

# Susceptibility of Various Accessions of *Convolvulus arvensis* to *Phomopsis convolvulus*

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**The susceptibility of *Convolvulus arvensis* L. accessions from different geographic locations to disease caused by the fungal pathogen, *Phomopsis convolvulus* Ormeno, was evaluated. In a postemergence application experiment, single excised plant shoots of *C. arvensis* collected from 11 different regions in North America and Europe were inoculated with *P. convolvulus* conidia. All *C. arvensis* accessions showed similar disease reactions. However, plants originating in Canada (Québec) and Spain showed significantly greater disease development than plants from a USA accession (Montana). In a separate preemergence application experiment, plants from two selected accessions originating in Greece and the USA (Montana) were grown from root stock and subjected to a granular formulation of *P. convolvulus* applied to the soil surface. The emerging shoots of both accessions showed severe disease development and the fungal application on Greek and Montana accessions reduced above-ground biomass 83 to 100% and 65 to 86%, respectively. Results of this study indicate that control of *C. arvensis* using *P. convolvulus* might be achieved in various geographic regions.** © 1999 Academic Press

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## INTRODUCTION

*Convolvulus arvensis* L. (field bindweed) is a serious, troublesome perennial weed in many important crops and is prevalent in temperate zones of Europe, West Asia, and North America (Holm *et al.*, 1977). The move toward reduced cultivation or zero tillage in the past 15 years has led to an increased prevalence of *C. arvensis* in many regions (Phillips *et al.*, 1980). Effective control

of *C. arvensis* using current methods including cultivation, crop rotation, and chemical herbicides (Derscheid *et al.*, 1970) is often not possible due to the extensive root system and strong competitiveness of this weed. In addition, variable susceptibility to several important herbicides has been demonstrated (Whitworth and Muzik, 1967; DeGennaro and Weller, 1984; Duncan and Weller, 1987; Kosinski and Weller, 1989; Westwood *et al.*, 1997). *Phomopsis convolvulus* Ormeno, a foliar pathogen native to Canada, was first reported infecting *C. arvensis* plants in 1988 (Ormeno-Núñez *et al.*, 1988a). Since then, studies on host specificity, mass production of conidia, storage, and efficacy of foliar applications have been carried out (Ormeno-Núñez *et al.*, 1988b; Morin *et al.*, 1989a,b, 1990). In an attempt to overcome a requirement for a relatively long dew period during the germination and infection phases of the disease cycle, a granular preemergence formulation of *P. convolvulus* has been developed and shown to be highly efficacious in suppressing *C. arvensis* seedlings as well as regrowth from established plants under both controlled environment and field conditions (Vogelgsang *et al.*, 1994, 1998b).

To date, the use of *P. convolvulus* as a potential bioherbicide has been tested only on *C. arvensis* accessions originating from the USA (Montana) (Morin *et al.*, 1989a; Vogelgsang *et al.*, 1994) or Canada (Québec) (Ormeno-Núñez *et al.*, 1988a). In order to have broad application as an effective biological control agent, *P. convolvulus* should control host plants from as many regions of the world as possible. Variations in morphological and physiological characteristics of *C. arvensis* have been reported. Garcia-Baudin and Darmency (1979) observed intraspecific variations among *C. arvensis* populations with respect to leaf shape, flowering habit, seed weight, and soluble seed proteins when grown under similar conditions. Whitesides (1979) reported varying length and number of vines, number of leaves and flowers, and seed yield per plant in several *C. arvensis* ecotypes. In addition, variations in floral characteristics, accumulation of shoot and root

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biomass, and flowering capacity of accessions have been demonstrated and linked to a differential susceptibility to chemical herbicides (DeGennaro and Weller, 1984). Variations in disease susceptibility to biological control agents are possible and have been observed in other host-pathogen systems (Shepherd, 1995; Raychhetry *et al.*, 1996; Okoli *et al.*, 1997).

The objectives of this study were: (1) to determine the degree of disease susceptibility in *C. arvensis* accessions originating from different regions of the world following foliar postemergence applications of *P. convolvulus* and (2) to evaluate possible differences in the disease response of plants from two selected accessions grown from root stock and subjected to granular preemergence applications of *P. convolvulus*.

