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Influence of cultural practices on incidence of *Phytophthora nicotianae* var. *parasitica* causing root rot of lavender (*Lavandula officinalis* L.)

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Summary. The influence of cultural practices on the incidence of root rot of lavender (*Lavandula officinalis* L.), caused by *Phytophthora nicotianae* var. *parasitica* was evaluated in two trials carried out in 1996 and 1997. The effects of type of substrate, type of pot and cultivation site (open field or under shade) were evaluated on lavender plants grown in soils with and without artificial inoculation with the pathogen. Growing plants under shade significantly reduced disease incidence in both seasons. Plants in larger pots had lower disease incidence, irrespective of type of substrate, or the presence or absence of soil inoculation. The data obtained in this study highlight the importance of light, soil temperature and pot volume in the epidemiology of *P. parasitica* on lavender.

Key words: root rot, cultural practices, lavender, *Phytophthora nicotianae* var. *parasitica*.

Introduction

Lavender (*Lavandula officinalis* L.) is an important aromatic and ornamental crop of Ligurian Riviera (Northern Italy) destined for the national and international markets, particularly Switzerland, Germany and The Netherlands. Initially, cultivation was concentrated on marginal land in the Riviera hinterland. As the crop, which generally requires very little care and provides a satisfactory revenue, became more popular, its cultivation has expanded to new areas, particularly those nearer the coast.

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Since 1992, a root rot caused by *Phytophthora nicotianae* var. *parasitica* has been observed in many lavender plantings and has of late become increasingly important and destructive (Minuto *et al*., 1999). On several farms it has been noticed that this disease is most damaging on plants grown in the open field and in plastic pots during the hottest months and is less severe on plants grown in clay pots and/or under shade. It also appears to occur mostly on plants with poor root systems.

These observations indicate that the development of *Phytophthora* root rot of lavender is influenced by environmental conditions. This study was conducted to examine the influence of substrate type, type of pot utilized and cultivation site on root rot of lavender growing in soils with and without artificial inoculation with the rot agent.

Materials and methods

The investigation was conducted in 1996 and 1997 at the Centro Regionale di Sperimentazione ed Assistenza Agricola of the Chamber of Commerce of Savona, located at Albenga (Savona), Italy.

The experiments lasted four months in 1996 and three months in 1997. The soil temperature was continuously recorded in 2 pots/type by placing a probe at 7 cm depth on the south quadrant of the pots. Twelve measurements/day were taken at the following times: 00.00, 02.00, 04.00, 06.00, 08.00, 10.00, 12.00 a.m. and 02.00, 04.00, 06.00, 08.00, 10.00 p.m.

Plants

A selection of lavender plants widely grown in the area was used for the tests. Plants were propagated from cuttings rooted on heated benches in plastic trays containing a peat:perlite (30:70 v/v) substrate. Rooted cuttings were transplanted after 30 days to pots filled with one of the substrates.

Substrates

A heavy substrate with pomix (HP) (peat, pomix, clay, 50:30:20, v:v:v), a heavy substrate with clay (HC) (peat, clay, conifer bark, 40:40:20, by vol.) and a light substrate with perlite (L) (peat, perlite, 70:30, v:v:v) were mixed in a commercial mixer (Turco Co, Bagnasco, Cuneo, Italy). Fertilization was carried out by adding 1.5 Kg/m^3 of PG Mix (Agrochimica, Bolzano, Italy) with a N:P:K ratio of 14:16:18 and 0.8 Kg/m^3 of Plantosan (Agrochimica, Bolzano, Italy), with a N:P:K ratio of 20:10:10.

Pot material and sizes

Clay and black plastic pots, with a diameter of 14 cm and a volume of 2 l were used in 1996. In 1997, black square plastic pots (14 cm, 2 l volume) and larger black plastic pots (diameter 18 cm, 3.5 l) were also used**.** Pots were filled with the substrates not more than 24 h before transplanting, to avoid the substrate drying up.

