Diseases of Basil and Their Management

Sweet basil (*Ocimum basilicum* L.) is an economically important herb crop in several Mediterranean countries. Approximately 80 ha are grown annually in Italy, 30 ha in France (C. Poncet, I.N.R.A., Antibes, France, *personal communication*), and 20 ha in Israel (T. Katan, ARO Volcani Center, Bet Dagan, Israel, *personal communication*). Basil is also an important fresh and processed (frozen and pesto sauce) crop in U.S. markets (7,38; A. P. Keinath, Clemson University, Charleston, SC, *personal communication*). It is used fresh, dried, and processed for flavoring and fragrances and in traditional medicines (5,55). The crop value in Italy can reach \$500,000 per ha per year.

Recently, increased interest in so-called "Mediterranean cuisine" has led to a significant increase in basil consumption worldwide. Basil has become associated with the consumption of pasta and with healthy eating habits. It ranks first among the herbs most commonly used by California restaurants (4). In its processed form (pesto), it is known worldwide, thus strongly contributing to the image of Italian cuisine.

In Italy, most production takes place in the Riviera Ligure (59) (Fig. 1), where 53 specialized farms with average areas of 1 ha, and about 100 nonspecialized farms with average areas of 0.15 to 0.20 ha, grow basil. All the Ligurian farms are typically family-managed properties. Basil's high value makes it suitable for farmers with small operations in other countries such as Israel (T. Katan, *personal communication*) and the United States (57).

O. basilicum apparently is native to India (26) and naturalized in Africa and the

Pacific Islands (53). However, recent findings show that this species was known in Egypt at the time of the pharaohs (39). Basil has been cultivated in Italy for more than 100 years. It is a member of *Labiatae* (*Ocimoideae*) and is related to other herbs, such as mint (*Mentha* spp.), oregano (*Origanum vulgare*), marjoram (*Origanum majorana*), sage (*Salvia officinalis*), lemon balm (*Melissa officinalis*), rosemary (*Rosmarinus officinalis*), and thyme (*Thymus serpyllum*).

In Italy, Genovese Gigante is the basil cultivar most appreciated for fresh consumption. It is the only cultivar used for industrial production of pesto and covers 90% of the total growing area (49).

Basil is grown year-round in Italy in the Riviera Ligure, but it is a fall, winter, or spring crop in other locations and latitudes. In Italy, basil typically is grown as a direct-seeded crop by using 10 to 12 g (1 g = 600 to 800 seeds) of seeds per m², with planting and management strategies dictated by

the market destination (fresh consumption or pesto sauce). The number of plants per m² can reach 5,000 to 6,000. In Italy, basil is often overseeded after the first two to three harvests of the previous crop and is repeat-harvested after regrowth. In Israel and the United States, basil is transplanted. Most fresh-market basil is hand-harvested and sold as bunches of 10 to 15 plants. Basil for processing often is harvested mechanically.

As with most agricultural commodities, diseases impose significant production constraints, affecting both yield and overall quality of basil. Many diseases afflict basil. This article focuses on the most important diseases of basil in Italy, with reference to work carried out by several authors in other regions where basil is grown.

Basil Cultivation on the Riviera Ligure

The Riviera Ligure is divided into two parts, the Eastern (Riviera di Levante) and

Fig. 1. Map of the Liguria regions where basil is largely grown for production of pesto sauce.

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Western (Riviera di Ponente) Riviera, with Genova representing the dividing point (Fig. 1). Such a division reflects different cultivation methods. In the Riviera di Levante, basil is grown under very simple wooden or iron structures supporting plastic (commonly polyethylene) or, more frequently, glass. Glass typically is wood-framed and removable. Such structures, often very old, are 2.5 m high at the center and 1.5 m at the sides (Fig. 2A). They are built on hilly, steep terraces facing the sea, without modifications of soil structure. The reduced height of such structures limits air volume and, consequently, air circulation. Moreover, crops grown under such structures are exposed to sudden temperature changes that generate high relative humidity (RH) during the night. The situation is complicated by the limited possibility of ventilation offered by such structures. Those greenhouses are heated by thermoventilation or radiators to maintain at least 18°C during the day and 15°C overnight. Frequently, because of the high cost of heating the air, the soil is heated by buried pipes.

In the Riviera di Ponente, basil frequently is grown in more modern glass-houses 4 m high (Fig. 2B). Under such conditions, air circulates better, permitting lower RH, and more illumination necessitates shading nets in the summer. Glass-houses in the Riviera di Ponente are heated by thermoventilators with plastic pipes running throughout the greenhouse and distributing uniform heat. In the Riviera di Ponente, basil can also be grown under plastic tunnels.