## MATERIALS AND METHODS

### *Inoculum Production of Starter Cultures and for Postemergence Experiments*

Single-conidia isolates of *P. convolvulus* were maintained on potato dextrose agar (PDA; Difco, Detroit, MI) at 4°C. From these stock cultures, small pieces of mycelia were placed on 9-cm-diameter petri dishes with PDA and incubated in the dark at  $24 \pm 1^\circ\text{C}$ . After 4 to 5 days, several mycelial plugs of 1-cm-diameter were transferred to PDA plates and incubated at room temperature ( $21 \pm 2^\circ\text{C}$ ) and 12 h/day near-ultraviolet light (F40 BLAB Blacklight; General Electric Lighting, Cleveland, OH). After 3 weeks, conidia were harvested by washing plates with sterile deionized water and conidia density was adjusted to the desired level with the aid of a hemocytometer.

### *Granular Inoculum Production for Preemergence Experiments*

Eighty milliliters of deionized water was added to 100 g of pot barley (*Hordeum vulgare* L.) grains in 1-liter screw cap jars and autoclaved (18 min, 100 kPa,  $120^\circ\text{C}$ ). Jars were cooled to room temperature and inoculated with 5 ml of the previously prepared conidia suspension at a density of  $1 \times 10^7$  conidia/ml. Jars were incubated at room temperature ( $21 \pm 2^\circ\text{C}$ ) and exposed to near-ultraviolet light for 12 h/day and shaken by hand every second day to prevent substrate clumping. Colonized barley grains were harvested after 3 weeks and milled using an electric coffee grinder (Braun KSM 2; Lynnfield, MA). The granules produced were dried for 2 days and ground a second time with an electric soil grinder (Quaker City Mill, Model 4-E; Westinghouse, PA). This resulted in a mixture of large- and small-sized particles with approximately 70% of the particles being smaller than 710  $\mu\text{m}$  in diameter. In an earlier study, inoculum of this size was found to have a high preemergence activity and a shelf-life of at least 6 months

(Vogelgsang *et al.*, 1994). Granular inoculum was routinely tested for conidia quantity and viability as described previously (Vogelgsang *et al.*, 1998a). One gram of granules contained between  $3 \times 10^8$  and  $1 \times 10^9$  conidia having >90% viability.

### *Plant Production*

*C. arvensis* plant material was obtained from the following 11 regions: Canada-Ontario (CAN1), -Québec (CAN2), France-Nantes (F), Germany-Swabia (FRG1), -Brandenburg (FRG2), -Rhineland-Palatinate (FRG3), Greece-Mandra (GR), Spain-Sevilla (E), UK-England (GB), USA-Montana (USA1), and -Iowa (USA2) (Table 1). 'CAN1' seeds were provided by Dr. J. E. Eckenwalder from the University of Toronto; 'CAN2' root stocks were collected on the Macdonald Campus of McGill University, Ste-Anne-de-Bellevue; 'F' seeds were obtained from the Jardin Botanique de Nantes; 'FRG1' and 'FRG3' root stocks were collected at Stuttgart and Rastatt, respectively; 'FRG2' and 'GR' seeds were provided by the Botanical Garden in Berlin-Dahlem, Germany; 'E' seeds were provided by A. J. Pujadas Salvá at the Jardín Botánico de Córdoba; 'GB' seeds were obtained from J. Parsons at the Royal Botanical Gardens, Kew; seeds from 'USA1' and 'USA2' were purchased from Valley Seed Co., Fresno, CA.

For *C. arvensis* establishment, seeds were washed under warm running tapwater for 2 h and soaked overnight in deionized water. Imbibed seeds were then incubated on moist paper towels in a glass petri dish in