Artificial inoculation of potted soils

Five isolates (seven in 1997) of *P. parasitica,* obtained from infected plants, were grown on an autoclaved mixture of wheat and hemp kernels (50:50). Colonized kernels were mixed into the substrate as required by the experimental layout at a dosage of 2 kg/m^3 24 h before transplanting at the same time as the pots were filled.

Fungicide treatments

A mixture of the fungicides metalaxyl + folpet (Ridomil Combi, Novartis, W.P., 50% a.i.) at a concentration of 20+80 g of a.i./100 l was applied by drenching each pot with 200 ml of fungicide. Drenching was carried out on May 22, 1996 (7 days after transplanting) in 1996 and on July 7, 1997 (10 days after transplanting) in 1997. No other fungicides were applied during the trials.

Cultivation site

Some plants were grown in the open and some under shade in each field. The two cultivation sites (300 m^2 each in each field) were 20 m apart. On the first site, plants were maintained in the open, on the second, they grew in an open tunnel covered with a black net (Nastex, Varese, Italy), providing a 60% reduction of light intensity. The net was put in place at the time the pots were arranged in the tunnel.

In both cases, pots were placed on black plastic film of a type locally used by growers to avoid algal contamination and weeds.

Identical cultural practices were adopted for all treatments: plants were sprinkle-irrigated, generally in the early morning. Pot density was 30 pots/m^2 for 14 cm diam. pots, 15 pots/m^2 for 18 cm diam. pots.

Disease incidence rating

From the appearance of first symptoms, the number of infected plants was determined by visual inspection. Disease incidence was expressed as mortality in percentage. Dead plants and their pots were eliminated.

Experimental layout

A randomized block design with three (1996) or four (1997) replicates, was used. Each treatment was represented respectively by 50 pots in 1996 and 25 pots in 1997.

The two environmental factors "open field" and "under shade" were taken to be different cultivation sites. All the data obtained were statistically analyzed by analysis of variance, considering each disease incidence value separately. The significance of 1^{st}–2^{nd} order interactions between factors

was tested with Tuckey's test (Gomez and Gomez, 1984). The disease incidence for June 26 and August 21 in 1996 and for July 28 and August 25 in 1997, when interactions among the factors were most significant, is shown. Later in the season, in both years, the significance of some interactions was reduced; this was probably due to the smaller difference in temperature between the two sites (shaded and open field) and to the spread of the pathogen by irrigation.

Results

Disease incidence was very high both with and without artificial soil inoculation with *P. parasitica*. It reached 93% mortality in 1996 (Table 2, treatment No. 30) and 88% in 1997 (Table 3, treatment No. 25).

Effect of the cultivation site

The site of cultivation (open field/shade) significantly influenced disease incidence both years. Growing plants in pots under shade reduced disease incidence strongly and significantly (Fig. 1 and 4, Table 1). This strong effect was probably due to substantial differences in temperature between the substrates at the two sites in these years. Maximum substrate temperatures were consistently higher in the open field, with differences of up to 18 ℃. Maximum temperatures recorded in the open field were 44 ℃ in 1996 and 40 ℃ in 1997 (Table 4).

Effect of soil inoculation with *P. parasitica*

Soil inoculation with *P. parasitica* significantly increased mortality, both in the open and under shade (Fig. 2 and 4). However, plants growing in non-inoculated media also showed a high incidence of root rot in 1997, especially those grown in the open field (Fig. 4). *P. parasitica* was frequently isolated from plants growing in non-inoculated media, indicating that the pathogepBspread from inoculated to non-inoculated plants, most probably through water splashes or cultural practices.

Table 1. Significance of trials carried out in 1996 and 1997, by analysis of variance (F probabilities).

