in 104 pots each of sterile and infested soils. They were divided into four groups of 26 and were completely randomized. Each group was further divided into two subgroups of 13 to accommodate two soil moisture treatments. All pots were kept in a greenhouse at 22 ± 4 C and were watered every other day for 2 wk before the seeds were planted. After germination, plants were thinned to two per pot.

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All measurements of temperature were made on sunny afternoons between 1400 and 1500 hours, except on several occasions when measurements also were made on cloudy days to determine the effects of cloud cover. Leaf temperatures were monitored on the youngest fully expanded leaves when plants had reached the second, third, and fourth trifoliate leaf stages. All experiments were repeated twice. Many researchers (7,14) have found that when plant temperature measurements were used to quantify crop water stress in the field, using the leaf-air temperature differentials, reasonable success could be obtained at about 1330 hours (7,14). Furthermore, it is known that throughout the greater portion of the daylight period, relationships of leaf-air temperature differentials and air vapor pressure deficits are linear for plants transpiring at the potential rate, irrespective of other environmental parameters except cloud cover (13). A hand-held infrared thermometer with a 3-degree field-of-view lens, a resolution of ±0.1 C, and a practical accuracy of ±0.5 C (model AG-42; Telatemp Corporation, Fullerton, CA) was employed. The greenhouse temperature was usually around 25–26 C at the time of measurement. Measurements were taken under two soil moisture conditions: a wet soil with 17.5% soil moisture (−3.0 kPa) and a dry soil with 6.9% moisture (−1,200 kPa). The field capacity of this soil was 16.1% (at −5.8 kPa) and the permanent wilting point was 5.3% (−1,500 kPa) by oven-dry weight. Later, the pots were flushed with water to bring the soil moisture to field capacity and the leaf temperature was measured again 20 min later.

After completion of temperature measurements, plants were carefully removed from the soil. The severity of root rot symptoms

TABLE 1. Summary of average leaf-minus-air temperature differentials (DT) and disease severity scores of two tolerant and two susceptible bean cultivars, grown in infested and sterile soil at field capacity and measured at the second trifoliate leaf stage

	Infested soil		Sterile soil	
Cultivar[x]	DT (C)	Disease severity (%)[y]	DT (C)	Disease severity (%)
Seafarer	−2.0 a	16.5 a[z]	−3.9 a	0.4 a
Kentwood	−2.1 a	15.4 a	−4.2 ab	0.4 a
PI 165.435	−4.0 b	8.3 b	−4.4 b	0.2 a
Wisconsin 46	−3.8 b	7.6 b	−4.2 ab	0.6 a

[x] Seafarer and Kentwood are susceptible and PI 165.435 and Wisconsin 46 are tolerant cultivars.

[y] Visual estimates of percentages of root systems with root rot. Each value represents the mean of 13 plants and three experiments.

[z] Means within a column followed by the same letter are not significantly different according to Duncan's multiple range test.

