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RESEARCH PAPERS

Factors influencing population dynamics of *Fusarium oxysporum* f. sp. *cumini* in the presence and absence of cumin crop in arid soils

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Summary. In a 16-month field experiment, the effects of fungi, bacteria, actinomycetes, total microbial population, soil moisture and soil temperature on the population dynamics of *Fusarium oxysporum* f. sp. *cumini* were studied in soils with or without a cumin (*Cuminum cyminum* L.) crop at different soil depths. The greatest fungal population and survival in cumin-planted soil were recorded at 0–5 cm depth, but the population density tended to decline progressively with increasing soil depth. The population of *Fusarium* increased progressively with continuous cultivation of cumin for two seasons, but remained almost stationary in fallow soil without a host. Correlations and path coefficient analyses were carried out to determine the role of individual factors influencing the population of *F. o.* f. sp. *cumini*. In soil planted with cumin, there were significant positive correlations of the *Fusarium* population with maximum soil temperature (r=0.50), bacteria (r=0.51) and total microbial population (r=0.53) at 0–5 cm soil depth. In path coefficient analyses, total bacteria had the highest direct effect on the *Fusarium* population, followed by microbial population and maximum soil temperature. However, in the soil not planted with a cumin crop, none of the studied factors had significant correlations with the *Fusarium* population at any soil depth,.

Key words: *Cuminum cyminum*, soil moisture, soil temperature, chlamydospore, microbial population.

Introduction

Cumin (*Cuminum cyminum* L.), one of the oldest spices, is grown extensively in the arid and semi-arid regions of India in the winter season (November–March) under assured irrigation on more than 300,000 ha (Singhal, 1999). It is also cultivated in Argentina, Bangladesh, Bulgaria, Egypt, Pakistan and Turkey. Diseases and improper soil fertilization are the two major reasons for low productivity. In the arid regions of India, approximately 40% of total yield loss is due to a wilt caused by *Fusarium oxysporum* f. sp. *cumini* (Lodha *et al*., 1986). Due to a high incidence of this fungus in conducive soils, farmers are often compelled to abandon cumin cultivation altogether after 3 successive years of cropping. In the absence of a wilt-resistant genotype, the only alternative is to use physical and biological means of control (Lodha, 1995; Mawar and Lodha, 2002). However, a knowledge of the quantitative and

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qualitative aspects of inoculum dynamics is necessary to improve the efficacy of such methods of controlling a soil-borne disease. Studies of population dynamics over time and space have two basic goals: a) to identify recurring patterns in the dynamics of a population; b) to understand how such patterns are generated.

Nash and Synder (1962), Burke *et al*. (1972) and Dryden and Alfen (1984) studied the distribution of *Fusarium solani* f. sp. *phaseolina* in the soil and found that the fungus was distributed uniformly throughout the ploughed layer (0–30 cm) and that the fungal population tended to decrease with soil depth as the bulk density of the soil increased. A knowledge of the survival and population dynamics of *F. oxysporum* in a field soil in the presence of other micro-organisms is important because those other micro-organisms may render the soil suppressive of *F. oxysporum*. Hopkins *et al*. (1987) reported that a soil became suppressive of *Fusarium* wilt of watermelon when a monoculture of a particular watermelon cultivar was grown on it. Larkin *et al.,* (1993) studied the population dynamics and chlamydospore germination of *F. o.* f. sp. *niveum*, as well as the colonization of watermelon roots by this fungus in relation to other micro-organisms in the soil and found that fungal populations remained stable in monoculture soils over a 6-month period, though they increased somewhat initially, and remained at higher levels when added to conducive soils.

At present, information on *F. o.* f. sp. *cumini* (*Foc*) in relation to other micro-organisms in the soil is lacking. The present investigation was undertaken to study how various biotic and abiotic factors influence the population dynamics of *Foc* in arid soils with and without a cumin crop.