TABLE 1

Leaf and Shoot Characteristics of *Convolvulus arvensis* Accessions Evaluated

Origin <sup>a</sup>	Leaf blade length (cm)	Leaves shoot <sup>-1</sup>	Leaf description
USA1	1.2-2.8	4-10	Light green, ovate, saggitate or hastate, slender
CAN1	1.3-2.8	5-7	Oblong, hastate
F	1.2-2.3	5-8	Dark green, ovate, saggitate, densely haired
FRG1	1.6-2.9	5-8	Oblong, saggitate
FRG2	1.9-3.9	4-6	Ovate to oblong, saggitate
FRG3	1.5-2.6	5-8	Narrow, ovate to lanceolate, saggitate
GB	1.1-1.9	5-8	Light green, oval, hastate, slender
GR	1.6-2.5	3-8	Dark green, narrow, lanceolate, saggitate, long lobes
CAN2	2.5-3.6	5-9	Ovate to lanceolate, hastate, long lobes, hairy
E	1.5-2.5	4-6	Oval, hastate, slender
USA2	2.5-3.4	6-8	Ovate to oval, saggitate or hastate

<sup>a</sup> Plant origins USA1: USA-Montana; CAN1: Canada-Ontario; F: France-Nantes; FRG1, 2, 3: Germany-Swabia, -Brandenburg; -Rhineland-Palatinate; GB: UK-England; GR: Greece-Mandra; CAN2: Canada-Québec; E: Spain-Sevilla; USA2: USA-Iowa.

the dark at  $24 \pm 1^\circ\text{C}$  for approximately 24 h. Five to 10 germinated seeds with emerging radicles were sown at a depth of 3 cm into 22-cm-diameter plastic pots containing a mixture of sandy loam (Modugno-Hortibec Inc., St-Laurent, QC, Canada), potting medium (Pro-Mix BX, Les Tourbières Premier Ltée, Rivière-du-Loup, QC), vermiculite (Vil Vermiculite Inc., Montréal, QC), and peat moss (Les Tourbières Premier Ltée, QC) [3:3:2:1 (v/v/v/v)]. For root stock material, several root pieces bearing root buds were planted at a depth of 5 cm. Pots were placed in a greenhouse programmed at  $23/18 \pm 1^\circ\text{C}$  day/night temperature provided with a 15-h photoperiod ( $350 \mu\text{Em}^{-2}\text{s}^{-1}$ ) and were watered as needed. After establishment, plants from both seed and root stock material were fertilized every second week with 200 ml of 20:20:20 (N:P:K, 3 g/liter).

For postemergence application experiments, single shoots of variable length (Table 1) and having 3 to 10 leaves per shoot were cut and placed in glass test tubes ( $15 \times 125$  mm) filled with deionized water. In order to prevent the shoots from sliding down and being partially submerged, stems were supported by a Parafilm layer (American Can Company, Chicago, IL) wrapped around the tube mouth. Plant material used for the second trial was approximately 3 months older than that for the first trial.

For preemergence granular application experiments, two *C. arvensis* accessions were selected. Based on the greatest morphological differences, plant material originating in the USA (Montana) and Greece were chosen. Plants from the USA possessed fairly thin, light green, and ovate leaves whereas leaves from *C. arvensis* plants of Greek origin were thicker, dark green, narrow, and lanceolate. For both accessions, one 13- to 15-cm root piece bearing root buds was planted per 15.5-cm-diameter pot at a depth of 5 cm containing the same soil mixture as described above. Pots were subsequently placed in the greenhouse under original growing conditions.

#### *Inoculation Procedure*

For postemergence application experiments, tubes containing shoots from different origins were randomly placed in tube racks and inoculated with a conidia suspension at a density of  $1 \times 10^7$  conidia/m<sup>2</sup>, using a spray chamber (RIC, Research Instruments Mfg. Co., Ltd., Mandel Sci. Co., Ltd., Guelph, ON, Canada) equipped with a full-cone nozzle (Teejet GTO 0.7, Spraying Systems Co., Wheaton, IL), 200 kPa air pressure, a speed of approximately 1 kph, and a spray volume of 500 liter/ha. The conidia density used was less than required (i.e.,  $1 \times 10^8$  to  $1 \times 10^9$  conidia/m<sup>2</sup>) for optimal disease development and high mortality (Morin *et al.*, 1989a) and was chosen to observe a range of responses to the fungal treatment. An equal number of shoots was sprayed with deionized water and served

as controls. Immediately after inoculation, tube racks were placed in a dew chamber ( $24^\circ\text{C}$ , 100% RH) for 24 h and subsequently transferred to a growth chamber (Conviron, Model E-15, Controlled Environments, Winnipeg, Manitoba, Canada) at  $23/18 \pm 1^\circ\text{C}$  day/night temperature with a 15-h photoperiod ( $350 \mu\text{Em}^{-2}\text{s}^{-1}$ ). Since *C. arvensis* accessions were not all available at the same time, postemergence experiments were performed in two sets. In both sets, plant material from the USA (Montana) served as a standard since plants originating from these seeds had also been used in earlier studies to evaluate the *P. convolvulus* pathogen (Morin *et al.*, 1989a; Vogelgsang *et al.*, 1994).