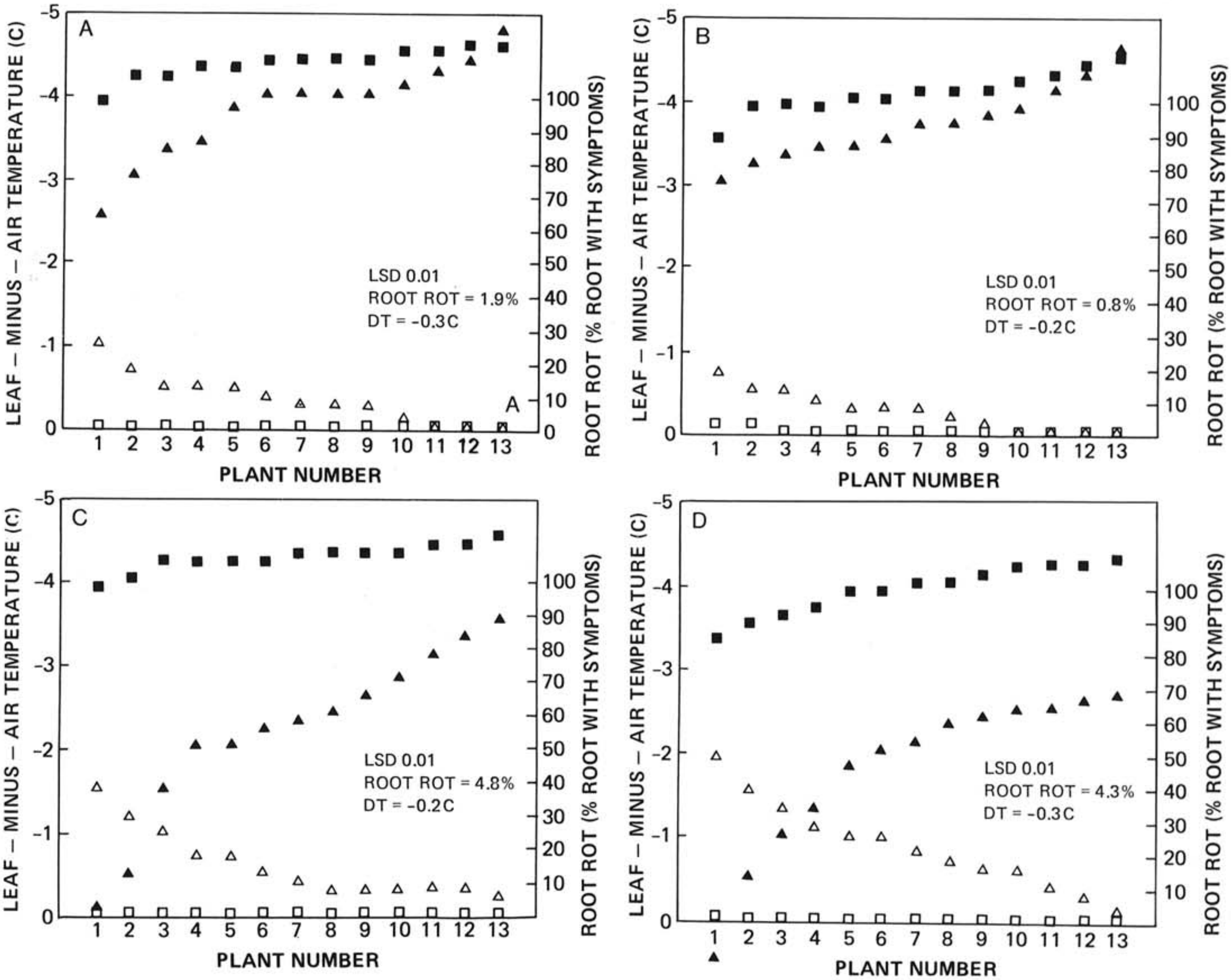