Source of variation	1996				1997			
	DF[a]	F[b] (6/26)	DF	F(8/21)	DF	F(7/28)	DF	F(8/25)
Pot	1	0.119	1	0.000	3	0.032	3	0.000
Substrate	2	0.038	2	0.380	1	0.002	1	0.001
Pathogen	1	0.000	1	0.000	1	0.000	1	0.000
Fungicide	1	0.014	1	0.006	1	0.338	1	0.016
Cultivation site	1	0.048	1	0.000	1	0.001	1	0.000
Cultivation site x pot	1	0.001	1	0.450	3	0.061	3	0.001
Cultivation site x substrate	2	0.003	2	0.000	1	0.101	1	0.481
Cultivation site x pathogen	1	0.000	1	0.000	1	0.000	1	0.002
Cultivation site x treatment	1	0.019	1	0.000	1	0.820	1	0.025
Pot x substrate	2	0.324	2	0.596	1	0.724	1	0.962
Pot x pathogen	1	0.148	1	0.000	3	0.166	3	0.002
Pot x treatment	1	0.140	1	0.129	3	0.120	3	0.264
Substrate x pathogen	2	0.000	2	0.352	1	0.000	1	0.002
Substrate x treatment	2	0.252	2	0.215	1	0.290	1	0.096
Pathogen x treatment	1	0.016	1	0.983	1	0.847	1	0.052
Cultivation site x pot x substrate	2	0.573	2	0.375	1	0.616	1	0.721
Cultivation site x pot x pathogen	1	0.017	1	0.000	3	0.829	3	0.000
Cultivation site x pot x treatment	1	0.012	1	0.045	3	0.368	3	0.852
Cultivation site x substrate x pathogen	2	0.005	2	0.124	1	0.005	1	0.695
Cultivation site x substrate x treatment	2	0.931	2	0.744	1	0.900	1	0.695
Cultivation site x pathogen x treatment	1	0.066	1	0.187	1	0.008	1	0.722

[a] DF, degree of freedom.
[b] Significance $P<0.05$.

Effect of pot material and size

In 1996, the use of plastic or clay pots did not influence disease incidence under shade, but in the open field and with soil inoculation there was a slight reduction in disease incidence in plants grown in clay pots (Fig. 1). In 1997, root rot mortality was significantly higher in plants grown in the smaller (2 l) pots both under shade and in the field with soil inoculation and in the open field without soil inoculation (Fig. 4).

Effect of substrate

In 1996, the medium used influenced disease incidence in the open field and where there had

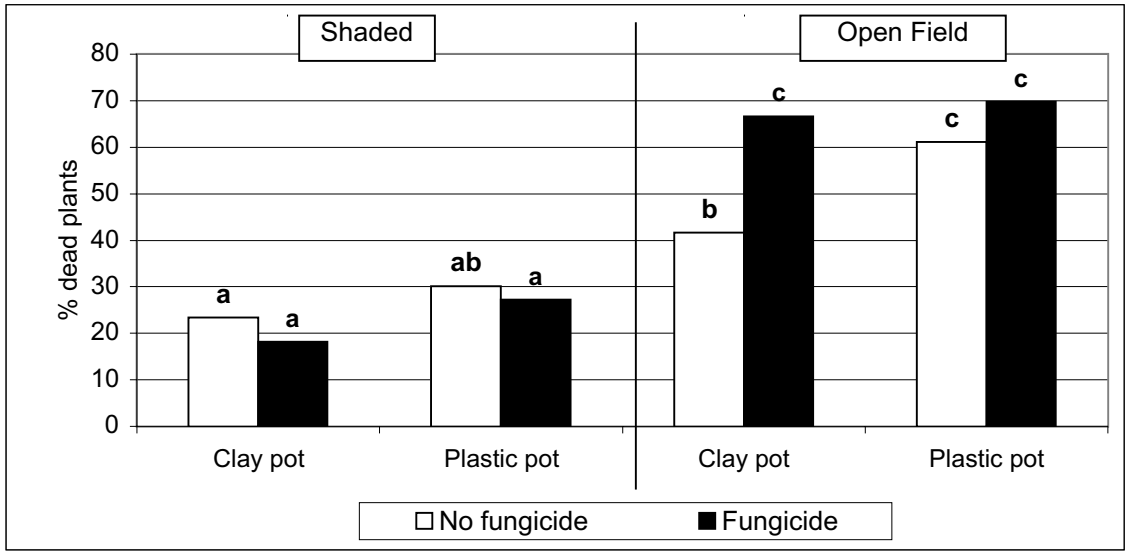

Fig. 1. Effect of pot type and fungicide treatment on mortality (%) of lavender plants with shaded and open-field cultivation irrespective of soil inoculation with *Phytophthora parasitica* or substrate type in 1996 (August 21).