For preemergence application experiments, 2.5 g of granular inoculum was spread onto the soil surface of 15.5-cm-diameter pots as evenly as possible by hand. The dose selected was based on preliminary studies that had made use of smaller pots (10-cm-diameter) and a dose of 1 g (Vogelgsang *et al.*, 1994). In trials 1 and 2, inoculum was applied 8 and 7 days after planting, respectively. Following inoculation, pots were subjected to irrigation using a system that was designed to simulate natural precipitation. Five pots were placed randomly in circles (60- to 70-cm-diameter) beneath each of four nozzles attached 1.3 m above the greenhouse bench (Orbit Shrub Head Nozzle, Model 54009, full spray pattern 3.7 m, 7.6 liters/min at an applied pressure of 140 kPa, Orbit Sprinklers, Bountiful, UT). The pots were irrigated for 12 h/night for 11 days. The duration of one irrigation cycle was 15 min, with a 1-min irrigation sequence followed by a 14-min pause. To avoid splash dispersal of conidia, inoculated and uninoculated pots were separated by a transparent plastic sheet vertically attached to the center of the greenhouse bench. The sheet was removed after 11 days (completion of irrigation period) and pot location was subsequently rerandomized.

#### *Assessment of Efficacy*

For postemergence experiments, foliar necrosis was evaluated 7 days after inoculation (DAI) using the following rating system: 0 = no visible symptoms, 1 = 1–25% necrosis, 2 = 26–50% necrosis, 3 = 51–75% necrosis, and 4 = 76–100% necrosis (Ormeno-Nuñez *et al.*, 1988a). Disease rating was performed for each shoot and results were averaged for each plant origin. Reisolations were attempted for inoculated shoots. Leaves showing symptoms were excised, soaked in 70% ethanol for a few seconds, and rinsed in sterile, deionized water, and 1-cm<sup>2</sup> diseased sections were cut using a flame-sterilized scalpel. Leaf sections were then immersed for 2 min in 1% sodium hypochlorite, subsequently rinsed in sterile water, and placed on sterile filter paper to dry. Leaf sections were placed on 1/2-strength PDA plates. Advancing edges from growing colonies were transferred to full-strength PDA, placed

under near UV-light for 12 h/day, and maintained for 4 weeks.

For preemergence experiments, the disease was rated 10 DAI on emerged shoots. Above-ground and root biomass were determined 21 and 22 days after planting, respectively. Plants were cut at the soil line, roots were carefully removed from the potting medium, and living tissues were dried in paper bags for 4 days at 60°C and weighed. For root biomass, both entire root material and new growth were included. In addition, the shoot/bud ratio was assessed by comparing the number of emerged shoots with the number of root buds observed.

### Experimental Design and Data Analysis

All experiments were performed twice and set-up in a completely randomized design. Post- and preemergence experiments had four and five replicates per treatment, respectively. Disease ratings were compared using the Kruskal–Wallis one-way analysis of variance by ranks ( $P = 0.15$ ), followed by a multiple-comparison procedure to evaluate differences between treatment means (Daniel, 1978). Data were arcsine (shoot/bud ratio) or  $\log_{10}(x + 1)$  (shoot number and biomass) transformed prior to analysis of variance and differences between treatment means were determined using Tukey's  $W$  test ( $P = 0.05$ ) (Steel and Torrie, 1980). In both post- and preemergence experiments, results for the two trials were not pooled due to heterogeneity of variances as determined by Levene's test (Dufner *et al.*, 1992).