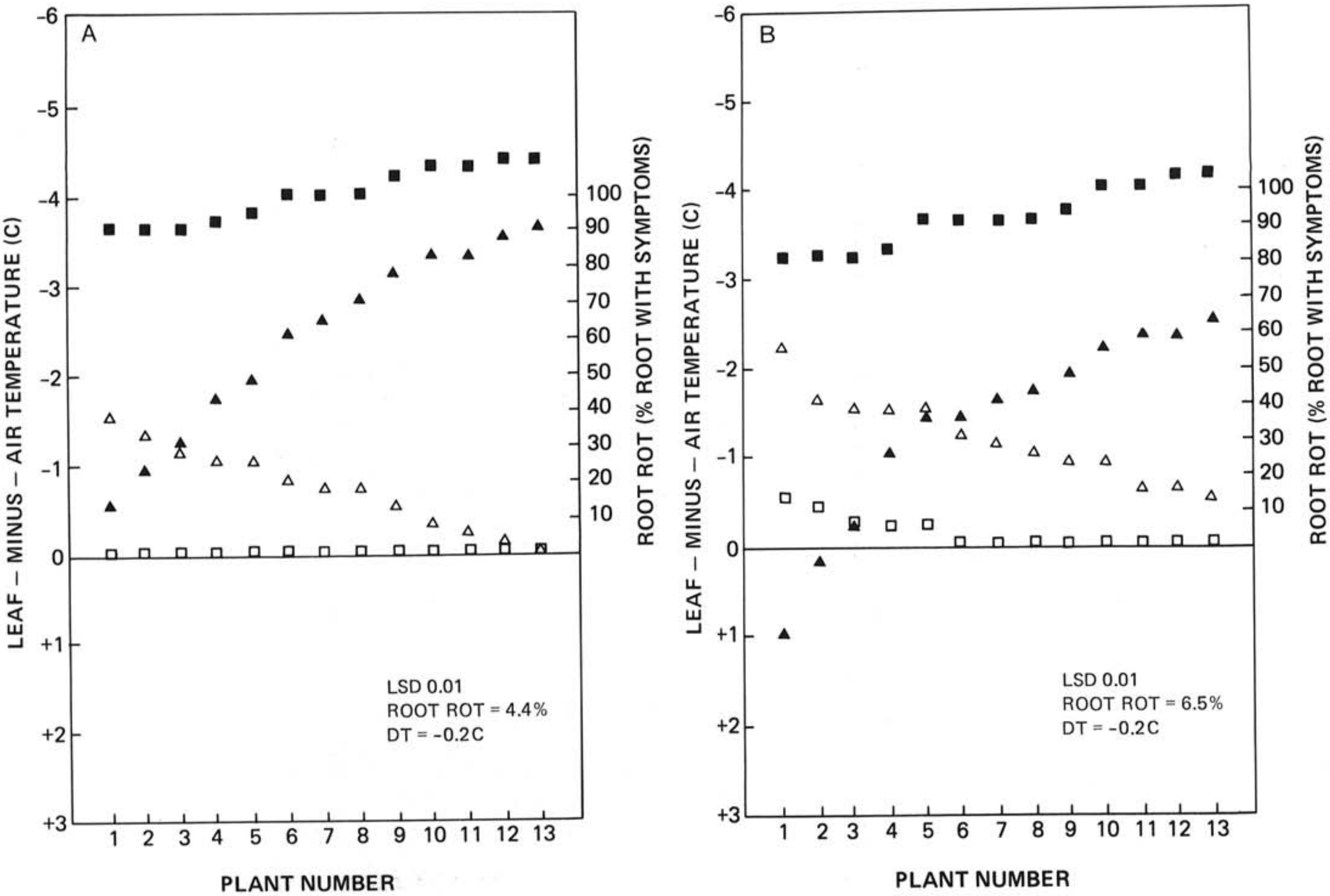