Materials and methods

Description of the test site

The experiment was conducted at the Central Arid Zone Research Institute, Jodhpur, India, during 1999–2001 on a field containing loamy sand soil (85% sand, 8.9% clay, 5.5% silt) with 0.03% total nitrogen; 0.25% organic carbon; 9 g g^{-1} Olsen-P at pH 8.1; electrical conductivity 0.88 d Sm^{-1} (soil:water ratio 1:2.5); bulk density 1.56 g cm^{-3} and 10.4% moisture holding capacity.

Inoculum preparation

A virulent pathogenic strain of *Foc*, isolated from infected roots of cumin, was multiplied in bulk on a 5% corn meal:sand medium for 15 days at 30±2°C. The spores of *Foc* (conidia and chlamydospores) so produced were passed through a 300 mesh (53 μm) sieve. The infected material left in the sieve was first examined under the microscope to ensure that it contained only chlamydospores, and was then mixed with several kg of field soil to prepare *Foc*-infected soil. The infected soil was left for 10 days in bright sunlight (37–41°C) for further stabilization before use.

Survival of *Foc* and other microbes

For survival studies, experimental plots (1×1 m) were artificially infested with *Foc* inoculum in the second week of November 1999. Inoculum multiplied as above was mixed with 2 kg of field soil per plot and ploughed uniformly to a depth of 30 cm with a hand spade. The plots were of two types: 1. soil planted with cumin and 2. fallow soil. Each soil treatment was replicated thrice. Initial samples were taken before sowing at 0–25 cm depth. The *Foc* population was determined by serial dilution 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 were used for each sample. Cumin seeds of the cv. RZ19 were sown on December 4, 1999 and on November 25, 2000 in the planted plots. These plots were watered regularly during crop growth; the fallow plots were not watered. Weeds were removed by hand soon after emergence. Three soil samples were collected randomly from each replication with a tubular probe (2.5 cm) on the 12th–16th of each month at 3 different depths, 0–5 cm, 6–15 cm and 16–25 cm beginning from December 1999 to March 2001 until harvest of the cumin crop. Proper care was taken to avoid any injury to the growing plants. Half of the soil samples were used for gravimetric moisture determination, while the remaining half was air-dried and processed for microbial analysis. Soil-moisture data were calculated to volumetric water content. Total microbial populations were determined by serial dilutions on Peptone-PCNB medium (*Foc*), Martin's Rose Bengal agar (fungi), Thornton's agar (bacteria)

and Ken-Knight agar (actinomycetes). Six Petri dishes (90 mm) per medium were used to count each category from one soil sample. The means of six Petri dishes were considered one estimate per replicate per soil treatment (cumin/fallow). Frequently, selected colonies were lifted, multiplied on Potato dextrose broth to establish pathogenicity on cumin seedlings. Minimum and maximum soil temperatures were recorded at all three depths at 2 p.m and 4 p.m. Weekly meteorological data were recorded throughout the test period at the agro-meteorological observatory of the Institute located some 200 m from the test site.

Statistical analysis

Correlation coefficients were calculated and multiple regression equation (step-wise) were constructed in relation to microbial population, soil temperature and soil moisture, to study factors influencing the population dynamics of *Foc* in the presence and absence of a cumin crop (Snedecor and Cochran, 1967). Path coefficient analysis was carried out according to the method given by Deway and Lu (1959). A path coefficient is a standardized partial-regression coefficient; as such it measures the direct influence of one variable upon another and permits the separation of the correlation coefficient into components of direct and indirect effects. Whereas correlation simply measures mutual association without regard to causation, the path coefficient analysis specifies the causes and measures their relative importance.

Results

Soil temperature and moisture

The temperature in the top soil layer was always higher than at the other depths (Fig. 1a). In the summer months it reached 56°C in May, and after a decline in July–August, increased again to 50°C in October. At a depth of 15 cm, temperature ranged between 27.8 and 49.1°C and remained always 4.1–14.4°C lower than that in the top soil layer (Fig. 1b). At a depth of 25 cm, the soil temperature was invariably higher at 4 p.m. than at 2 p.m, and was 2.7–11.1°C lower than at a 15 cm depth, ranging from 21.2 to 43.4°C (Fig. 1c).

