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Brassica amendments and summer irrigation for the control of *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *cumini* in hot arid region

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Summary. The combined effect of *Brassica* amendments (mustard oil–cake or mustard residue at 2.5 tons ha^{-1}) and summer irrigation was tested for survival of *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *cumini* and on the severity of dry root rot on clusterbean in the rainy season and on wilt of cumin in the subsequent winter season in the same field. Seed coating with a *Bacillus* sp., an antagonist bacterium against *M. phaseolina*, was also integrated with pod residues to improve control of dry root rot. The soil temperature of amended soil after one summer irrigation in June ranged from 38–44°C at 15-cm depth. These temperatures were 0.5–5°C higher than those recorded in unamended soil for the same period and 6–16°C higher when amendments were incorporated in July. A single summer irrigation led to a significant reduction in viable propagules of *M. phaseolina, Fusarium oxysporum* f. sp. *cumini*, plant mortality due to dry root rot in clusterbean and incidence of wilt on cumin from *Brassica* amendments, as compared with the application of amendments in July. A seed coating with *Bacillus* sp. alone was also effective, but integration with residues did not improve control of dry root rot. In general, amended soil held more soil moisture than unamended soil. These findings have a potential value for irrigated pockets in the hot arid zone of India as well as for many countries with the appropriate climatic conditions.

Key words: soil amendment, soil-borne plant pathogens, clusterbean, cumin.

Introduction

In the arid regions of India, with their dry and warm growing conditions, *Macrophomina phaseolina* causes charcoal rot or dry root rot in many economically valuable crops, including legumes and oil seeds (Lodha *et al*., 1986). Moreover, in certain pockets of these regions, cumin (*Cuminum cyminum* L.), an important spice crop, is cultivated with irrigation in the same fields during the winter season. Heavy losses due to wilt caused by *Fusarium oxysporum* f. sp. *cumini* (*Foc*) often compel growers to abandon cultivation of this crop after three successive years (Lodha, 1995). The population of these pathogens increases in agricultural lands with increasing years of cultivation of susceptible crops, and inoculum density in the soil is directly proportional to disease incidence in the field. The management of these soil-borne pathogens in arid soils is very important because they survive in the form of heat-tolerant resting structures (sclerotia and chlamydospores). High soil temperatures in the summer months (50–60°C) also do not eliminate more than 10–15% of soil inoculum

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because the soil remains dry (Lodha *et al*. 1990; Lodha and Mawar, 2000).

An attempt to reduce the severity of dry root rot of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] and wilt of cumin by the use of soil solarization in combination with soil amendments (Urea – N and farmyard manure) was found effective in reducing inoculum density and disease incidence on both crops in the same field (Lodha, 1995). However, this control method is not widely accepted in the resource-deficient farming community of the region due to the high cost of polyethylene film.

Cruciferous residues as soil amendments are effective in reducing the population densities of many soil-borne plant pathogens (Ramirez-Villapudua and Munnecke, 1987, 1988; Muehlchen *et al*., 1990; Mojtahedi *et al*., 1993; Angus *et al*., 1994; Keinath, 1996; Mayton *et al*., 1996). These residues produce many biotoxic volatile compounds in the soil during decomposition (Brown *et al*. 1991). The production and release of these compounds has seemed especially promising when combined with solarization because the concentration of volatile compounds evolved was directly related to increased heating of soil (Gamliel and Stapleton, 1993). Thus, solarization of soil amended with cruciferous residues gave greater control of *Fusarium oxysporum* f. sp. *conglutinans* (Ramirez-Villapudua and Munnecke, 1988).

In hot arid regions, combining cruciferous residues such as those of mustard [*Brassica juncea* (L.) Czern. & Coss. cv. Pusa bold] with one summer irrigation (without polyethylene mulching) in June caused a 70–80% reduction in the soil population densities of *M. phaseolina* and *Foc* because the maximum soil temperature of such amended soil after irrigation reached 45ºC even at 15-cm depth (Lodha *et al*., 1997; Lodha and Mawar, 2000). However, further information is required on the role of surviving sclerotia and chlamydospores of these pathogens in increasing or decreasing the severity of diseases on clusterbean and cumin crops, respectively.

The present investigation aims to determine how readily available cruciferous residues combined with one summer irrigation affect the survival of *M. phaseolina* and *Foc*, and the severity of dry root rot of clusterbean and wilt of cumin.

Materials and methods

The experiments were conducted at the Central Arid Zone Research Institute, Jodhpur, India in the summer (May–June), the rainy (July–Oct) and the winter (Nov–March) seasons of 1998–2001. The soil of the experimental site is loamy sand formed by aeolian activity having 85.0% sand, 8.9% clay, 5.5% silt, 0.031% total nitrogen, 0.25% organic carbon, 9 ppm available phosphorus (Olsen and Dean, 1965), pH 8.1, electrical conductivity 0.088 dSm^{-1} (soil : water ratio 1:2.5); bulk density 1.56 g cm^{-3} and 10.4% moisture holding capacity (MHC).