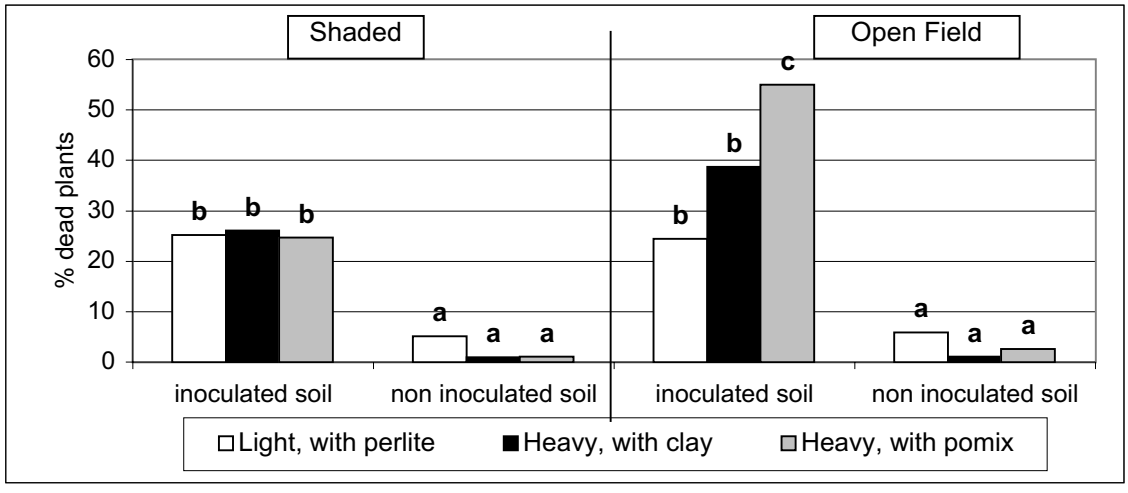

Fig. 2. Effect of substrate type and soil-inoculation with *Phytophthora parasitica* on mortality (%) of lavender plants with shaded and open-field cultivation irrespective of fungicide treatment in 1996 (June 26).

Table 2. Effectiveness of different growing conditions of lavender on root rot, expressed as percent of dead plants at two dates, June 26 and August 21, 1996.