In general, the lowest soil moisture was at 0–5 cm soil depth, but it increased with increasing soil depth throughout the experimental period with or without a cumin crop (Fig. 2 and 3).

Population dynamics of *Foc* and other microbes

Plots planted with cumin

The population density of *Foc* was greatest at 0–5 cm depth, and tended to decline with increasing soil depth. Population density ranges were 2.3–15×10^3 cfu g^{-1} at 0–5 cm soil depth (average 7.9×10^3 cfu g^{-1}), 2.3–6.6×10^3 cfu g^{-1} at 6–15 cm soil depth (average 4.9×10^3 cfu g^{-1}) and 2.3–4.3×10^3 cfu g^{-1} at 16–25 cm soil depth (average 2.9×10^3 cfu g^{-1}) (Fig. 2). The initial population of 2.3×10^3 cfu g^{-1} gradually increased in soil planted with cumin, reaching 8.6×10^3 cfu g^{-1} soil in April 2000 after the harvest of the crop. The population did not fluctuate on fallow soil from April to November, remaining in the range of 8.3–9×10^3 cfu g^{-1} soil. After sowing of the second cumin crop in November 2000, *Foc* populations further increased and reached 15×10^3 cfu g^{-1} soil by the end of the second season. There was a 6-fold increase in the population of *Foc* in the top soil layer of plots planted with two successive cumin crops.

Populations of bacteria, fungi and actinomycetes followed a trend similar to that of *Foc* during the growth of cumin plants in the first season at 0–5 cm soil depth, but the greatest increase at this depth was that of the actinomycetes (Fig. 2a). Unlike *Foc*, these microbes tended to increase in fallow soil from April to November, after an initial decline in summer. During the second cumin crop, there was a sharp decline in actinomycetes, but populations of individual groups of microbes were generally higher after the harvest of second crop than after the first. *Foc* populations were significantly correlated with maximum soil temperature (r=0.50), bacteria (0.51) and the microbial population (0.53). Path coefficient analysis revealed that only maximum soil temperature and total bacteria had a maximum positive direct effect on *Foc* (Table 1). But the positive effect of bacteria was nullified by the total microbial population, which had a maximum negative indirect effect.

A similar upward trend in the *Foc* population size was also found at the 6–15 cm soil depth during crop seasons, and even in the fallow field (Fig. 2b). But the increase in these cases was significantly less than that at the top layer. During first cumin season, the populations of all three groups