The experimental field had native populations of both pathogens due to a previous history of cultivation of susceptible legume and cumin crops. For population counts, 12 samples to soil depths of 0–30 cm were collected randomly from the field using a 2.5-cm diameter soil auger. Populations of *M. phaseolina* and *Foc* were determined on their respective selective medium (see biological assays section). *Bacillus* sp., a specific bio-control agent against *M. phaseolina* isolated from arid soils (IMTC, Chandigarh, India), was also integrated as seed coating in the rainy-season experiments on dry root rot of clusterbean. Experimental plots (4×3 m) were arranged in a completely randomised block design with nine treatments or treatment-combinations: 1) mustard oil-cake amendment (MC, 0.11% or 2.5 ton ha^{-1}) in May + summer irrigation (SI), (MC+SI); 2) MC amendment applied in July before sowing (NS), (MC+NS); 3) mustard residue amendment (MR, 0.11%) in May + SI, (MR+SI); 4) MR+NS; 5) MR+SI plus seed coating with *Bacillus* sp. (ST), (MR+SI+ST); 6) MR+NS+ST; 7) ST only; 8) SI only and, 9) control (without MC, NS, ST or SI). However, in the winter-season experiments on cumin, treatments 5, 6 and 7 were not applied, but cumin seeds were sown in these plots. All treatments had three replications.

Brassica oil-cake or residues were incorporated on May 30 each year in their respective plots (MC-1, MR-3 and MR-5) at 3 kg per plot by uniformly mixing in the residues with a hand spade to a soil depth of 30 cm. One summer irrigation to a depth of 45 cm was applied on June 1 by flooding to bring it to field capacity (10.4% w:w or 0.003 MPa) in all the plots with SI. The soil temperature at 15-cm depth was recorded at 4 p.m. every day for 15 days in selected treatments by inserting thermometers to that depth.

In July, oil-cake and residues were incorporated into the plots with NS and MC or MR (treatments 2, 4 and 6) as described above. Clusterbean cv. HG-75 was sown on July 31 in 1998 and on July 25 in 1999, while the cumin cv. RZ-19 was sown in the following winter seasons on December 1 in 1998, and on December 7 in 1999, in accordance with standard agronomic practices. *Bacillus* sp. was multiplied on 30-ml Czapeck's dox liquid medium in 100-ml flasks incubated at 28±2°C. After 7 days, 5-ml of liquid medium containing the *Bacillus* sp. (10^7 ml^{-1}) was spread on a 12-cm Petri dish; 0.5 g carboxyl methyl chloride was sprinkled on it and 90 g of clusterbean seeds were coated with the bacterium**.** The seeds were then spread in an enamel tray (45×12 cm) for 24 h and used for sowing in plots with ST (treatments 5, 6 and 7).

During the rainy-season experiment of 1999, soil samples were collected at depths of 0–30 cm from each replication at frequent intervals and soil moisture was determined gravimetrically. The severity of dry root rot on clusterbean and wilt on cumin (% mortality) was recorded 15 days before harvest on the four central rows of clusterbean and on a 1 m^2 area of cumin from each replication. In the second year, however, severity was recorded weekly from the initiation of disease till harvest. Per-cent mortality from dry root rot was calculated in these rows and the mean of the four rows was considered as an estimation for each replication, while the incidence of wilt was calculated on the basis of the area observed. Due to a long spell of moisture stress, in 1999 one life-saving irrigation was given on 19 September to the clusterbean crop.

Three soil samples at depths of 0–30 cm were collected randomly from each replication of all the treatments 15 days after the harvest of crops. The samples were bulked to make one sample per replicate and then processed for estimating populations of *M. phaseolina* and *Foc*.

Biological assays

The soil samples were air-dried and ground to pass through a 2-mm sieve to count the pathogenic propagules. The sclerotial population of *M. phaseolina* was estimated by sprinkling 50 mg of each soil sample on chloroneb-mercury-rose-bengal agar (CMRA), a selective medium (Meyer *et al.*, 1973). The population of *Foc* was estimated by a serial dilution technique on modified peptone-PCNB medium (Papavizas, 1967). White restricted colonies of *Foc,* which later turned pinkish, were easily distinguishable from other formae speciales because of their distinct shape and size. Six Petri dishes per medium per replication were used.

Statistical analysis

Pathogen populations and disease indices were subjected to analysis of variance (ANOVA) and the treatment means were compared with the LSD test (P=0.05). Data on per-cent mortality were converted to angular transformed values before analysis. Values on the development of dry root rot on clusterbean and of wilt on cumin were subjected to analysis in a three factor-factorial design (Snedecor and Cochran, 1967). Correlation analysis was done to determine the relationship between *M. phaseolina* and dry root rot on clusterbean, and between *Foc* and wilt incidence on cumin.