## RESULTS

### Postemergence Experiment

Disease symptoms developed on shoots of all *C. arvensis* accessions inoculated with *P. convolvulus* (Table 2) but not on controls. Necrotic spots on leaves and leaf tips were visible 2 to 3 days after inoculation. The diseased areas subsequently expanded and developed anthracnose symptoms on leaves and several stems. Severe disease development often resulted in the complete wilting of treated shoots. In the first set of shoots tested, the disease reaction was not similar for all accessions, but differences were not significant ( $P > 0.15$ ), and results for the two trials were inconsistent (Table 2). In the second set of shoots tested, the disease reactions for the Canadian (CAN2; Québec) and Spanish (E) accessions were significantly greater than the disease reaction for the USA (USA1; Montana) accession (Table 2). For both sets, symptoms were less severe in the second trial. Except for the slightly lower disease reaction observed in the French accession with pubescent leaves, morphological leaf variation between

TABLE 2

Disease Reaction of Various *Convolvulus arvensis* Accessions to a Postemergence Application of *Phomopsis convolvulus*<sup>a</sup>

Origin <sup>c</sup>	Set 1 <sup>b</sup>		Origin	Set 2	
	Trial 1	Trial 2		Trial 1	Trial 2
USA1 <sup>d</sup>	1.8 a	1.0 a	USA1 <sup>c</sup>	1.0 a	1.0 a
CAN1	2.5 a	1.0 a	CAN2	2.8 bc	2.0 c
F	1.5 a	0.8 a	E	2.8 c	1.5 bc
FRG1	2.5 a	1.0 a	USA2	1.3 ab	1.3 ab
FRG2	1.5 a	1.0 a			
FRG3	2.8 a	1.3 a			
GB	1.8 a	1.0 a			
GR	3.0 a	0.8 a			

<sup>a</sup> *Convolvulus arvensis* shoots were sprayed at a rate of  $1 \times 10^7$  conidia/m<sup>2</sup>. Disease rating scale is 0 = no visible foliar symptoms, 1 = 1–25% necrosis, 2 = 26–50% necrosis, 3 = 51–75% necrosis, 4 = 76–100% necrosis. Data of uninoculated controls are mentioned under Results.

<sup>b</sup> Experiments were performed in two sets based on the availability of plant material. Means (back-transformed values are shown) in each column with the same letter are not significantly different according to the Kruskal–Wallis one-way analysis of variance test followed by a multiple comparison procedure ( $P = 0.15$ ).

<sup>c</sup> Plant origins as for Table 1.

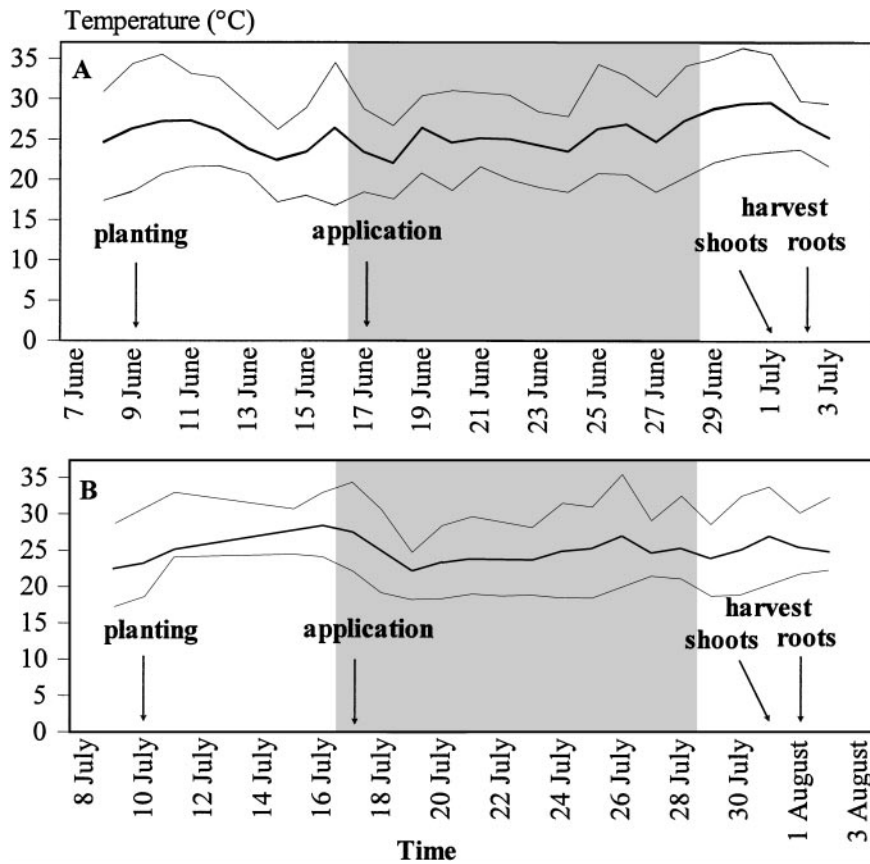
<sup>d</sup> USA1 plant material was used as a standard.