Number and site[a]	Pot, volume (l)	Substrate[b]	Substrate inoculation	Fungicide treatment	% dead plants at	
					June 26	August 21
S	Clay, 2	L	+	-	33.8	62.0
S	Clay, 2	HC	+	-	15.2	27.0
S	Clay, 2	HP	+	-	27.5	46.3
S	Clay, 2	L	+	+	26.3	46.4
S	Clay, 2	HC	+	+	19.3	31.3
S	Clay, 2	HP	+	+	14.7	23.3
S	Clay, 2	L	-	-	2.0	3.3
S	Clay, 2	HC	-	-	0.0	0.0
S	Clay, 2	HP	-	-	0.0	1.3
S	Clay, 2	L	-	+	3.8	3.8
S	Clay, 2	HC	-	+	2.0	2.0
S	Clay, 2	HP	-	+	1.9	1.9
S	Plastic, 2	L	+	-	22.1	55.2
S	Plastic, 2	HC	+	-	27.5	54.5
S	Plastic, 2	HP	+	-	27.4	46.3
S	Plastic, 2	L	+	+	18.3	39.7
S	Plastic, 2	HC	+	+	42.2	63.4
S	Plastic, 2	HP	+	+	29.1	44.2
S	Plastic, 2	L	-	-	7.4	18.9
S	Plastic, 2	HC	-	-	0.0	2.0
S	Plastic, 2	HP	-	-	1.3	3.4
S	Plastic, 2	L	-	+	7.2	12.2
S	Plastic, 2	HC	-	+	1.4	2.7
S	Plastic, 2	HP	-	+	0.7	0.7
O	Clay, 2	L	+	-	22.4	48.4
O	Clay, 2	HC	+	-	18.4	55.0
O	Clay, 2	HP	+	-	59.9	85.8
O	Clay, 2	L	+	+	44.3	83.7
O	Clay, 2	HC	+	+	74.1	90.8
O	Clay, 2	HP	+	+	65.4	93.3
O	Clay, 2	L	-	-	3.5	16.7
O	Clay, 2	HC	-	-	0.0	23.0
O	Clay, 2	HP	-	-	0.7	20.5
O	Clay, 2	L	-	+	9.1	31.7
O	Clay, 2	HC	-	+	1.4	50.1
O	Plastic, 2	HP	-	+	9.2	49.8
O	Plastic, 2	L	+	-	14.6	34.2
O	Plastic, 2	HC	+	-	36.3	65.7
O	Plastic, 2	HP	+	-	39.4	64.4
O	Plastic, 2	L	+	+	16.3	58.0
O	Plastic, 2	HC	+	+	26.1	60.8
O	Plastic, 2	HP	+	+	55.0	85.7
O	Plastic, 2	L	-	-	5.5	75.2
O	Plastic, 2	HC	-	-	0.0	55.1
O	Plastic, 2	HP	-	-	0.0	71.8
O	Plastic, 2	L	-	+	5.1	63.4
O	Plastic, 2	HC	-	+	2.6	78.1
O	Plastic, 2	HP	-	+	0.0	72.5

[a] S, shaded; O, open field.
[b] L: light, with perlite; HC: heavy, with clay; HP: heavy, with pomix.

Table 3. Effectiveness of different growing conditions of lavender on root rot, expressed as percent of dead plants at two dates, July 28 and August 25, 1997.

Number and site[a]	Pot, volume (l)[b]	Substrate[c]	Substrate inoculation	Fungicide Treatment	% dead plants at	
					July 28	August 25
S	Clay, 2	L	+	-	18.0	35.0
S	PL sq, 2	HP	+	-	12.0	15.0
S	Clay, 2	L	+	-	15.0	15.0
S	Clay, 2	HP	+	+	36.0	44.0
S	PL sq, 2	L	+	+	22.0	27.0
S	Clay, 2	HP	+	+	31.0	37.0
S	Clay, 2	L	-	-	2.0	8.0
S	PL sq, 2	HP	-	-	0.0	0.0
S	Clay, 2	L	-	-	0.0	6.0
S	Clay, 2	HP	-	+	2.0	5.0
S	PL sq, 2	L	-	+	0.0	1.0
S	Clay, 2	HP	-	+	0.0	2.0
S	PL 14, 2	L	+	-	28.0	50.0
S	PL 18, 3.5	HP	+	-	13.0	14.0
S	PL 14, 2	L	+	-	11.0	20.0
S	PL 14, 2	HP	+	+	19.0	31.0
S	PL 18, 3.5	L	+	+	10.0	13.0
S	PL 14, 2	HP	+	+	20.0	27.0
S	PL 14, 2	L	-	-	2.0	8.0
S	PL18, 3.5	HP	-	-	1.0	1.0
S	PL 14, 2	L	-	-	3.0	5.0
S	PL 14, 2	HP	-	+	2.0	6.0
S	PL18, 3.5	L	-	+	1.0	1.0
S	PL 14, 2	HP	-	+	3.0	5.0
O	Clay, 2	L	+	-	62.6	88.0
O	PL sq, 2	HP	+	-	14.0	27.0
O	Clay, 2	L	+	-	31.0	59.0
O	Clay, 2	HP	+	+	54.0	75.0
O	PL sq, 2	L	+	+	31.0	45.0
O	Clay, 2	HP	+	+	31.6	51.8
O	Clay, 2	L	-	-	6.0	75.0
O	PL sq, 2	HP	-	-	1.0	72.0
O	Clay, 2	L	-	-	4.0	73.0
O	Clay, 2	HP	-	+	9.0	72.0
O	PL sq, 2	L	-	+	6.0	42.0
O	Clay, 2	HP	-	+	8.0	61.0
O	PL 14, 2	L	+	-	67.0	92.0
O	PL 18, 3.5	HP	+	-	22.0	28.0
O	PL 14, 2	L	+	-	42.0	72.0
O	PL 14, 2	HP	+	+	53.5	76.7
O	PL18, 3.5	L	+	+	19.0	25.0
O	PL 14, 2	HP	+	+	32.0	54.0
O	PL 14, 2	L	-	-	8.0	65.5
O	PL18, 3.5	HP	-	-	3.0	15.0
O	PL 14, 2	L	-	-	9.1	42.9
O	PL 14, 2	HP	-	+	17.0	31.0
O	PL18, 3.5	L	-	+	4.0	5.0
O	PL 14, 2	HP	-	+	17.0	39.0