Results

Maximum air temperature, wind speed, sunshine, solar irradiations and evaporation were higher in June than in July of both test years (Table 1).

Table 1. Maximum air temperature range and related weather data recorded during the test period.

Year	Period[a]	Max. air temperature (°C)	Wind speed ($km\ h^{-1}$)	Sunshine (hd^{-1})	Solar irradiation ($MJ\ m^2d^{-1}$)	Evaporation (mm water day^{-1})
1998	June 1–15	27.2–44.5	1.7–11.7	0.4–11.8	22.9–30.1	5.4 –17.1
1999	June 1–15	25.9–41.6	6.2–12.8	7.5–11.6	25.5–30.3	10.3–15.0
1998	July31–Aug 14	35.6–38.4	5.0–7.6	4.4–9.4	17.5–23.9	6.0–8.7
1999	July 25–Aug 8	30.8–36.5	6.0–10.9	3.1–8.0	7.9–21.2	3.1–9.5

[a] Summer season (June) and rainy season (July–August).

Air temperatures were 5–6°C higher in June than in July for at least 10 days.

Soil temperature

Soil temperature at 15-cm depth in bare dry soil measured at 4 p.m., was higher in June than in July of both test years (Table 2). A single irrigation of the unamended dry plot initially brought the soil temperature down to 37°C in June, but a gradual increase to 41°C followed within 15 days. Similarly, in July soil temperatures dropped to 22°C due to precipitation, but then remained within 34°C in next 15 days. In the amended plots, for the first 7 to 8 days soil temperatures were 0.5–5°C higher than in the corresponding unamended plots in June, but were only 0.5–1.5°C higher in July.

Crop growing situation

There were six good, well-spaced-out rain events after clusterbean seeds were sown in 1998. The crop therefore did not experience an extended period of moisture stress. As a result the season was not very favourable for occurrence of dry root rot in severe form though the inoculum load in the soil remained far above the economic threshold level. The 1999 crop received a good spell of rainfall (148 mm) soon after sowing, but thereafter it was affected by severe drought. The crop began to experience mild moisture stress from 15 days after sowing, which became severe after 25 days. Dry root rot symptoms on clusterbean became conspicuous in various treatments from the last week of August onwards till maturity, and variations were quite discernible when recording disease severity at weekly intervals.

The winter seasons remained quite suitable for the cultivation of cumin. Both winter seasons were almost dry, except that 14.2-mm rainfall was received in the second half of February 1999.

Dry root rot incidence on cluster bean

Soil amendments with cruciferous residues with or without summer irrigation, summer irrigation alone, and the coating of seeds with *Bacillus* sp., were found to be significantly better in reducing clusterbean mortality from dry root rot compared with the unamended controls in both test years (Table 3). Merely one summer irrigation in dry unamended plots reduced disease severity significantly by 34–39% compared with the unamended control without irrigation. *Bacillus*-coated seeds planted in unamended plots also reduced mortality, which was significantly lower than in plots with SI alone. The incorporation of mustard oil-cake or mustard residues into the soil just before sowing was more effective than SI alone in controlling dry root rot, but mustard oil-cake was the only one that was significantly superior to SI alone. In 1999, soil amendment with mustard oil-cake produced a significantly healthier clusterbean crop than when only *Bacillus* coated seeds were planted in untreated soil, but in 1998 the reverse occurred, with *Bacillus* coat, more effective as a disease inhibitor than mustard oil-cake amendment. A single irrigation in summer further augmented the efficiency of cruciferous residues to control dry root rot in both test years. Of the residues, mustard oil-cake was 38% more effective than mustard residues in reducing rot severity. However, planting of *Bacillus* coated seeds in combination with MR+SI was significantly better than MR+NS i.e. without SI (Table 3).

Table 2. Temperature ranges (°C) after soil amendment and summer irrigation/rains.

Treatment	1998		1999	
	June	July–Aug[a]	June	July–Aug[a]
Mustard residue (MR) + summer irrigation (SI)	40–42	23–35	38–44	22 –32
Mustard oil-cake (MC) + summer irrigation (SI)	39–42	23–35	38–43	22–32
Summer irrigation (SI)	38–40	23–34	37–41	22–31
Dry soil	37–47	27–36	33–43	28–39

[a] Temperatures recorded after amending soil in rainy season.

Table 3. Effect of cruciferous residues as a soil amendment on *Macrophomina phaseolina* and clusterbean mortality due to dry root rot on clusterbean.