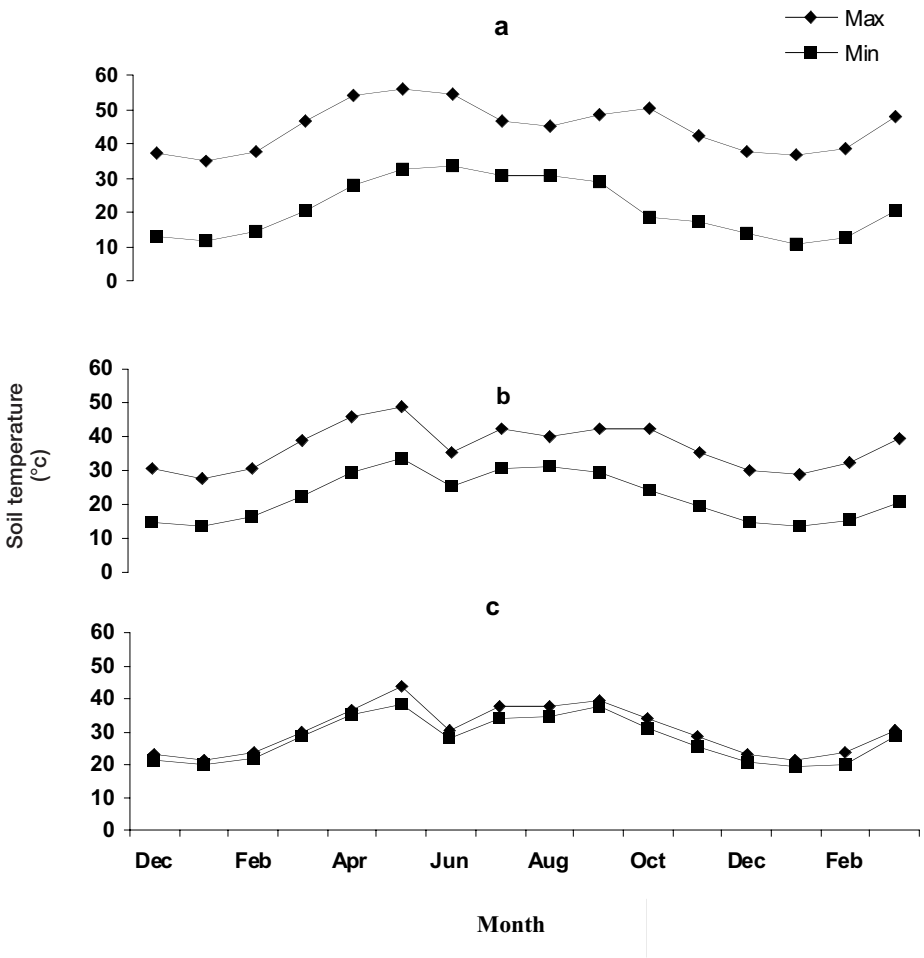

Fig. 1. Soil temperatures recorded during the test period at soil depths of 5 cm (a), 15 cm (b) and 25 cm (c).

of microbes also increased, with the greatest increase in total fungi. However, in the fallow field total actinomycetes and bacteria increased considerably at this depth, but then remained almost stationary even after the second cumin crop, except in case of total bacteria, which declined sharply.

Variations in the *Foc* population were significantly correlated with maximum soil temperature (r=0.64), minimum soil temperature (0.55) and total fungi (0.76), while there was a significant negative correlation of the *Foc* population with soil moisture (-0.59). In path coefficient analysis, maximum soil temperature had the highest direct effect on the *Foc* population followed by total microbial population, while total bacteria and minimum soil temperature had the greatest negative direct effect (Table 1). The greatest negative indirect effect of the microbial population was also that of total bacteria.

At the 16–25 cm soil depth, the rate of increase in the *Foc* population in the field with the first and second cumin crop was slower than that at the two lesser depths. Among microbes there was a dramatic increase in total fungi and bacteria, but the actinomycete population remained almost stationary after the first cumin harvest (Fig. 2c). A sudden upsurge in actinomycetes came at the end of the test in the fallow field, contrasting with a decline in total fungi and bacteria. However, this upsurge did not occur after the second cumin har-