Fig. 1. Relationships between leaf-minus-air temperature differentials (DT) and root rot severity in individual bean (*Phaseolus vulgaris*) plants at the second trifoliate leaf stage of growth in infested or sterile soil with moisture at field capacity. Cultivars: **A,** PI 165.435 and **B,** Wisconsin 46 are tolerant to root rot and **C,** Kentwood and **D,** Seafarer are susceptible. Symbols for DT are: ■ for plants in sterile soil, and ▲ for plants in infested soil. Symbols for root rot are: □ for plants in sterile soil and △ for plants in infested soil.



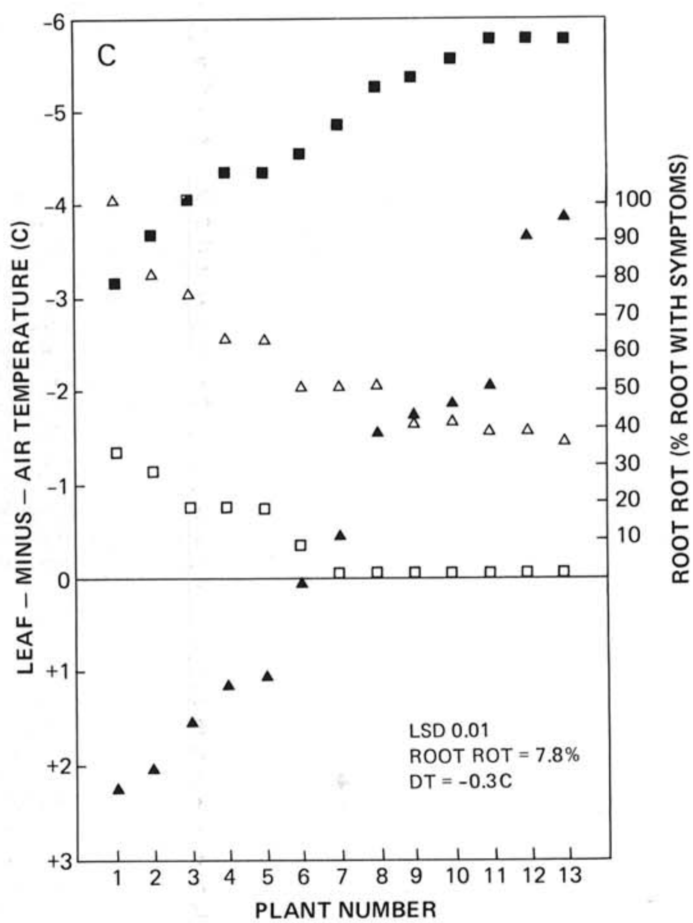


Fig. 2. Relationships between leaf-minus-air temperature differentials (DT) and root rot severity in individual bean (*Phaseolus vulgaris* 'Seafarer') plants at the **A,** second, **B,** third, and **C,** fourth trifoliate leaf stages of growth in infested or sterile soil at field capacity. Symbols for DT are: ■ for plants in sterile soil, and Δ for plants in infested soil. Symbols for root rot are: □ for plants in sterile soil and ▲ for plants in infested soil.

was scored visually on a 0–9 scale (0 = no disease, 1 = 1–10%, 2 = 11–20%, . . . and 9 = 91–100% of the root system affected).

RESULTS

Differences between leaf surface and ambient air temperatures in the greenhouse (DT) at the second trifoliate stage of the four cultivars, and the severity of root rot, are summarized in Table 1 and Fig. 1A–D. The measurements were taken from plants growing in soil with moisture at field capacity. The cultivars differed significantly in DT and root rot severity when grown in infested soil (Table 1). The average DTs of the susceptible cultivars were 2.0–2.3 C higher than those of the tolerant ones. Susceptible cultivars also developed more severe root rot symptoms. In sterile soil, however, few symptoms developed and DT and disease severity among cultivars were not significantly different.

Fig. 1A–D illustrates for two susceptible and two tolerant cultivars the relationships between DT and root rot severity of randomly selected individual plants in infested and sterile soil. When the tolerant cultivars (PI 165.435 and Wisconsin 46) were grown in infested soil, disease developed in some plants. Diseased plants could be easily identified by comparing the DT value of each plant in infested soil with that in sterile soil. The DT increased ($P \leqslant 0.01$) with increasing severity of disease (Fig. 1A and B). Plants of susceptible cultivars grown in infested soil all suffered various degrees of root rot. This was evidenced by the wide spread of DT values between diseased and healthy plants. Again, the DT values increased ($P \leqslant 0.01$) with increasing severity of root