Disease monitoring over the past 4 years in 37 specialized farms on the Riviera di Levante and the Riviera di Ponente showed that different greenhouse structures and cultural practices can influence the development of certain basil diseases. In simple greenhouses, lower night temperatures and dew depositions caused by higher RH favor the development of diseases such as gray mold and black spot, especially after cool nights following warm, humid days.

Fig. 2. Typical greenhouse structures in (A) eastern and (B) western parts of the Ligurian coast.

Disease Management: An Integrated Approach

The intensified use of cultivation systems, coupled with increasing restrictions on the use of fungicides, led to severe epidemics. The recent widespread outbreaks of *Fusarium* wilt (8,10,14,16,20,25,34,43, 58,61) and black spot on basil in Italy (19,23) clearly show that effective control measures against both soilborne and airborne pathogens are needed to maintain economically profitable crops. The development of effective, practical control strategies has been our goal for several years.

Our research efforts over the past 5 years have focused on developing an integrated management approach for the most important diseases. The study started with identification of the main diseases through a survey that included 37 farms on the Riviera Ligure that specialize in basil production (Fig. 1). Once the main phytopathological problems of the crop were identified, possible solutions were investigated.

Several fungal pathogens have been described on basil. Some are restricted to certain areas, while others are more widespread. Recently, intensive cultivation of the crop favored the outbreak of severe epidemics of some diseases and the appearance of new ones. The following section briefly describes the most important diseases of basil. It does not take into account those diseases considered of minor importance (3,9,50,51,56). Soilborne and foliar diseases are considered separately.

Soilborne Diseases

Fusarium wilt and crown rot.

Fusarium wilt, incited by *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *basilici* (Dzidzariya) Armst. & Armst., was first

described in the former USSR (11,36) and later spread to many basil-growing areas (8,12,14,16,20,25,34,43,58,61). Infected plants show epinasty, asymmetric growth, curling, chlorosis, and wilt, starting from the apical leaves (Fig. 3A and B). External symptoms are associated with xylem discoloration, which is more marked in the apical part of the plant. Necrosis follows, extending basipetally from the vegetative apex to the entire plant, while the roots and the base of the stem remain symptomless until the final disease stage. Young plants die rapidly, 4 to 7 days after the first symptoms develop; older plants may survive longer. Crown and root rot symptoms have been observed in infected plants in Israel (Fig. 3C) (16): stems of diseased plants often are covered with a pale pink-orange layer consisting of macroconidia of *F. oxysporum* f. sp. *basilici* (16,20). Studies in the United States and Israel show that the Israeli, American, and Italian isolates of *F. oxysporum* f. sp. *basilici* tested all belong to the common VCG 0160 group (14,33).

F. oxysporum f. sp. *basilici* displays both soil- and airborne behavior (16). The large number of conidia produced and frequent air circulation caused by fan operation in the greenhouse greatly facilitate dispersal of airborne propagules. Sprayer operation and other crop management practices also might enhance dispersal (16). In Italy, such dispersal is not common. For instance, there was no transfer of inoculum among nearby benches during a 6- to 8-month period of cultivation (A. Garibaldi, unpublished).

The pathogen has been isolated from seeds before and after disinfestation with sodium hypochlorite; 0.4% of nondisinfested and 0.2% of disinfested commercial seeds harbored *F. oxysporum* f. sp. *basilici*

Fig. 3. *Fusarium* wilt on (A) young and (B) old basil plants, and (C) crown and root rot symptoms. (C, courtesy Avraham Gamliel, ARO Volcani Center, Bet Dagan, Israel)

(40). Epidemiological considerations suggest that rapid local spread of *Fusarium* wilt and crown rot of basil is caused by airborne inoculum derived mainly from macroconidial masses on stem surfaces (16), through soil particles, and during harvest; whereas seedborne inoculum probably is responsible for its long-distance transmission (14,16,40).

Among several herbs in the family *Lamiaceae*, only sweet basil displayed symptoms typical of *Fusarium* wilt when artificially inoculated with *F. oxysporum* f. sp. *basilici* (34,58). *Ocimum basilicum* var. *minimum* cv. Fine Verde is particularly susceptible to *F. oxysporum* f. sp. *basilici*. This cultivar wilts in the presence of 10^2 CFU/ml of soil, compared with 3×10^2 CFU/ml of soil for *O. basilicum* cv. Genovese Gigante (A. Garibaldi and G. Minuto, unpublished).

Basal rots. *Rhizoctonia solani* Kühn, *Sclerotinia sclerotiorum* (Lib.) de Bary, *S. minor* Jagger, and *Microdochium tabacinum* (Van Beyma) Arx are the causal agents of basal rots of basil.