Treatment[a]	Mortality (%)		*M. phaseolina* population[b] (sclerotia g^{-1} soil)	
	1998	1999	1998	1999
MC + SI	4.7 (12.0)[c]	5.1 (14.2)	180	120
MC + NS	9.8 (18.2)	8.7 (17.5)	220	168
MR + SI	7.2 (15.5)	6.5 (14.7)	206	148
MR + NS	10.3 (18.7)	10.7 (19.1)	248	188
MR + SI + ST	6.8 (15.1)	5.4 (14.6)	200	136
MR + NS + ST	7.2 (15.6)	10.6 (18.9)	240	170
SI	11.3 (19.6)	13.9 (22.2)	284	220
ST	7.9 (16.2)	11.6 (19.1)	352	388
Control (unamended)	18.8 (25.7)	21.3 (27.4)	385	432
LSD (*P*= 0.05)	1.1	3.0	32	38

[a] MC, mustard oil-cake (2.5 ton ha^{-1}); MR, mustard residues (2.5 ton ha^{-1}); NS, application of the amendment at the time of clusterbean sowing in July; SI, summer irrigation in June; ST, seed coating with *Bacillus* spp.
[b] Initial population was 340 sclerotia g^{-1} soil.
[c] Angular transformed values.

Progression of dry root rot on clusterbean

The pattern of dry root rot development was similar when oil-cake was applied either in May with summer irrigation (MC+SI) or in July (MC+NS) at the time of sowing clusterbean seeds (Fig. 1). However, disease development was significantly greater in the plots amended in July. A similar trend in disease progression was observed with the amendment of mustard residue in both the environments. In SI and unamended plots, there was a rapid initial onset of dry root rot but after 14 days mortality was significantly greater in the unamended plots (Fig. 1).

Soil moisture

The amended soil generally held more moisture than the unamended soil. In the samples collected on August 6, 1999, soil moisture was 6–6.6% in amended plots and 5.1–5.8% in unamended plots. When averages were pooled, amended soil held 14.8% more moisture than unamended soil. Soil-moisture retention in the amended plots was greatest on August 26, when it ranged from 1.1–2.3%, compared with 0.3–1.7% for unamended soil. It was also greater on September 22, 1999 after one life-saving irrigation (7.3–9.8% compared with unamended soil 4.4–8.2%), but the differences were smaller. Among residues, MC-amended soils retained more soil moisture than MR-amended soils.

***M. phaseolina* population**

An initial population of 340 sclerotia g^{-1} soil of *M. phaseolina* in 1998 decreased with all the amendments irrespective of the time of application (Table 3). A further reduction in *M. phaseolina* propagules due to soil moisture was also discernible in all treatments. However, maximum reduction in *Macrophomina* counts was achieved with MC+SI, which was significantly better than MC+NS. Treatment MR+SI was also significantly better than the control. In spite of soil moisture, the population of *M. phaseolina* in the control plots increased significantly, reaching 385 sclerotia g^{-1} soil after the harvest of clusterbean crop in 1998. In 1999, the *M. phaseolina* population decreased further in all amended plots (Table 3). The maximum reduction in pathogenic propagules was found in those treatments where amendments were combined with summer irrigation, but the reduction was also significantly greater when amendments were applied in July. Counts of *M. phaseolina* were highest, however, when only *Bacillus* sp. coated seeds were planted and in the control. There was a significant correlation (r=0.73) between the *M. phaseolina* population and dry root rot incidence.

Wilt incidence on cumin

Maximum wilt incidence (26.8%) was recorded in the unamended control plots (Table 4). A single summer irrigation, or soil amendment with residues either combined with summer irrigation or applied in July at the time of clusterbean planting, significantly reduced wilt incidence. Amending the soil with MR or MC in summer or with mustard oil-cake in July significantly reduced wilt incidence as compared with SI alone. Of the residues, mustard oil-cake was significantly more effective than mustard pod straw with a 34% greater reduction in wilt incidence, but differences relating to the time of application were not significant (Table 4).

Development of wilt on cumin

Wilt incidence after initiation varied between plots amended in June with one summer irrigation, and plots amended at the time of normal sowing in July. With treatments MC+SI and MR+SI, wilt symptoms were conspicuous after 7 days in the control, but thereafter incidence did not increase significantly till maturity (Fig. 2). By contrast, with MC+NS wilt incidence increased linearly until the end of the observation period. Plots