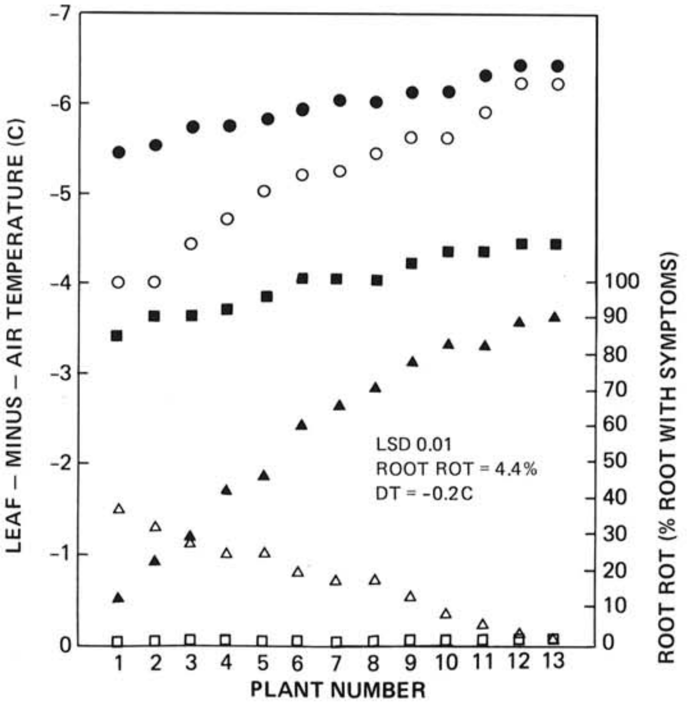


Fig. 3. Relationships between leaf-minus-air temperature differentials (DT) and root rot severity in individual bean (*Phaseolus vulgaris* 'Seafarer') plants at the second trifoliate leaf stage of growth in infested or sterile soil at field capacity under cloudy (524 $\mu E \cdot m^{-2} \cdot sec^{-1}$) and sunny (1047 $\mu E \cdot m^{-2} \cdot sec^{-1}$) conditions. Symbols for DT are: ■ for plants in sterile soil, and ▲ for plants in infested soil in sunny conditions; and ● for plants in sterile soil and O for plants in infested soil in cloudy conditions. Symbols for root rot are: □ for plants in sterile soil and △ for plants in infested soil.

rot (Fig. 1C and D). The DT for the healthy plants of the four cultivars averaged -4.2 ± 0.4 C (Table 1).

The effect of growth stage on DT also was investigated. The pattern of change in DT with growth stage was similar in all four cultivars. However, the magnitude of change was larger in the susceptible than in the tolerant cultivars. To illustrate the pattern of change, results from Seafarer plants at the second, third, and fourth trifoliate stages are presented in Fig. 2A–C. The DT was more variable in older plants. This phenomenon was observed in plants grown in both infested and sterile soil. Nevertheless, the phenomenon appeared to be more marked in the infested soil. The increased variation in DT was attributed in part to the increased root rot severity as plant age advanced (compare Fig. 2A, B and C). For example, at the second trifoliate stage, all plants grown in the sterile soil were free from root rot and the variation among these plants approximated ± 0.45 C (Fig. 2A). The deviation was within the practical range (± 0.5 C) of the instrument. However, as the plants grew older, some disease symptoms appeared in plants growing in sterile soil and consequently the DT values of these plants increased (Fig. 2C). Data for the asymptomatic plants in Fig. 2C show the variation of DT values to be greater than those in Fig. 2A. Thus, the second trifoliate stage appeared to be the most desirable growth stage for the application of this technique.

The effect of light intensity on DT was investigated under cloudy (524 $\mu E \cdot m^{-2} \cdot sec^{-1}$) and sunny (1,048 $\mu E \cdot m^{-2} \cdot sec^{-1}$) conditions. The responses of the cultivars were similar and the results, summarized for Seafarer in Fig. 3, showed a substantial reduction in DT values on cloudy days in plants grown in both infested soil and sterile soil. The distribution of DT values on cloudy days for plants in sterile soil was roughly parallel to those on sunny days except that measurements on cloudy days were approximately 3 C smaller. A similar parallel distribution of DT values under sunny and cloudy conditions was found in plants grown in sterile soil. However, the two parallel lines differed by approximately 2 C