the different accessions did not appear to play a major role in the disease response to *P. convolvulus*. Reisolation of the pathogen from leaf sections of all tested plants resulted in development of *P. convolvulus* mycelia, pycnidia, and conidia.

### Preemergence Experiment

Most shoots began to emerge 7 to 8 days after sowing; however, emergence continued until the end of the experiment. The number of shoots produced was highly variable, with 0 to 7 shoots per pot for inoculated plants and 4 to 9 shoots per pot for controls, respectively. In both trials, maximum temperatures reached 36°C (Fig. 1).

During the irrigation period, droplets of fungal matrix were observed on the soil surface of inoculated pots, and emerging shoots from the two accessions rapidly developed severe necrosis so that by 10 DAI, the number of shoots with fully developed leaves was significantly lower than for uninoculated controls in Trial 1 (Table 3). Similarly, the shoot/root bud ratio was greater for uninoculated controls compared with inoculated plants in both trials (Table 3), and significant biomass reductions were achieved for both accessions tested (Fig. 2). In the two trials, above-ground biomass reductions for plants from Greece ranged from 83 to 100%, whereas the biomass from plants originating in the USA (Montana) was reduced by 65 to 86%, compared with uninoculated controls. Reductions of root biomass were less uniform than those of above-ground



**FIG. 1.** Air temperatures (darker line: mean; lighter lines: minimum, maximum) in greenhouse during (A) Trial 1 and (B) Trial 2. Grey shaded areas refer to irrigation period.

biomass. For example, total root biomass of the Greek accession was reduced by 40 to 52% whereas reductions for the USA (Montana) accession ranged from 9 to 46% (Fig. 3). However, biomass reductions for new root growth were similar for both accessions (56 to 72% for the Greek accession and 58 to 70% for the USA accession) (Fig. 3).

**DISCUSSION**

In this study, the susceptibility of *C. arvensis* accessions from various geographical regions to disease caused by the fungal pathogen *P. convolvulus* was evaluated. Following a postemergence inoculation on single excised shoots, disease development was gener-

**TABLE 3**

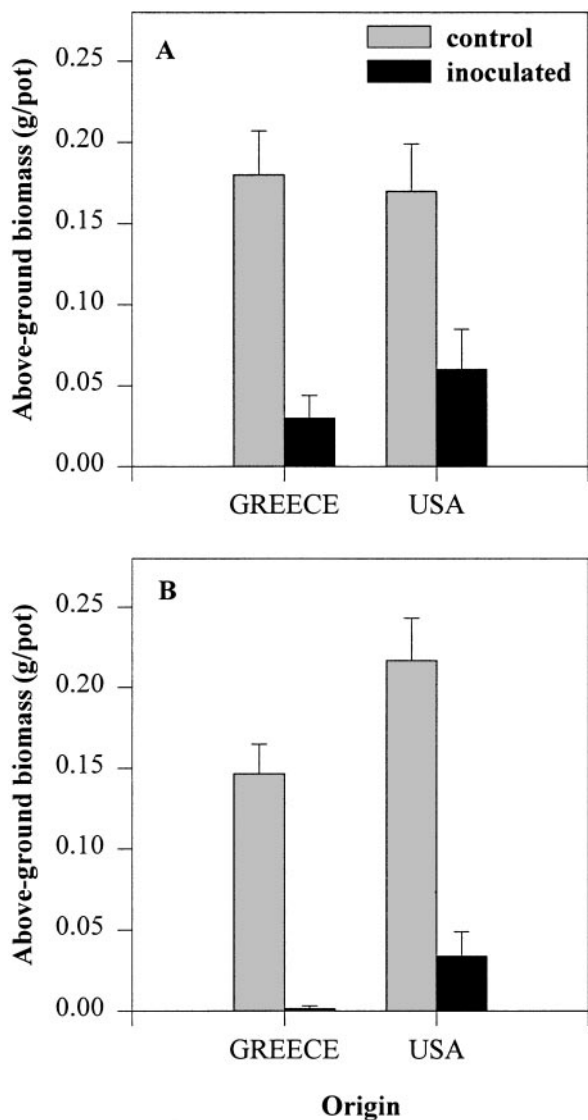
Susceptibility of Two *Convolvulus arvensis* Accessions to a Preemergence Application of *Phomopsis convolvulus*