R. solani attacks most frequently, affecting plants at all growth stages (42,51). The organism is particularly serious on young plants, causing damping-off (Fig. 4). *R. solani* rapidly colonizes the basal parts of the stem, creating wide, sunken, zonate, dry-looking necrotic areas from the soil level to just below the soil surface. Lesions often girdle the entire stem. When the lesion is examined with a lens, the brown mycelia of the fungus can be seen on the lesion surface. In high humidity, common

Fig. 4. Symptoms caused by *Rhizoctonia solani* on basil.

Fig. 5. Attack of *Rhizoctonia solani* on basil. Note the mycelial web connecting infected plants.

in large basil crops, the mycelium can form a visible net (mycelial webbing) among infected plants at the soil level (Fig. 5). In cultivated fields, *R. solani* damping-off generally starts as a small, circular patch (10 to 15 cm diameter), which later enlarges to 1 m or more in diameter (Fig. 6). The pathogen grows through the soil quickly and is a rapid colonizer of disinfested soil. Inside the patch, most plants are damped-off. Often, the first symptoms develop close to greenhouse passages used by growers.

S. sclerotiorum and *S. minor* are less frequently the causes of basil stem rot (Fig. 7) (42). *S. minor* as a basil pathogen has recently been described in the United States (35). Because *Sclerotinia* rot develops at relatively low temperatures (20°C or below), it is found most commonly in Italy during fall and winter (A. Garibaldi, unpublished). In Italy, *Sclerotinia* rot is more frequent in the Riviera di Ponente, probably because of the many nearby susceptible vegetable (lettuce, lamb's lettuce, carrot, dill, and tomato) and ornamental (gerbera, poinsettia, chrysanthemum) crops from which aerial diffusion of pathogen ascospores can take place. Such diffusion has been well-documented for *S. sclerotiorum* (1,2) on bean, reported for *S. minor* (29) on lettuce, and observed in basil crops grown on steam-disinfested raised benches (A. Garibaldi and A. Minuto, unpublished).

M. tabacinum, which is a common saprophyte, can cause superficial necrosis (black leg) of the basal part of the stem (41). The disease occurs in patches in heated greenhouses, with optimal growth at 25 to 26°C in high RH. Infections that occur late in the crop production cycle are

Fig. 6. Patch caused by *Rhizoctonia solani* on basil crop.

Fig. 7. Basil stem rot incited by *Sclerotinia sclerotiorum*.

tolerated by the plant. Early infections may collapse the inner tissues without completely interrupting xylem flow. The upper portion of the plant shows reduced growth and turns yellow.

Pythium damping-off. *Pythium ultimum* Trow causes damping off of basil. It is particularly virulent on seedlings, on which it causes wet rot or traditional damping-off (42). It invades the host stem at or just below the soil surface and spreads, producing a soft, colorless to dark brown rot. The infection does not cause softening of young plants but flattens the stems, which collapse from the soil line upward for 5 to 10 cm. At later stages, the infection proceeds more slowly and the plants collapse completely. Patches of poor growth are common when basil is affected by damping-off (Fig. 8). In general, damping-off on basil is most often associated with *P. ultimum*.

Infection by *P. ultimum* is influenced by a range of factors: inoculum density; soil moisture, temperature, and pH; cation composition of the medium; and light intensity. Favored by cool conditions, *P. ultimum* usually infects at temperatures below 20°C. *Pythium irregulare* Buisman and an unidentified species of *Pythium* also have been described as causal agents of basil root rot in Florida (3).

Foliar Diseases

Gray mold. Under favorable conditions during spring and fall, *Botrytis cinerea* Pers.:Fr. is very common in basil cultivation systems and causes typical gray mold symptoms on leaves (Fig. 9A) and stems. Infected organs produce profuse off-white to gray mycelia covered with dark conidia. Conidia are very easily disseminated in wind currents or by rain splashing from plant to plant. Saprophytic mycelia or sclerotia survive unfavorable periods on crop debris. Observations of gray mold development in commercial Israeli greenhouses showed that infections occur on the stem cuttings soon after harvest (Fig. 9B). The disease then progresses, killing all leaves and secondary buds. When it reaches the main stem at the bottom of the plant, the entire plant dies (54). Stem cuttings are highly receptive to infection soon after harvest, and receptivity diminishes gradu-

Fig. 8. Patches of poor growth of basil caused by attack of *Pythium ultimum*.

ally with time; by 48 hours after harvest, most of the infected stem cuttings remain healthy (54). *B. cinerea* may also develop on the packed bunches (Fig. 9C) during shipment to market, resulting in rot of the entire package (54).