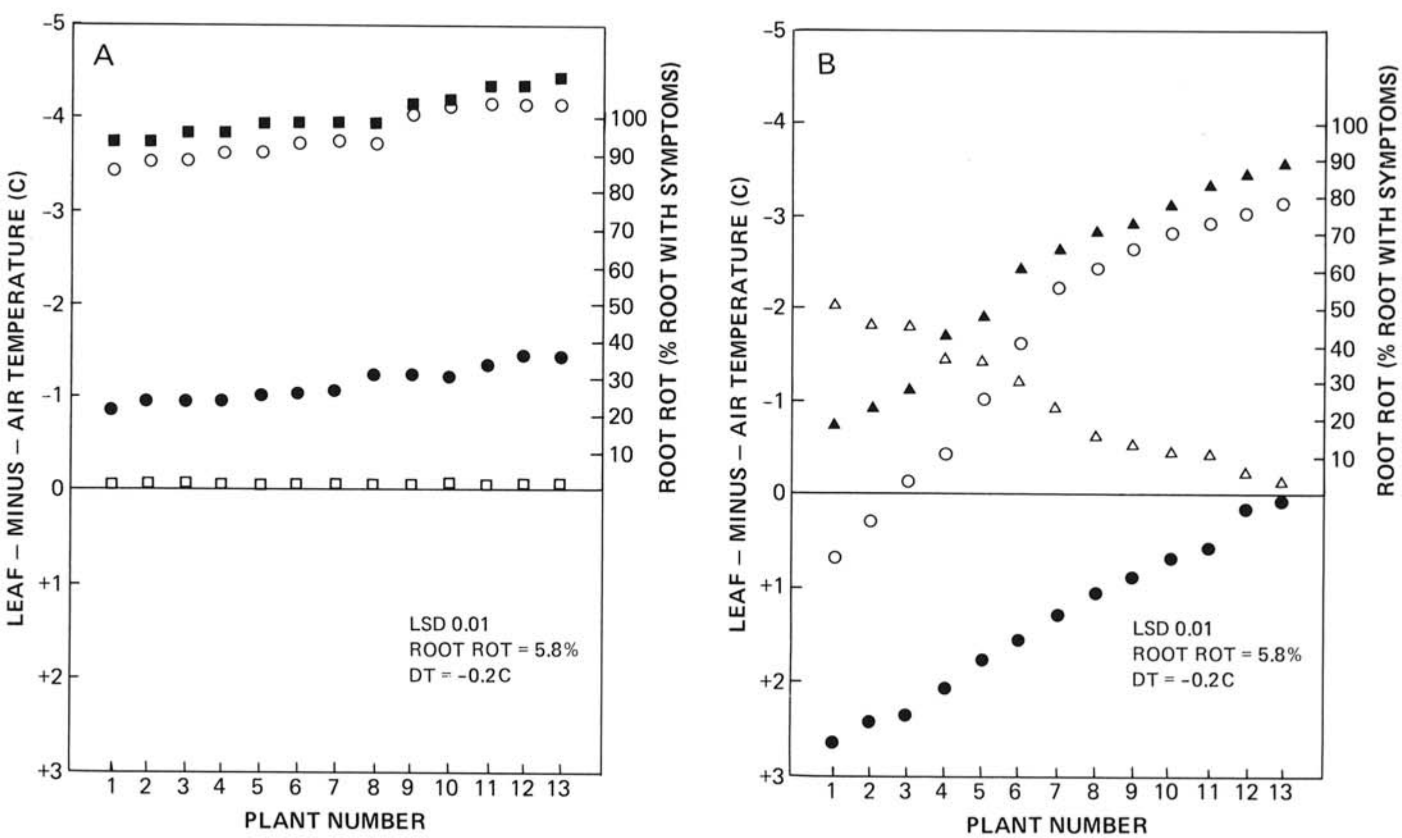


Fig. 4. Relationships between leaf-minus-air temperature differentials (DT) and root rot severity for the bean (*Phaseolus vulgaris* 'Seafarer') as influenced by a drying and wetting process. The soil was dried to near permanent wilting point and replenished with water. The plants were grown in **A**, sterile and **B**, infested soil. Symbols for DT are: ■ for plants in sterile soil and ▲ for plants in infested soil at the field capacity; and ● for plants in soil with moisture approaching permanent wiling point; and O for plants in soil with moisture at the field capacity, 20 min after the soil was replenished with water. Symbols for root rot are: □ for plants in sterile soil and △ for plants in infested soil.

between cloudy and sunny days (Fig. 3). It was also found that differences between DT values for diseased and healthy plants were larger on sunny days than on cloudy days (Fig. 3).