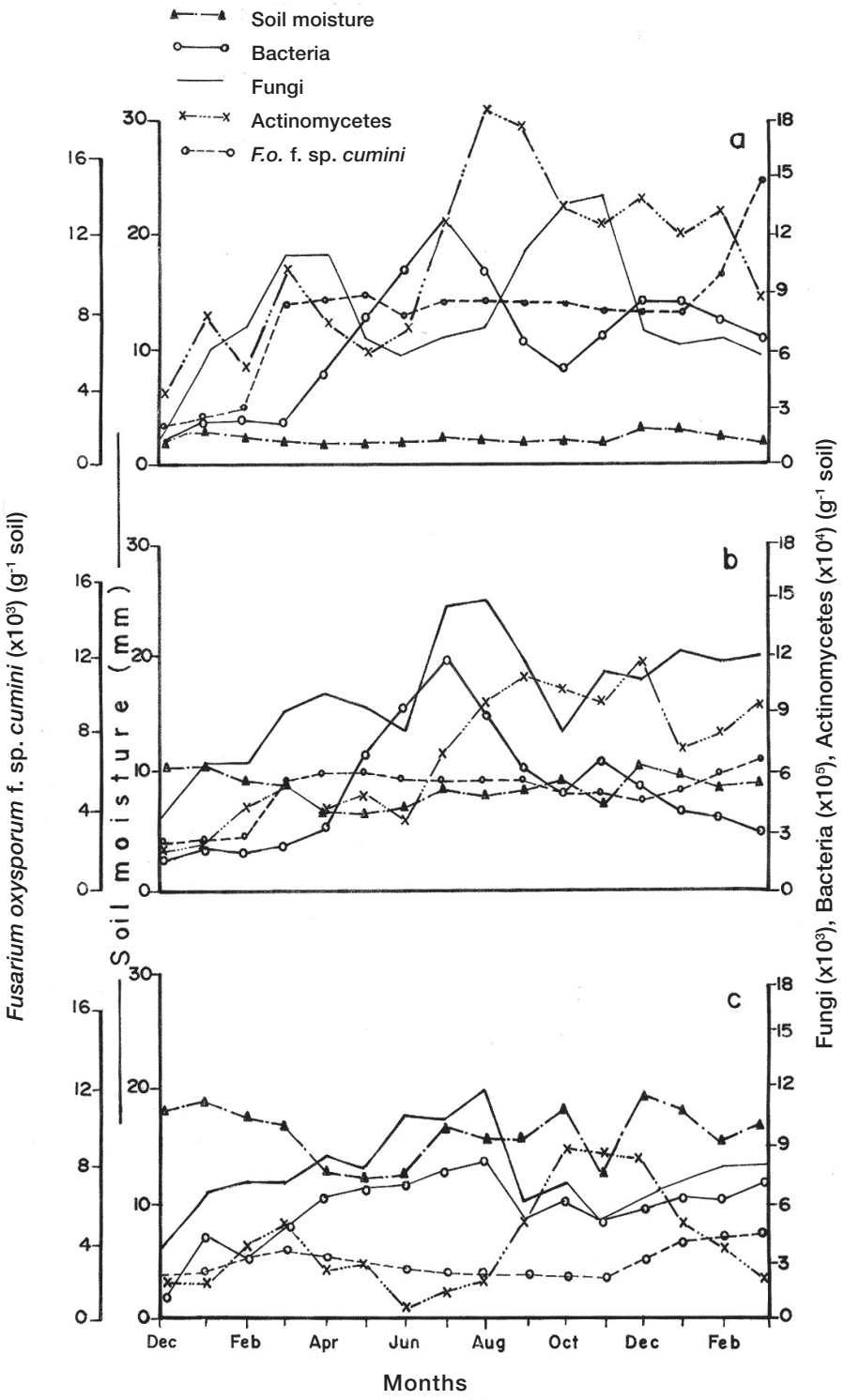

Fig. 2. Mean monthly levels of soil moisture, and presence of *Fusarium oxysporum* f. sp. *cumini,* and other microbial populations at different soil depths, in fields planted with cumin (a) at 0–5 cm soil depth; (b) at 6–15 cm, and (c) at 16–25 cm.

Table 1. Direct and indirect effects of certain factors influencing *Fusarium oxysporum* f. sp. *cumini* populations at different soil depths in fields planted with cumin.