[a] S, shaded; O, open field.
[b] PL, plastic pot; PL sq, plastic square pot.
[c] L: light, with perlite; HP: heavy, with pomix.

been soil inoculation (Fig. 2). Here disease incidence was lowest in the substrate L, somewhat higher in HC, and highest in HP (Fig. 2). In 1997, by contrast, the type of medium influenced disease incidence both in the open field and under shade, when there had been soil inoculation (Fig. 3). This was probably due to interactions with other factors such as soil temperature. Neither in 1996 nor in 1997 were there any differences among uninoculated substrates.

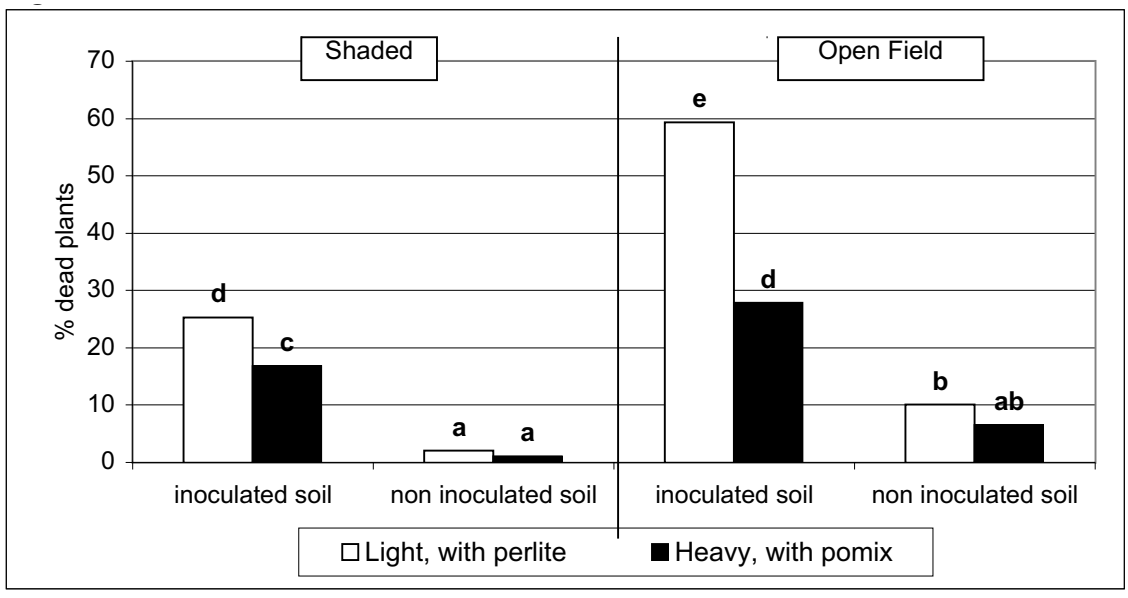

Fig. 3. Effect of substrate type and soil-inoculation with *Phytophthora parasitica* on mortality (%) of lavender plants with shaded and open-field cultivation irrespective of pot type and fungicide treatment in 1997 (July 28).