The effects of soil moisture on DT were investigated under three soil moisture conditions: (a) at near field capacity (−3.0 kPa), (b) near permanent wilting point (−1,200 kPa), and (c) after replenishing the moisture in a dry soil with excess water (−3.0 kPa). The results are summarized in Fig. 4. No root rot was apparent for plants grown in the sterile soil at this stage (Fig. 4A). The average DTs for conditions (a), (b), and (c) were -4 ± 0.3 C, -1.2 ± 0.2 C, and -3.7 ± 0.3 C, respectively. The leaf temperatures of plants in treatment b rose an average of 2.8 C, and 20 min after treatment c was applied, the leaf temperatures shifted back to near the level of treatment a. The average difference in DT between conditions (a) and (c) was 0.3 C. This difference suggests that more time might have been needed for the DT in condition (c) to finally reach that of condition (a).

For plants grown in the infested soil (Fig. 4B), disease incidence varied from 1 to 50% of root systems with symptoms, and the distribution followed a linear slope. The DT values obtained under condition (a) increased ($P \leqslant 0.01$) with increased disease severity, and the distribution of the DT followed a linear slope. The change from condition (a) to (b) resulted in a shift of the DT slope by about 3.5 C. The two slopes, however, were approximately parallel. When the dry soil was replenished with water, the resilience of DT was inversely related to the disease severity.

DISCUSSION

Results presented in this paper indicate that bean plants with root rot had higher leaf temperatures than those of healthy plants. Presumably, reduced water uptake by diseased roots reduced the water supply to the leaves. Consequently, reduced transpirational cooling was responsible for the increased leaf temperature (16). This occurred in plants growing in soil with moisture at field capacity. The increases in leaf temperature due to root diseases resemble those that occur with soil moisture depletion. Although the mechanisms are different, the end results are the same. With root rot, the degree of increase in leaf temperature is positively related to the proportion of roots with symptoms ($P \leqslant 0.01$). With soil moisture depletion, the degree of increase in leaf temperature is positively related to the availability of water in the rhizosphere. When soil moisture becomes depleted, soil-water tension increases and water movement decreases.

This technique with infrared thermometry works well: when plants are in the early stages of growth (e.g., second trifoliate stage); when both diseased and healthy plants are available for comparison; when temperature measurements of leaves are taken in the early afternoon on a sunny day; and when the plants are grown in soil with moisture at field capacity.

As growth advanced beyond the second and third trifoliate leaf stages, two difficulties developed. The first was that some of the plants grown in sterile soil showed root rot symptoms (Fig. 2B and C), which reduced their effectiveness as controls. The second, was that plants in infested soil developed varying degrees of root rot. More severely affected plants were stunted and had less foliage. The difference in total leaf area might affect the temperature measurement. For example, a given amount of water uptake would provide more cooling for a plant with less leaf area than one with more leaf area. Thus, as plants grew, the variation in DT values among plants within the same age groups increased. For this reason, bean plants at the second trifoliate stage appear most suitable for applying this technique.

Other factors that affect the efficiency of this technique are cloud cover and soil moisture level. Cloud cover could reduce the sensitivity of this method because it narrows the differential of the temperature readings due to reduced transpirational demand. The degree of interference is relative to the amount of cloud cover and the resulting light intensity. As mentioned previously, different levels of soil moisture are known to induce leaf temperature changes that resemble those induced by root rot. Therefore, temperature measurements should be taken with soil moisture near field capacity because those taken under variable soil moisture conditions are often misleading and would not reflect disease severity. However, inducing moisture stress of plants to near the permanent wilting point and then replenishing the soil with water 20 min before measuring the leaf temperature could greatly increase the sensitivity of this method (Fig. 4B). Apparently, water-stressed plants with more severe root rot require more time to return to their original state than those with little or no root rot.

In conclusion, the DT values can be used not only to detect the presence of root rot disease but also to monitor in situ the disease severity in a plant. Undoubtedly, plants with root rot will eventually develop stunting and other top symptoms due to a continued water stress. Thus, the advantage of this method is that it can detect water stress in plants with root rot before stunting and other top symptoms develop. This method is simple and accurate and a plant can be monitored repeatedly. Thus, it is ideal for screening segregating progeny derived from crosses of resistant and susceptible cultivars.

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