Origin/treatment	Trial 1 <sup>a</sup>			Trial 2		
	Disease rating <sup>b,c</sup>	Shoots/ pot	Shoot/bud ratio	Disease rating	Shoots/pot	Shoot/bud ratio
USA/control	0.0 a	7.8 a	1.1 a	0.0 a	6.2 a	0.9 a
USA/inoculated	1.4 b	1.2 b	0.2 c	3.0 b	3.4 a	0.4 b
Greece/control	0.0 a	6.6 a	0.7 b	0.0 a	5.2 a	0.7 a
Greece/inoculated	2.2 b	1.0 b	0.1 c	3.0 b	4.2 a	0.4 b

<sup>a</sup> Trial 1, 2: 2.5 g of *P. convolvulus* inoculum granules/pot were applied to the soil surface 8 and 7 days after planting, respectively.

<sup>b</sup> Disease rating data were recorded 10 days after inoculation; shoot/bud ratio was determined 22 days after planting. Disease rating scale as for Table 2.

<sup>c</sup> Means (back-transformed values are shown) in each column with the same letter are not significantly different according to the Kruskal–Wallis one-way analysis of variance test followed by a multiple comparison procedure ( $P = 0.15$ ) (disease rating) or according to Tukey's grouping ( $P = 0.05$ ) (shoots, shoot/bud ratio).



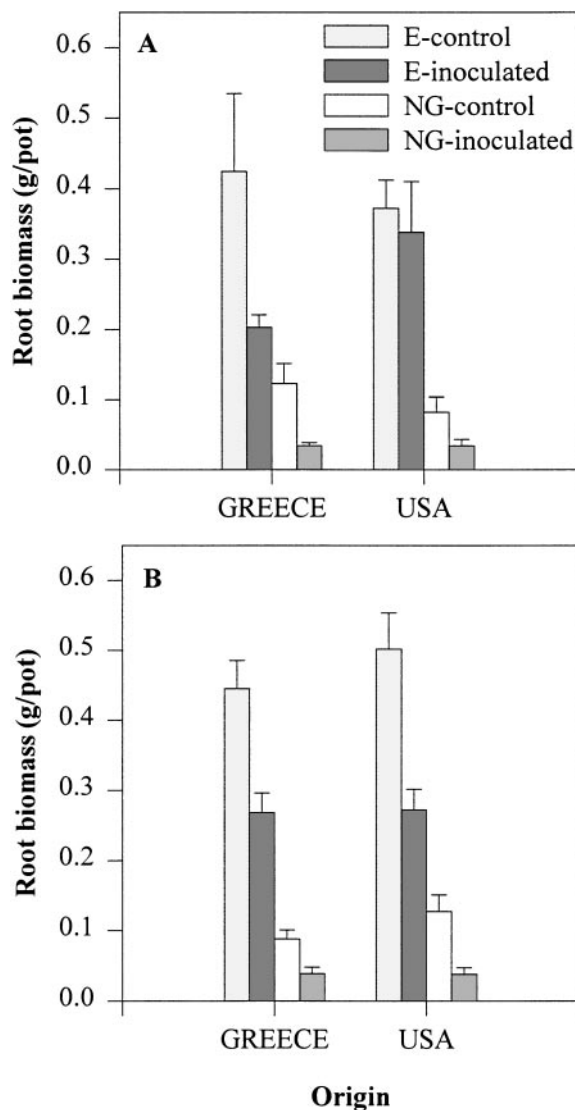
**FIG. 2.** Effect of preemergence application of 2.5 g of *Phomopsis convolvulus* inoculum granules applied onto the soil surface of 15-cm-diameter pots 8 (Trial 1) or 7 (Trial 2) days after planting on above-ground biomass of two *Convolvulus arvensis* accessions in (A) Trial 1 and (B) Trial 2. Plant material was harvested 21 days after planting. Vertical bars indicate the SEM.