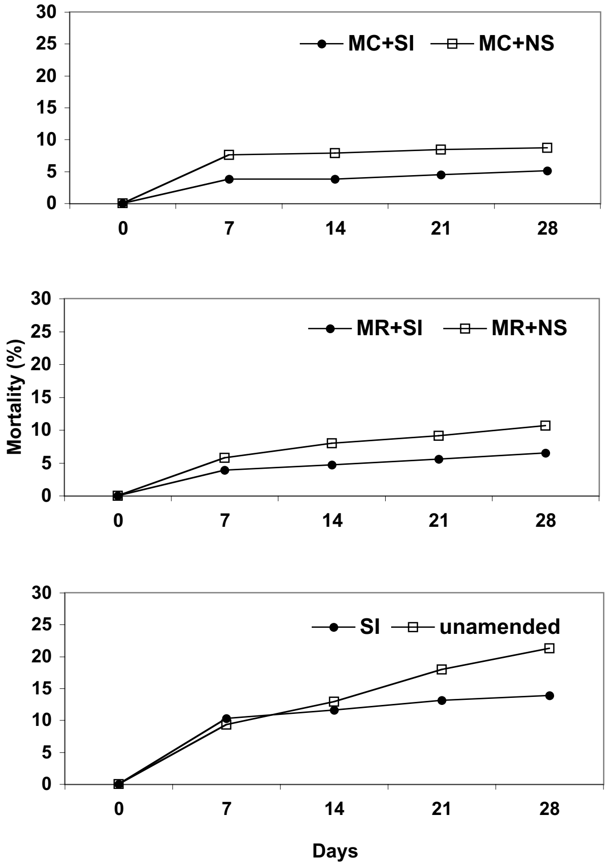

Fig . 1. Dry root rot of clusterbean in soils amended with mustard oil-cake (MC), mustard residue (MR), and with summer irrigation (SI), or without summer irrigation (NS, normal sowing). LSD (P=0.05): treatment 1.3; interval 0.8; treatment × interval 2.6.

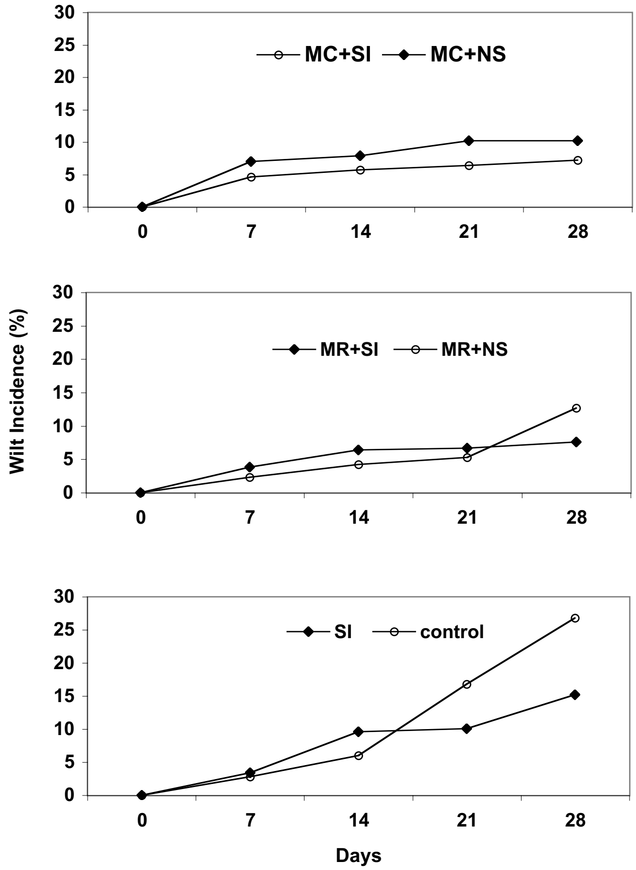

Fig. 2. Wilt incidence of cumin in soils amended with mustard oil-cake (MC), mustard residue (MR), and with summer irrigation (SI) or without summer irrigation (NS, normal sowing). LSD (P=0.05): treatment 5.2; interval 2.9; treatment × interval 8.9.

Table 4. Efficacy of cruciferous residues as soil amendment on population of *Fusarium oxysporum* f. sp. *cumini* and wilt incidence on cumin.

Treatment[a]	Wilt incidence		*Fusarium* population[b] ($\times 10^3$ cfu g^{-1} soil)	
	1999	2000	1999	2000
MC + SI	5.2 (13.2)[c]	7.2 (15.5)	8.5	4.2
MC + NS	12.1 (20.4)	10.2 (18.6)	11.2	8.9
MR + SI	8.6 (18.1)	7.8 (16.0)	10.4	4.9
MR + NS	11.4 (19.8)	12.7 (20.8)	12.5	9.3
SI	17.8 (24.9)	15.2 (22.9)	13.2	13.8
Control (unamended)	23.3 (28.8)	26.8 (31.1)	18.6	21.4
LSD (P=0.05)	1.5	1.1	1.7	1.4

[a] MC, mustard oil-cake (2.5 ton ha^{-1}); MR, mustard residues (2.5 ton ha^{-1}); NS, application of the amendment at the time of clusterbean sowing in July; SI, summer irrigation in June.
[b] Initial population was 17.5×10^3 cfu g^{-1} soil.
[c] Angular transformed values.

amended with mustard residues in July (MR+NS) followed a similar trend for the first 21 days, but showed a sudden increase in wilt incidence thereafter. With the two unamended treatments (SI and control), wilt began to increase soon after initiation, but after 14 days the increase in wilt was significantly greater in the control plots.