Factor		Soil temperature		Soil moisture	Bacteria	Fungi	Actinomycetes	Microbial population
		Max	Min					
0–5 cm								
Soil temperature	Max	2.06	1.76	-1.61	0.61	0.08	0.58	0.66
	Min	-1.73	-2.00	1.65	-1.06	-0.31	-0.21	-1.07
Soil moisture		0.29	0.30	-0.37	0.07	0.03	0.09	0.07
Bacteria		7.03	12.43	-4.53	23.81	13.08	0.39	23.68
Fungi		-0.02	-0.02	0.02	-0.04	-0.08	-0.05	-0.04
Actinomycetes		-1.45	-0.95	-0.88	-2.71	-6.17	-8.92	-3.54
Microbial population		-7.59	-12.47	4.91	-23.59	-14.25	- 2.89	-23.72
Residual factor = 0.41								
6–15 cm								
Soil temperature	Max	0.91	0.84	-0.61	0.37	0.30	0.14	0.38
	Min	-0.71	-0.77	0.54	-0.49	-0.27	-0.08	-0.48
Soil moisture		0.19	0.21	-0.29	0.15	0.08	-0.02	0.14
Bacteria		-35.47	54.89	42.87	-85.23	-44.12	-25.87	-84.80
Fungi		-0.02	- 0.02	0.02	-0.04	-0.08	-0.05	-0.04
Actinomycetes		-1.45	-0.95	-0.88	-2.71	-6.17	-8.92	-3.54
Microbial population		37.19	56.15	-42.25	88.38	51.03	35.28	88.82
Residual factor = 0.39								
16–25 cm								
Soil temperature	Max	-1.13	-1.12	0.65	-0.63	-0.54	0.16	-0.61
	Min	0.47	0.47	-0.26	0.25	0.22	-0.07	0.24
Soil moisture		0.04	0.04	-0.08	0.03	0.02	-0.01	0.02
Bacteria		-42.99	-40.38	28.94	-76.70	-62.58	11.61	-75.88
Fungi		-0.73	-0.70	0.51	-1.24	-1.52	0.79	-1.14
Actinomycetes		1.80	1.86	-2.77	1.83	6.34	-12.12	0.06
Microbial population		42.25	39.53	-26.90	76.63	58.10	-0.42	77.46
Residual factor = 0.82								

vest. None of the studied factors were significantly correlated with the *Foc* population. In path analysis too, the highest negative direct effect of total bacteria was counterbalanced by the positive direct effect of the microbial populations. As a result, a high residual factor (0.82) was calculated at 16–25 cm soil depth.

To quantify the contribution of each factor on the *Foc* population, regression analysis was carried out at different soil depths. The multiple regression equations after eliminating non-significant factors so obtained were as follows ($P<0.05$):

0–5 cm: $\hat{Y} = -25.02 + 0.92x_1 - 0.64x_2 + 29.21x_4 + 0.80x_5 + 2.63x_6 - 2.89x_7$ ($R^2 = 0.81$)

6–15 cm: $\hat{Y} = 0.83 + 0.18x_1 - 0.14x_2 - 0.30x_3 - 32.27x_4 - 3.24x_6 + 3.23x_7$ ($R^2 = 0.55$)

16–25 cm: $\hat{Y} = 5.21 - 0.07x_1 - 0.02x_3 - 30.66x_4 - 0.54x_5 - 3.20x_6 + 3.11x_7$ ($R^2 = 0.69$)

Where $\hat{Y}$, x_1, x_2, x_3, x_4, x_5, x_6 and x_7 represent *Foc* size, maximum soil temperature, minimum soil temperature, soil moisture, total bacteria, total fungi, total actinomycetes and total microbial population, respectively. At soil depths of 0–5, 6–15 and 16–25 cm, therefore, the test factors account-