Black spot. A leaf spot caused by *Colletotrichum* sp. was reported in Florida in 1984 (3). More recently, a similar disease incited by *C. gloeosporioides* (Penz.) Penz. & Sacc. in Penz. was described in Italy (23). Symptoms develop on leaves and stems. On leaves, lesions appear as either circular or irregular necrotic spots that often expand and coalesce (Fig. 10A). Older lesions appear desiccated, with shredded tissue at the center. Stem lesions (Fig. 10B) are similar to those caused by *R. solani* or *Sclerotinia* sp. and can girdle the entire stem, leading to plant death (Fig. 10C).

Colletotrichum spp. are favored by high RH at 15 to 20°C, which leads to long periods of leaf wetness. It is particularly severe in very dense crops.

The recent outbreak of black spot in Italy can be at least partially explained by the large reduction in the number of sprays for other foliar pathogens, such as gray mold. In the late 1980s, illegal fungicide residues on fresh and processed basil were detected, and the consequent legal problems forced growers to drastically reduce the use of foliar sprays. We hypothesize that some of the fungicides illegally applied against gray mold (e.g., benzimidazoles) also controlled black spot.

Constraints and Opportunities in Disease Management

Disease management of minor crops

such as basil is hampered severely by several factors. A limited number of fungicides is registered for use on such crops compared with those allowed on other vegetables, such as tomato. Moreover, even fewer fungicides will be available in the future because of the generally low priority given by agrichemical companies to registration of new chemicals for minor crops and the loss of some older ones through the reregistration process (6,24, 37,52). Even when effective chemicals are registered, limitations in their use depend on the presence of residues in the crop leaves and the repeat-harvest system adopted (54). Thus, control of foliar diseases remains a major problem that must be solved mainly by adoption of proper cultural practices, a difficult undertaking in old greenhouse structures.

Soil disinfestation with methyl bromide and, to a lesser extent, soil steaming, are the most commonly adopted control measures against soilborne diseases. Soil disinfestation generally provides satisfactory control, although reinfestation can occur easily. Recent restrictions on methyl bromide have created a major problem (18). Methyl bromide emission abatement has already led to restriction in its use; in Italy, for instance, it can be applied only every other year. Moreover, further compliance with the Montreal Protocol abatement decision will force growers to adapt to some changes in soil disinfestation.

Soilborne diseases. The intensive nature of the crop and the limited size of specialized farms (at least in countries such as Italy, Israel, and France) make crop rotation nearly impossible. Repeated planting of basil results in increased in-

oculum potential and, consequently, increased vulnerability to pathogens such as *F. oxysporum* f. sp. *basilici*, *R. solani*, and less frequently, *Sclerotinia* sp. and *Pythium* sp. Cultural controls such as low-density planting (not easy to adopt in a crop such as basil) and regulation of soil moisture can help reduce *P. ultimum* attacks.

Resistant germ plasm is crucial for the control of several pathogens and is the most suitable control economically. However, basil and many other vegetable crops are not resistant to *R. solani*, *Sclerotinia* spp., or *Pythium* spp.

Cultivars resistant to Fusarium wilt are being sought by seed companies. However, at least in Italy, it will not be easy to replace widely grown cultivars such as Genovese Gigante.

Because of the spread of Fusarium wilt and crown rot in several countries, a number of researchers worldwide have focused on control strategies. The infectious potential of *F. oxysporum* f. sp. *basilici* requires development of an integrated approach toward different inoculum sources at various sites before, during, and after planting (16). Primary disease avoidance means eliminating inoculum sources, including contaminated seeds. Seed dressing represents an easy, low-cost method for control

Fig. 9. Symptoms of gray mold, incited by *Botrytis cinerea*, on (A) leaves, (B) stems, and (C) packed bunches of basil. (B and C, courtesy Dani Shtienberg, ARO Volcani Center, Bet Dagan, Israel)

Fig. 10. Symptoms of black spot, caused by *Colletotrichum gloeosporioides*, on (A) leaves, (B) stems, and (C) basal parts of the plant.

Table 1. Effect of seed dressing against *Fusarium oxysporum* f. sp. *basilici* on basil cv. Genovese Gigante^w

Treatment	Dosage	Dressing	Infected plants (%)	
			Trial 1 (56 dd ^x)	Trial 2 (42 dd)
Untreated check	...	...	4.30 b ^y	6.80 b
Benomyl	20 g/kg seed	Dry	0.71 a	2.68 a
Benomyl	30 g/liter	Wet, 30'	0.97 a	2.90 a
NaClO ₂ ^z	50 g/liter	Wet, 5'	0.93 a	5.18 b

^w Ten percent of seeds were infected artificially with the pathogen (10⁵ CFU/g) (44).