***Fusarium oxysporum* f. sp. *cumini* population**

The initial population of 17.5×10^3 g^{-1} soil of *Foc* was drastically reduced with all treatments including SI alone (Table 4). The reduction was significantly greater in the summer-irrigated amended plots than in the plots amended in July. However, counts of *Foc* increased in the control plots after the cumin harvest in March 1999. *Foc* was further reduced in amended plots after the second cumin crop in March 2000. The reduction was greatest in the plots with soil amendment + SI. An increase in population of *Foc* was significantly correlated (r=0.80) with an increase in wilt incidence.

Discussion

In the hot, arid climate where the tests took place, *Brassica* amendments combined with one summer irrigation reduced native populations of *M. phaseolina* and *Foc* as well as dry root rot on clusterbean in the rainy season, and wilt on cumin in the subsequent winter season in the same field.

In the test plots, soil temperatures in June were higher under moist conditions (without polyethylene mulching) than those observed in other parts of the world with a similar climate (Katan *et al*., 1980; Mihail and Alcorn, 1984; Abdel-Rahim *et al*., 1988; Abu Blan *et al*., 1998). In dry soils, soil moisture (summer irrigation) enhanced the sensitivity of sclerotia and chlamydospores to heat treatment (Lodha, 1995). Irrigation of heated soil may have diluted the fungistatic behaviour of the soil, stimulating germination of resting structures, which then are more vulnerable to heat conduction and microbial activity (Katan *et al*., 1976). In the presence of water, less energy is required to unfold the peptide chain of protein resulting in lower heat resistance (Precht *et al*., 1973). The greater reduction in counts of *Macrophomina* than *Foc* after one summer irrigation could be a result of increased microbial antagonism against *M. phaseolina*. In our tests, enhanced populations of *Aspergillus versicolor,* species of *Bacillus* and *Streptomyces* were found in heated amended soil. Germ-tubes and subsequent hyphae from germinating sclerotia of *M. phaseolina* are sensitive to bacteria and actinomycetes, and this results in lysis of the fungal cell walls (Kovoor, 1954).

In an earlier study it was found that amending the soil with urea-N and farmyard manure improved the effectiveness of summer irrigation in controlling *M. phaseolina* and *Foc* (Lodha, 1995). Substituting *Brassica* residues for these amendments in the present study further reduced these pathogenic agents. This reduction may be a cumulative effect of bio-toxic volatile compounds released during the decomposition of the residues at prevalent high soil temperatures (38–42°C) and subsequent microbial antagonism. Sulphur-containing volatile substances are toxic on *Aphanomyces euteiches* and *Rhizoctonia solani* from decomposing cabbage, a crucifer (Lewis and Papavizas, 1970; 1971). Allyl glucosinolate is one of the predominant glucosinolates in *Brassica* sp. and is generally converted to allyl isothiocyanate (AITC) at a pH of 4.0 or greater (Tollsten and Bergstrom, 1988; Duncan, 1991; Borek *et al*., 1994). AITC, a volatile compound, is as toxic to fungi as methyl isothiocyanate, an active ingredient in commercial soil fumigants (Lewis and Papavizas, 1971; Vaughan *et al*., 1993). The concentration of the AITC was found to be directly related to heating of the soil up to 45°C (Gamliel and Stapleton, 1993). However, isothiocyanates were not detected at low temperatures (Lewis and Papavizas, 1970; 1971). Moreover, in the present study, when *Brassica* residues were incorporated into the soil at high soil temperatures (41–42°C) pathogen and disease control was greater than when residues were incorporated in July, with soil temperatures at 32–37°C. The greater difference in temperature between amended and unamended soil in June than in July is a further indication of a greater exothermic reaction during the hot summer days. However, a considerable part of the reduction in pathogenic propagules even with a July amendment (compared to the unamended control) can be attributed to the release of certain other, less toxic volatile compounds.

Amendment of the soil with mustard oil–cake caused a significant reduction in populations of *M. phaseolina* and *Foc* (Sharma *et al*., 1995; Lodha *et al*., 1997) and in wilt incidence on cumin (Champawat and Pathak, 1988). A lower dose of this amendment in the present field experiment was almost equally effective; probably because the prolonged exposure of infested soil to dry heat exerted a weakening effect on pathogenic propagules (Lodha and Mawar, 2000). The high concentration of bio-toxic volatile compounds and nitrogen (5%) could explain why oil-cake provided better pathogen and disease control than the other residue amendments. Organic amendments containing nitrogen effectively control soil-borne pathogens (Rodrigues-Kabana *et al*., 1990; Lazarovits *et al*., 2000). Improved soil moisture in oil-cake amended soil further enhanced microbial antagonism, as reported earlier (Sharma *et al*., 1995). The ability of mustard pod residues to control pathogens and diseases, demonstrated in our study, is important in resource-deficient farming since this source of *Brassica* residue is cheaper and more readily available than oil-cake. The slow initial progress of both diseases in the summer-irrigated amended plots could be the combined result of a low population of pathogenic propagules and better soil-moisture conditions.