ally similar for all accessions tested. However, a Canadian (Québec) and a Spanish accession were more susceptible than a USA (Montana) accession. Thus, despite the wide range of morphological attributes observed in the *C. arvensis* accessions tested, physical features generally appear to play a minor role in disease susceptibility to the pathogen. However, the rate of conidia applied ( $1 \times 10^7$  conidia/m<sup>2</sup>) was too low to result in mortality of treated shoots (Morin *et al.*, 1989a). Thus, different responses might have been obtained had higher conidia rates been used.

The overall lower disease incidence in the second trial might have been caused by insufficient coverage

during spraying and/or by lower conidia viability. In addition, the second trial was performed using more mature plants than was the case for the first trial. Hence, leaves of these older plants might have developed thicker cuticles, possibly resulting in altered defence mechanisms (Martin, 1965).

Application of *P. convolvulus* conidia suspensions on excised *C. arvensis* shoots provided a fast and effective method to assess host-plant susceptibility of a relatively large number of accessions. Caution must be used in interpreting such results since data obtained may not be representative of disease reactions that would be observed on intact, perennial plants of *C.*



**FIG. 3.** Effect of preemergence application of *Phomopsis convolvulus* on root biomass of two *Convolvulus arvensis* accessions in (A) Trial 1 and (B) Trial 2. E and NG refer to biomass of entire roots and new root growth, respectively. Application dates and dose as for Fig. 2. Roots were harvested 22 days after planting. Vertical bars indicate the SEM.

*arvensis*. However, preemergence granular applications were conducted with established *C. arvensis* plants from cloned root stocks. High disease incidence and excellent biomass reductions were observed for the two selected accessions, one from Southern Europe (Greece) and the other from North America (Montana, USA). In addition to large reductions in above-ground biomass, new root growth of both accessions was also substantially reduced. These findings differ to some degree from earlier studies in controlled environment using preemergence applications of *P. convolvulus* in which it had been difficult to consistently reproduce high levels of weed suppression, especially when established plant material was used (Vogelgsang *et al.*, 1998a,b). Fungal application in those studies was typically followed by a moisture treatment using a dew chamber or covering pots with plastic bags. However, the development of a disease epidemic is also dependent upon an adequate distribution of the pathogen on its host. In this study, the irrigation system was designed to simulate natural rainfall, thus likely providing both sufficient moisture as well as effective splash dispersal of conidia. Consequently, dissemination of the fungal inoculum on the soil surface might have been enhanced (Fitt *et al.*, 1989; Madden, 1992). In addition to determining susceptibility of geographically diverse *C. arvensis* accessions to *P. convolvulus* infection, this experiment also suggests a more suitable methodology for carrying out such trials under controlled environment conditions.

Following preemergence granular application, air temperatures in the greenhouse were relatively high (>30°C). Nonetheless, the granular formulation of *P. convolvulus* used was capable of performing well under these conditions. Similar findings in which the efficacy of granular preemergence applications was superior to postemergence foliar sprays has been demonstrated in other weed-pathosystems (Walker, 1981; Walker and Connick, 1983; Boyette and Walker, 1985; Weidemann and Templeton, 1988).

The results of our study indicate that, despite obvious morphological variations among the *C. arvensis* accessions investigated, limited differential susceptibility to *P. convolvulus* was present. However, it should be noted that plant material was collected principally from Northern latitudes. Hence, trials with plant material from other regions of the world (e.g., South America, Australia, Asia) and a greater number of test plants could provide more accurate information about the genetic diversity of *C. arvensis* host plants to infection by *P. convolvulus*. Moreover, in this study, all *C. arvensis* accessions were grown under controlled environment, so that little can be implied about the stability or heredity of various morphological characteristics under field conditions. Therefore, *in situ* studies would be required to fully evaluate the efficacy of *P. convolvulus*

as a biocontrol agent of *C. arvensis* in different geographical regions of the world.

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