^x Days after seeding.

^y Means in a column with a letter in common are not significantly different (Duncan's multiple range test, *P* = 0.05). n = 3 replicates of 2,500 plants per plot.

^z Phytotoxicity observed.

Table 2. Effectiveness of different treatments against *Rhizoctonia solani* on basil cv. Genovese Gigante^v

Treatment	Dosage (g or CFU)	Applied		Mean patch diameter (cm)		
		Soil	Seed	Trial 1 (29 dd ^w)	Trial 2 (38 dd)	Trial 3 (30 dd)
Untreated check	...	...	...	30.4 e ^x	44.2 f	87.9 b
Tolclofos-methyl ^y	30/kg	...	+	0.0 a	7.7 a-c	9.4 a
Tolclofos-methyl	20/kg	...	+	NT ^z	10.5 c	9.0 a
Tolclofos-methyl	1.0/m ²	Dust	...	0.0 a	8.5 bc	NT
Tolclofos-methyl	0.5/m ²	Dust	...	NT	6.3 a-c	NT
Tolclofos-methyl	1.5/m ²	Drench	...	0.0 a	NT	NT
Tolclofos-methyl	1.0/m ²	Drench	...	0.0 a	5.8 ab	5.4 a
Tolclofos-methyl	0.5/m ²	Drench	...	NT	3.8 a	5.3 a
Dichloran	4.0/m ²	Drench	...	25.7 c	43.7 f	NT
Iprodione ^y	4.0/m ²	Dust	...	22.3 b	38.0 de	NT
Benomyl	30/kg	...	+	27.8 d	44.7 f	NT
<i>Trichoderma</i> ^y	10 ⁶ /ml	Dust	...	25.1 c	36.7 d	NT

^v Soil was artificially infested with infected wheat kernels placed at two corners of the plots after basil germination (A. Garibaldi and G. Minuto, unpublished).

^w Days after seeding.

^x Means in a column with a letter in common are not significantly different (Duncan's multiple range test, *P* = 0.05). n = 4.

^y Not registered for basil in Italy.

^z Not tested.

Table 3. Effectiveness of different fungicides against *Sclerotinia* sp. on basil cv. Genovese Gigante^v

Treatment	Dosage (g/m ²)	Timing of soil drench	Mean patch diameter (cm)		
			Trial 1 (40 dd ^w)	Trial 2 (34 dd)	Trial 3 (43 dd)
Untreated check	...	...	21.5 b ^x	26.4 c	20.5 d
Dichloran	1.00	Germination	3.4 a	17.5 b	7.0 ab
Dichloran	1.25	Germination	4.1 a	15.2 b	5.3 ab
Procymidone ^y	0.50	Germination	2.7 a	4.6 a	0.0 a
Dichloran	1.00	Sowing	4.1 a	16.6 b	9.7 bc
Dichloran	1.25	Sowing	5.2 a	15.9 b	14.5 cd
Tolclofos-methyl ^y	0.50	Germination	NT ^z	NT	19.7 d
Tolclofos-methyl	1.00	Germination	NT	NT	18.2 d

^v Soil was infested at two corners of the plot with infected wheat kernels (A. Garibaldi, M. L. Gullino, and G. Minuto, unpublished).

^w Days after seeding.

^x Means in a column with a letter in common are not significantly different (Duncan's multiple range test, *P* = 0.05). n = 4.

^y Not registered for basil in Italy.

^z Not tested.

of soilborne pathogens. Fungicidal soil treatment, alone or combined with seed dressing, can provide satisfactory disease control when specific and well-identified problems are present.

To avoid *F. oxysporum* f. sp. *basilici*, use certified seeds whenever possible. In Italy, at least two companies have started testing their seed for *F. oxysporum* f. sp. *basilici*. One of them is selling seed certified to be *F. oxysporum* f. sp. *basilici*-free. The lower incidence of *Fusarium* wilt in greenhouses on the Riviera di Levante can be explained by a more widespread use of certified seed. Control of air movement and measures that suppress conidial production on aerial parts should help reduce spatial spread of *F. oxysporum* f. sp. *basilici* (16).

When seeds are not certified, benzimidazoles, the only effective compounds permitted as seed dressings in Italy, applied as a wet (30 g/liter for 30 min) or dry (20 g/kg of seed) coating, significantly reduce seed transmission of *F. oxysporum* f. sp. *basilici* (Table 1) but are not effective against inoculum in the soil (44).