Statistically and economically significant control of dry root rot merely by coating clusterbean seeds with the *Bacillus* sp. is also of practical value in low-input sustainable agriculture (LISA). Greater control of dry root rot with this *Bacillus* sp. in the 1998 crop season was probably due to adequate soil moisture enhancing bacterial antagonism (Dhingra and Sinclair, 1975; Lodha, 1996). This bacterial activity decreased with decreasing soil moisture (Griffin and Quail, 1968). There was no significant improvement in disease control when *Brassica* residues were combined with the *Bacillus* coating of the seeds: this was most likely due to the concurrent operation of two different management strategies. However, coating will help in establishing the *Bacillus* sp. in amended soil for inducing suppressiveness.

The present study revealed a simple, practical and cost-effective means to control two major soil-borne pathogens in hot arid regions. Wheat-mustard-cumin rotation in the winter season ensures that *Brassica* residues are available in March. High temperatures available during the crop-free summer period give the residues time to release their bio-toxic volatile compounds. The decomposed materials also enrich the nutrient-deficient sandy soil and conserve moisture.

Literature cited

Abdel-Rahim M.F., M.M. Satour, K.Y. Mickeaill, S.A. El Eraki, A. Gristein, Y. Chen and J. Katan 1988. Effectiveness of soil solarization in furrow-irrigated Egyptian soil. *Plant Disease* 72, 143–146.

Abu-Blan H.A., W. Abu-Gharbieh and F. Shatat, 1998. Long-term effect of soil solarization on density levels of *Fusarium solani* in established fruit tree orchards. In: *Soil Solarization and Integrated Management of Soil-borne Pests* (J.J. Stapleton *et al*., ed.), *FAO Plant Production and Protection Paper* 147, 121–130.

Angus J.F., P.A. Gardner, J.A. Kirkegaard and J.M. Desmarchelier, 1994. Biofumigation: iso-thiocyanates released from brassica roots inhibit growth of the take all fungus. *Plant and Soil* 162, 107–112.

Borek V., M.J. Morra, P.D. Brown, and J.P. McCaffrey, 1994. Allelochemicals produced during sinigrin decomposition in soil. *Journal of Agriculture and Food Chemistry* 42, 1030–1034.

Brown P.D., M.J. Moora, J.P, Mccaffrey, D.L., Auld and L. Williams, 1991. Allelochemicals produced during glucosinolate degradation in soil. *Journal of Chemical Ecology* 17, 2021–2034.

Champawat R.S. and V.N. Pathak, 1988. Role of nitrogen, phosphorus and potassium fertilizers and organic amendments in cumin (*Cuminum cyminum*) wilt incited by *Fusarium oxysporum* f. sp. *cumini*. *Indian Journal of Agricultural Sciences* 58, 728–730.

Dhingra O.D. and J.B. Sinclair, 1975. Survival of *Macrophomina phaseolina* sclerotia in soil: effect of soil moisture: carbon:nitrogen ratios, carbon sources and nitrogen concentrations. *Phytopathology* 65, 236–240.

Duncan A, 1991. Glucosinolates. In: *Toxic Substrates in Crop Plants*. (J.P.Mello, C.M. Duffus, J.H. Duffus, ed.) Cambridge, UK, Royal Society of Chemistry, 127–147.

Gamliel A. and J.J. Stapleton, 1993. Characterization of antifungal volatile compounds evolved from solarized soil amended with cabbage residue. *Phytopathology* 83, 899–905.

Griffin D.M. and G. Quail, 1968. Movement of bacteria in moist particulate systems. *Australian Journal of Biological Sciences* 21, 579–582.

Katan J., A. Greenberger, H. Alon and A. Grinstein, 1976. Solar heating by polyethylene mulching for the control of diseases caused by soil-borne pathogens. *Phytopathology* 66, 683–688.

Katan J., I. Rotem, Y. Finkel and J. Daniel, 1980. Solar heating of the soil for the control of Pink root and other soil borne diseases in onions. *Phytoparasitica* 8, 39–50.

Keinath A.P., 1996. Soil amendment with cabbage residue and crop rotation to reduce gummy stem blight and increase growth and yield of watermelon. *Plant Disease* 80, 564–570.

Kovoor A.T.A., 1954. Some factors affecting the growth of *Rhizoctonia bataticola* in soil. *Journal of Madras University* 24, 47–52.