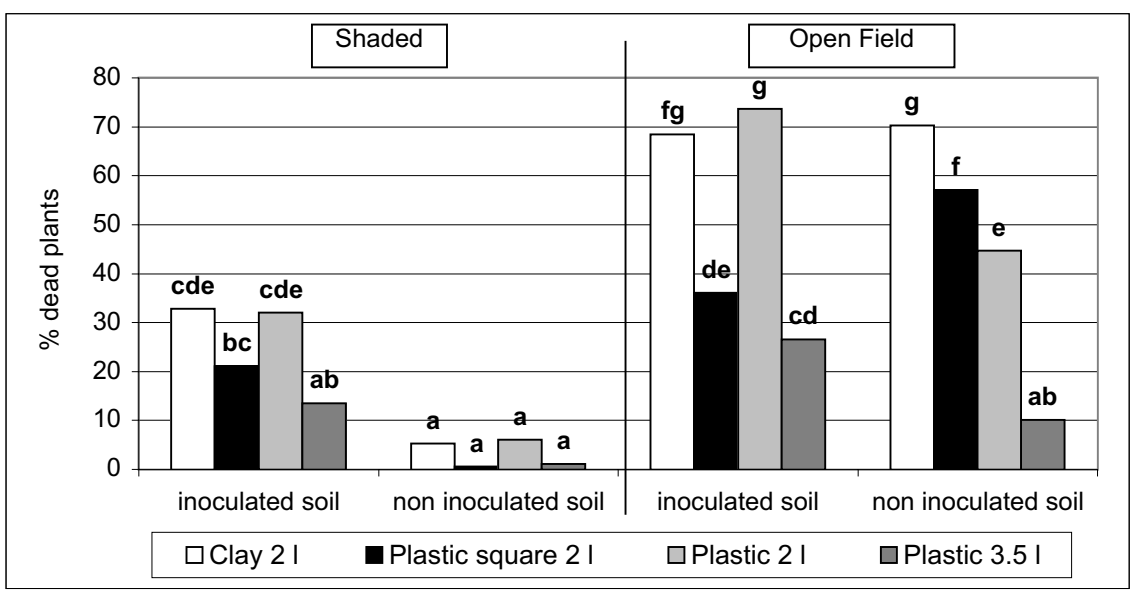

Fig. 4. Effect of pot material and size type and soil-inoculation with *Phytophthora parasitica* on mortality (%) of lavender plants with shaded and open-field cultivation irrespective of substrate type and fungicide treatment in 1997 (August 25).

Table 4. Minimum and maximum temperatures (°C) reached by the growing media in 2 l pots in shaded and open field cultivation in 1996 and 1997 (average of 12 measurements).

Month	Pot	Substrate[a]	1996				1997			
			Open field		Shaded		Open field		Shaded	
			Min	Max	Min	Max	Min	Max	Min	Max
May										
	Clay	L	17	30	16	26	—	—	—	—
	Clay	HC	17	32	13	24	—	—	—	—
	Clay	HP	17	33	13	22	—	—	—	—
	Plastic	L	17	37	14	28	—	—	—	—
	Plastic	HC	17	31	15	29	—	—	—	—
	Plastic	HP	17	31	15	29	—	—	—	—
June										
	Clay	L	18	35	16	30	—	—	—	—
	Clay	HC	18	38	15	29	—	—	—	—
	Clay	HP	18	44	15	26	—	—	—	—
	Plastic	L	18	38	15	33	—	—	—	—
	Plastic	HC	18	36	15	31	—	—	—	—
	Plastic	HP	18	35	15	32	—	—	—	—
July										
	Clay	L	21	33	19	28	21	32	18	28
	Clay	HC	21	36	19	27	—	—	—	—
	Clay	HP	21	41	18	27	20	40	17	27
	Plastic	L	21	39	19	28	21	37	18	28
	Plastic	HC	21	38	19	29	—	—	—	—
	Plastic	HP	21	39	19	29	21	37	17	28
August										
	Clay	L	—	—	—	—	22	34	19	30
	Clay	HP	—	—	—	—	22	40	19	28
	Plastic	L	—	—	—	—	23	39	20	30
	Plastic	HP					22	38	19	30

[a] L: light, with perlite; HC: heavy, with clay; HP: heavy, with pomix.