Benzimidazoles do not provide satisfactory control of *R. solani*. Dichloran and iprodione (not registered on basil in Italy) did not control *R. solani* in our experiment (A. Garibaldi and G. Minuto, unpublished). Tolclofos-methyl, if registered, could provide good control at very low dosages when applied as a soil mixture or seed dressing (Table 2), leaving very little residue (A. Garibaldi, G. Minuto, and M. Gennari, unpublished). *Sclerotinia* sp. could be controlled by drenching the soil with dichloran and procymidone (not registered) (Table 3; A. Garibaldi, M. L. Gullino, and G. Minuto, unpublished). When necessary, thiram or propamocarb, both registered for use on basil in Italy, can be applied as a soil treatment or seed dressing for control of *Pythium* damping-off.

Another option is biological control. Biocontrol agents effective against soilborne diseases of basil have long been sought. In the 1960s, species of *Trichoderma* were used against *Fusarium* wilt in the former Soviet Union (27), with interesting results in terms of disease control and increased growth response. More recently, saprophytic *Fusarium* spp. that were isolated from *Fusarium*-suppressive soils and effective against several formae speciales of *Fusarium oxysporum* have been applied in basil cultivation as a seed dressing, soil treatment, or both. Seed dressing alone only partially reduces wilt severity (46). Antagonistic *Fusarium*, as well as other biocontrol agents, cannot eradicate infection already present on seed. Their action is directed toward the pathogen present in the soil. Antagonistic *Fusarium* performs better when applied both as a seed dressing and as a soil treatment (Table 4; 46,47). Another biocontrol agent, *Streptomyces griseoviridis* strain K

Table 4. Effect on Fusarium wilt severity of antagonistic *Fusarium oxysporum* strain 251/2 applied as a soil treatment (soil) at 10^5 CFU/ml of soil and a seed coating (seed) at 3×10^7 CFU/g of seed^x

Antagonist	Application	Mean percentage healthy plants		
		Crop 1 (55 dd ^y)	Crop 2 (42 dd)	Crop 3 (48 dd)
...	...	75.0 b ^z	53.8 b	86.2 b
251/2	Seed + soil	96.8 a	85.9 a	96.0 a

^x Soil was infested with *Fusarium oxysporum* f. sp. *basilici* at 10^3 CFU/ml (46).

^y Days after seeding.

^z Means in a column with a letter in common are not significantly different (Duncan's multiple range test, $P = 0.01$). $n = 4$.

61 (Mycostop), applied as a soil drench 3 days before artificial inoculation with *F. oxysporum* f. sp. *basilici*, did not prevent Fusarium wilt (34). The strains of *Trichoderma* spp. tested against *R. solani* provided only slight disease control (Table 2).

However, it should be noted that biocontrol agents require registration. Such a process can be as difficult as the process for minor-crop chemicals (21).

Soil disinfestation remains the most effective method for managing soilborne pathogens, weeds, and soil insects. For the past 50 years, it has been carried out with steam, chemical fumigants, or both (30). Steam disinfestation, mostly used for bench cultivation in the Riviera di Ponente, is not practical for the narrow, steep greenhouses of the Riviera di Levante. The need to reduce the use of methyl bromide, a fumigant highly effective against *F. oxysporum* f. sp. *basilici* (12) and other diseases, pests, and weeds, will challenge researchers and growers to implement effective and reliable alternatives.

Dazomet and metham sodium fumigants

provide control of soilborne pathogens. Their efficacy improves when they are combined with solarization (17). Soil solarization is particularly effective against *R. solani* and *F. oxysporum* f. sp. *basilici* in the Liguria region, even when used for fewer than 4 weeks, and particularly when combined with the use of dazomet (Tables 5 and 6). The results obtained in Italy indicate that solarization and dazomet have control potential and, depending on cropping situations and specific needs, can be tested at reduced rates in combination (48).

Soil solarization has potential advantages over other soil disinfestation methods, especially in protected minor crops. It is less expensive than other methods and does not involve the use of potentially toxic substances (31). Soil solarization will play an important role in the protection of basil against soilborne pathogens in Liguria because such a method coincides with sustainable agriculture (32). The use of solarization is slowly expanding on the Riviera di Levante; in 1995, it was used on 5 ha of basil. Applying it under greenhouse conditions also expands its use in marginal areas such as northern Italy (17). Combined with reduced dosages of chemical fumigants, solarization permits better management of a full range of soilborne pests, diseases, and weeds. Solarization with

subsequent use of biocontrol agents is also very promising (60).

Major changes in cultural techniques in the Riviera di Ponente include the use of raised benches, which permits thorough soil disinfestation and helps reduce the incidence of soilborne pathogens. Hydroponic and soilless cultivation are not yet widespread in Italy, since they are not easily adaptable in the present structures, especially in the Riviera di Levante. They should, however, become more common in the Riviera di Ponente.