Lazarovits G., M. Tenuta and K.L. Conn, 2000. Utilisation of high nitrogen and swine manure amendments for control of soil-borne diseases: efficacy and mode of action. *Acta Horticulturae* 532, 59–64.

Lewis J.A. and G.C. Papavizas, 1970. Evolution of volatile sulfur containing compounds from decomposition of crucifers in soil. *Soil Biology and Biochemistry* 2, 239–246.

Lewis J.A. and G.C. Papavizas, 1971. Effect of sulfur containing volatile compounds and vapors from cabbage decomposition on *Aphanomyces euteiches*. *Phytopathology* 61, 208–214.

Lodha S., 1995. Soil solarization, summer irrigation and amendments for the control of *Fusarium oxysporum* f. sp. *cumini* and *Macrophomina phaseolina* in arid soils. *Crop Protection* 14, 215–219.

Lodha S., 1996. Influence of moisture conservation techniques on *Macrophomina phaseolina* population, dry root rot and yield of clusterbean. *Indian Phytopathology* 49, 342–349.

Lodha S., G.K. Gupta and S. Singh, 1986. Crop disease situation and some new records in Indian arid zone. *Annals of Arid Zone* 25, 311–320.

Lodha S., B.K. Mathur and K.R. Solanki, 1990. Factors influencing population dynamics of *Macrophomina phaseolina* in arid soil. *Plant and Soil* 125, 75–80.

Lodha S. and R. Mawar, 2000. Utilizing solar heat for enhancing efficiency of cruciferous residues for disinfesting soilborne pathogens from aridisols. *Acta Horticulturae* 532, 49–52.

Lodha S., S.K. Sharma and R.K. Aggarwal, 1997. Solarization and natural heating of irrigated soil amended with cruciferous residue and improved control of *Macrophomina phaseolina*. *Plant Pathology* 46, 186–190.

Meyer W.A., J.B. Sinclair and M.N. Khare, 1973. Biology of *Macrophomina phaseolina* in soil studied with selective media. *Phytopathology* 63, 613–620.

Mayton H.S., C. Olivier., S.F. Vaughan, and R. Loria, 1996. Correlation of fungicidal activity of Brassica species with allyl isothiocyanate production in macerated leaf tissue. *Phytopathology* 86, 267–271.

Mihail J.D. and S.M. Alcorn, 1984. Effect of soil solarization on *Macrophomina phaseolina* and *Sclerotium rolfsii*. *Plant Disease* 68, 156–159.

Mojtahedi H., G.S. Santo., J.H. Wilson and A.N. Hang, 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. *Plant Disease* 77, 42–46.

Muehlchen A.M. and J.L. Parke, 1990 Evaluation of crucifer green manure for controlling Aphanomyces root rot of peas. *Plant Disease* 74, 651–654.

Olsen S.R. and L.A. Dean, 1965. Phosphorus. In: *Methods of Soil Analysis*. Part 2 (C.A. Black ed.) Agronomy Monographs No. 9. American Society of Agronomy, Madison, WI, USA, 1035–1049.

Papavizas G.C., 1967. Evaluation of various media and antimicrobial agents for isolation of *Fusarium* from soil. *Phytopathology* 57, 848–852.

Precht H., J. Christophersen, H. Hensel and W. Lartcher, 1973. *Temperature and Life*. Springer, Berlin, Germany, 330 pp.

Ramirez-Villapudua J. and D.E. Munnecke, 1987. Control of cabbage yellows (*Fusarium oxysporum* f. sp. *conglutinans*) by solar heating of field soil amended with dry cabbage residues. *Plant Disease* 71, 217–221.

Ramirez-Villapudua J. and D.E. Munnecke, 1988. Effects of solar heating and soil amendments of cruciferous residues on *Fusarium oxysporum* f. sp. *conglutinans* and other micro-organisms. *Phytopathology* 78, 289–295.

Rodriguez-Kabana R., D. Boube and R.W. Young, 1990. Chitinous materials from blue crab for control of root rot nematode: II. Effect of soybean meal. *Nematropica* 20, 153–168.

Sharma S.K., R.K. Aggarwal and S. Lodha, 1995. Population changes of *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *cumini* in the oil-cake and crop residue amended sandy soils. *Applied Soil Ecology* 2, 281–284.

Snedecor G.E. and W.J. Cochran, 1967. Statistical Methods. Oxford & IBH Publishing Co., Calcutta, India, 258–298 pp.

Tollsten L. and G. Bergstrom, 1988. Headspace volatiles of whole plants and macerated plant parts of *Brassica* and *Sinapis*. *Phytochemistry* 27, 4013–4018.

Vaughan S.F., G.F. Spencer and R. Loria, 1993. Inhibition of *Helminthosporium solani* strains by natural isothiocyanates. *American Potato Journal* 75, 852–853.

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