Effect of fungicide treatment

In 1996 fungicide treatment with a mixture of metalaxyl and folpet did not always significantly reduce root rot, even when the substrate had been inoculated (Fig. 1). In 1997 chemical treatment did not show any significant effect (data not shown). This could be due at least partially to a loss of activity of the fungicide, which was applied only once, 7-10 days after plants were transplanted.

Discussion

Phytophthora root rots are an important group of diseases affecting container-grown plants and can have severe effects on plants exposed to extremes in soil water status (Duniway, 1977; Blaker and MacDonald, 1981; Wilcox and Mircetich, 1985; Ownley and Benson, 1991), oxygen deficiency (Heritage and Duniway, 1985; Filmer *et al*., 1986), salinity (Mac Donald, 1984) or excess in temperature (Lyles *et al*., 1992).

The high level of rot incidence reached in the two years of the present study even in soils that were not inoculated, indicates the damage potential of this disease to a hardy crop such as lavender. The data shown also suggest that under field conditions only a few infected plants

can cause a quick spread of the pathogen by irrigation water and rain splashes.

The reduction in rot incidence achieved by growing plants under shade was very evident in both seasons. A reduction of more than 50% seemed to be accounted for by the cultivation site. Results obtained in both seasons on plants growing in inoculated soils showed that growing plants under shade provided sufficient enough root rot control for practical cultivation conditions. The high temperatures to which lavender roots are subjected during cultivation in the open field, due to solar radiation on the soil surface and/or the exposed container walls, seemed to be the most important factor predisposing the roots to infection. While the root-zone temperature has been studied in its relation to root rot, a high temperature has generally been stated to favour pathogen growth and activity (Patil and Young, 1960; Hine *et al*., 1964). Only a few studies report heat as a factor predisposing roots to infection. Roots of soybean cv. that were resistant to *Phytophthora megasperma* var. *sojae* became susceptible when immersed in water at 44 ℃ for 1 h, while exposure to 50 ℃ for 2 min caused irreversible susceptibility (Chamberlain, 1970). Temperatures of 40 ℃ predisposed roots of *Dendranthema grandiflorum* to root rot caused by *Phytophthora cryptogea* (MacDonald, 1991). Roots of *Hibiscus rosasinensis*, exposed to the sun (at temperatures reaching 52 ℃) showed higher rot severity, from *P. parasitica* than the roots of shaded plants (Lyles *et al*., 1992). The work on *Hibiscus*, which was specifically aimed at studying the short- and long-term stress effects of heat on *Phytophthora* root rot, did not reveal a definite temperature threshold predisposing the roots to infection. In *Hibiscus* plants grown hydroponically, temperatures >30 ℃ greatly increased root rot severity; in hibiscus grown outdoors root rot became more severe at >40 ℃ (Lyles *et al*., 1992). Soil temperatures of 40 ℃ and higher were recorded around the roots of sun-exposed plants in the present study, and management practices that reduce root-zone heating, such as shading, may help to reduce the incidence or severity of root infections as it does in hibiscus (Lyles *et al*., 1992).

Another important factor causing symptoms appears to be the amount of substrate, rather than the type of substrate available to the roots. The results of the 1997 trial suggest that pot volume is important: plants growing in a larger volume of substrate (irrespective of whatever the pots were, plastic or clay) had a lower disease incidence, even when the soil had been artificially inoculated with *P. parasitica*. That plants grown in a greater volume of soil have much stronger and healthier roots was confirmed by regular and frequent visual inspection throughout the experiment. Poorly rooted plants were more predisposed to the disease. The type of growing medium, as such, did not seem to influence disease incidence.

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A. Minuto carried out the experimental work, P. Titone carried out the statistical analysis, M.L. Gullino wrote the manuscript, A. Garibaldi planned the work.

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