Foliar diseases. Foliar diseases thrive with high temperature, RH, and soil nitrogen. Careful regulation of nutrients, temperature, irrigation, and RH to control foliar pathogens is possible, at least in properly equipped glasshouses, where all cultural parameters can be monitored and controlled automatically (28). In plastic houses, tunnels, and old greenhouses in which air circulation is scanty, RH management relies mainly on open windows or forced ventilation (15). Reduction of crop density favors better aeration of leaves, thus reducing leaf wetness. Also, the method and timing of irrigation can help minimize RH levels (15). Cultural methods, particularly reduction of relative humidity and leaf wetness, reduce black spot and gray mold incidence. Assuming that optimal conditions for the pathogen prevail in the greenhouse during rainy periods, losses to *B. cinerea* can be reduced by appropriate timing of harvests (54).

Fungicides will probably be minor but essential instruments for the control of some foliar diseases. Since most of the newly developed fungicides will be unavailable for use on basil, they must be carefully chosen. Among registered fungicides, ziram as a foliar spray (121.5 g/100 liters) and thiram (125 g/100 liters) effectively controlled black spot (Table 7; 45). Both fungicides were applied twice at 7-day intervals; the first treatment took place when cotyledons were fully expanded

Table 5. Efficacy of solarization, dazomet, and both treatments in combination against *Rhizoctonia solani* on basil (cv. Genovese Gigante) grown in a greenhouse^x

Dazomet (g a.i./m ²)	Solarization (days)	Dead plants ^y (%)
...	...	36.4 c ^z
...	30	2.2 a
25	...	34.1 c
50	...	22.8 b
25	7	1.4 a
50	7	7.1 a
25	30	0.9 a
50	30	0.6 a

^x Soil was artificially infested with *R. solani* (12 g of infested wheat kernels per m²) before fumigation, solarization, or both. Sowing: 08/05/93, reading: 09/21/93 (48).

^y 45 days after sowing.

^z Means in a column with a letter in common are not significantly different (Duncan's multiple range test, $P = 0.05$). $n = 3$.

Table 6. Efficacy of solarization, dazomet, and their combination against *Rhizoctonia solani* and *Fusarium oxysporum* f. sp. *basilici* on two basil cultivars, Fine Verde (FV) and Genovese Gigante (GG), grown in different plots in a greenhouse, with evaluation 50 days after sowing (48)

Dazomet (g a.i./m ²)	Solarization (days)	Plants infected (%)			
		<i>R. solani</i>		<i>F. oxysporum</i> f. sp. <i>basilici</i>	
		FV	GG	FV	GG
...	...	70.6 b ^z	51.8 b	59.4 b	17.5 b
...	28	1.7 a	0.5 a	4.6 a	0.4 a
...	21	4.4 a	0.8 a	3.7 a	0.2 a
...	14	0.0 a	3.1 a	7.8 a	5.0 a
40	...	5.6 a	3.0 a	6.0 a	1.0 a
70	...	5.3 a	0.8 a	5.8 a	1.2 a
40	14	9.2 a	1.3 a	4.8 a	3.4 a
40	21	4.1 a	0.3 a	5.6 a	0.3 a

^z Means in a column with a letter in common are not significantly different (Duncan's multiple range test, $P = 0.05$). $n = 4$.

Table 7. Efficacy of different fungicides against black spot of basil cv. Genovese Gigante^x

Treatment	g a.i./ 100 liters	No. sprays	Percent infected area		Plants with stem necrosis (%)
			Cotyledons 4/27	Leaves 5/02	
Untreated check	...	...	62.2 b ^y	42.3 e	79.0 e
Thiram	125.0	1	13.8 a	27.9 de	70.3 e
Thiram	125.0	2	8.7 a	8.0 a-c	42.0 c
Ziram	121.5	1	6.3 a	16.4 b-d	52.3 cd
Ziram	121.5	2	4.2 a	3.4 ab	25.3 b
Cu hydroxide	112.0	2	7.2 a	15.2 a-d	26.8 b
Cu hydroxide	168.0	2	5.6 a	12.1 a-c	48.8 c
Cu oxychloride	80.0	2	14.7 a	22.6 c-e	59.7 d
Chlorothalonil ^z	150.0	2	5.6 a	9.2 a-c	23.0 ab
Dichlofluanid ^z	100.0	2	1.9 a	1.2 a	13.3 a
Dithianon ^z	150.0	2	5.2 a	4.0 a-c	16.0 ab

^x Fungicides were applied twice, first spray at extended cotyledons and second spray at extended true leaves. *Colletotrichum gloeosporioides* was artificially inoculated (10⁵ conidia per ml) 2 days after the first spray. Seeding 22 March (45).

^y Means in a column with a letter in common are not significantly different (Duncan's multiple range test, $P = 0.05$). n = 3 replicates of 100 plants per plot.

^z Not registered for use on basil in Italy.

Table 8. Efficacy of several treatments against *Botrytis cinerea* on basil cv. Genovese Gigante^v

Treatment	g or CFU/100 liters	Infected plants (%) 30 dd ^w	Disease index (0 to 5) ^x
Untreated check	...	63 b ^y	2.5 b
<i>Trichoderma</i> ^z	10 ⁸	43 a	1.6 a
Dichloran	100	43 a	1.6 a
Procymidone ^z	30	54 ab	1.9 ab
Cu hydroxide	160	54 ab	2.0 ab
Ziram	121	45 a	1.7 a

^v Sowing occurred on 22 September. Two artificial inoculations with the pathogen were carried out at 12-day intervals. Treatments were carried out three times: 09/22, 09/28, and 10/04. *Trichoderma* was also sprayed on 12 October (A. Garibaldi, A. Minuto, and M. L. Gullino, unpublished).

^w Days after seeding.

^x 0 = healthy plant, 5 = completely rotted plant.

^y Means in a column with a letter in common are not significantly different (Duncan's multiple range test, $P = 0.05$). n = 3 replicates of 100 plants per plot.

^z Not registered for use on basil in Italy.

(Table 7). With no specific fungicides allowed during cultivation, the only one able to reduce gray mold incidence is thiram (Table 8), which also controls black spot.

Whenever possible, chemicals active against more than one pathogen should be used. The results obtained in the control of black spot (Table 7) and gray mold (Table 8) show that it is possible to obtain satisfactory results with registered products (45; A. Garibaldi, A. Minuto, and M. L. Gullino, unpublished). We recommend integrating fungicides with cultural practices to help reduce the risk of developing fungicide-resistant strains of pathogens and reducing the efficacy of fungicides with narrow modes of action. For example, solar heating carried out in greenhouses abates black spot inoculum in crop residues in soil (A. Garibaldi, A. Minuto, and M. L. Gullino, unpublished).

Very few biocontrol agents are registered and available for use against foliar diseases (22). A formulation based on *Trichoderma harzianum*, which is active against gray mold (13), soon will be registered, possibly for basil.

Integrated Disease Management

An integrated disease management approach that includes cultural practices, careful irrigation, fertility management, soil disinfestation, application of biocontrol agents (when available), and limited fungicide use is necessary to produce high-quality basil.

Using solarization for soil disinfestation, *Fusarium* spp. antagonistic to *F. oxysporum* f. sp. *basilici*, and a limited number of treatments with registered fungicides against some foliar diseases (mostly black spot and gray mold), good results may be obtainable. Appropriate cultural practices, particularly ventilation and heating, are very important to reduce incidence of foliar diseases; however, such practices can be adopted only in properly equipped greenhouses.

Table 9. Control measures available against pathogens of basil

Control measures	Pathogen	Example
Indirect		
Use of healthy propagation material	<i>Fusarium oxysporum</i> f. sp. <i>basilici</i>	Certified seed
Cultural practices	<i>Botrytis cinerea</i> , <i>Colletotrichum gloeosporioides</i> <i>Pythium ultimum</i>	Ventilation, heating, fertilization, light pH
Direct		
Physical	<i>F. oxysporum</i> f. sp. <i>basilici</i> , <i>Rhizoctonia solani</i> , <i>P. ultimum</i> , <i>Sclerotinia minor</i> , <i>Fusarium tabacinum</i>	Steam, solarization
Chemical	<i>F. oxysporum</i> f. sp. <i>basilici</i> <i>F. oxysporum</i> f. sp. <i>basilici</i> , <i>R. solani</i> , <i>P. ultimum</i> , <i>F. tabacinum</i> <i>R. solani</i> , <i>C. gloeosporioides</i>	Seed dressing Soil fumigation Soil or foliar treatments
Biological	<i>F. oxysporum</i> f. sp. <i>basilici</i> <i>R. solani</i> <i>B. cinerea</i>	Antagonistic strains of <i>Fusarium</i> spp. <i>Trichoderma</i> spp. ^z <i>Trichoderma harzianum</i> ^z

^z Biocontrol agent not yet available in Italy.

A fully integrated disease management strategy aimed at limiting chemical use for controlling basil pathogens is feasible. Integration of available control measures (Table 9) and the support of a well-trained extension service will permit very satisfactory results under practical conditions.

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