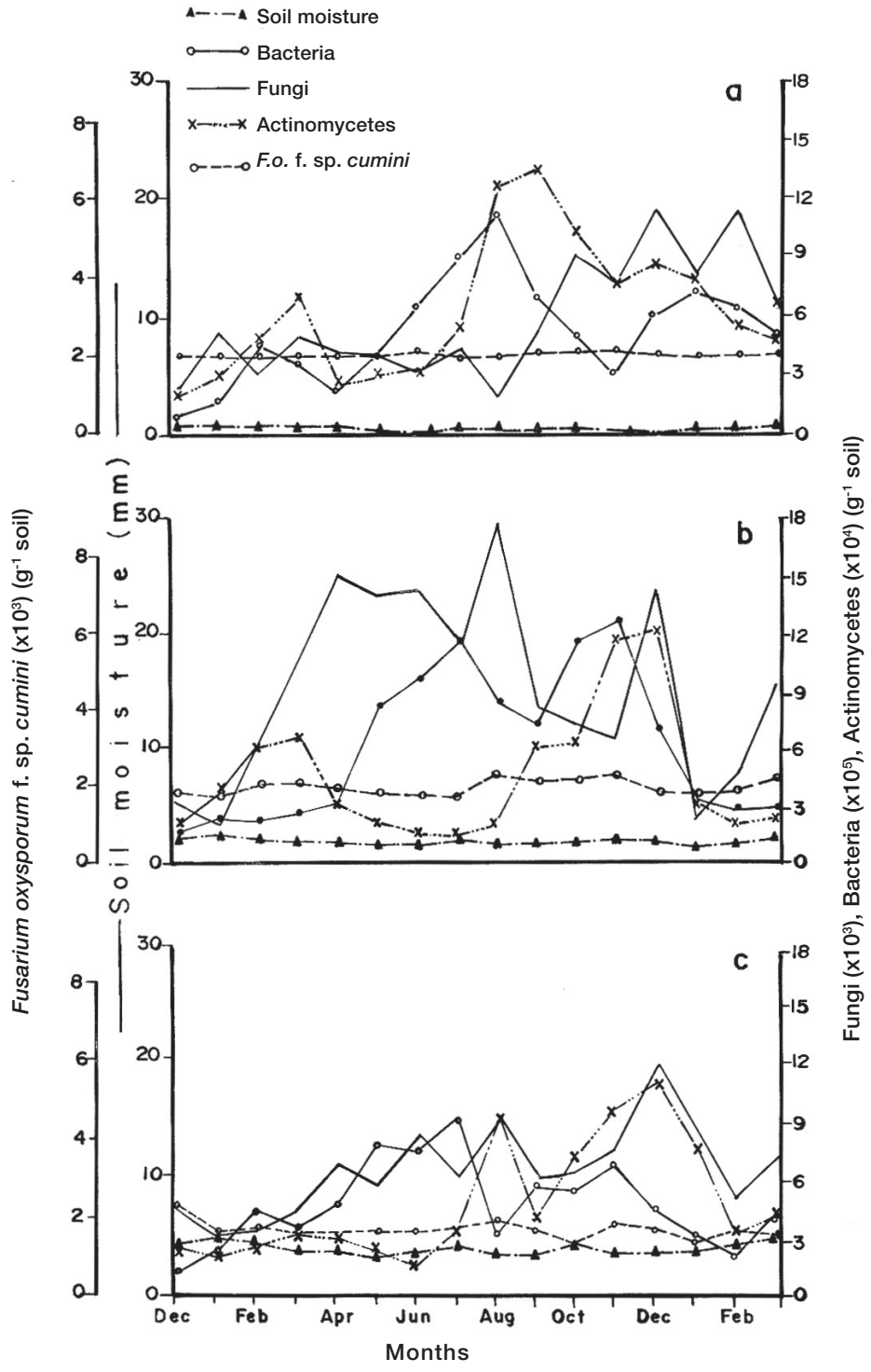

Fig. 3. Mean monthly levels of soil moisture, and presence of *Fusarium oxysporum* f. sp. *cumini* and other microbial populations at different soil depths in fallow fields (a) at 0–5 cm soil depth; (b) at 6–15 cm, and (c) at 16–25 cm.

ed for almost 81, 55 and 69% respectively of variations in the *Foc* population.

Plots left fallow

In the fallow plots, the population of *Foc* also decreased with increasing soil depth. At a depth of 0–5 cm, *Foc* density was 2.2–2.4×10^3 cfu g^{-1} (average 2.3×10^3 cfu g^{-1}) (Fig. 3a). At a 6–15 cm depth it was 1.8–2.3×10^3 cfu g^{-1} and at a 16–25 cm depth 1.4–2.3×10^3 cfu g^{-1}, with averages of 1.9 and 1.5×10^3 cfu g^{-1} respectively (Fig. 3b and c). In general, these population ranges were considerably lower than those in plots planted with cumin. At soil depths of 0–5 and 6–15 cm, the *Foc* population remained almost stationary throughout the experimental period, but at the lowest depth it declined from 2.3×10^3 cfu g^{-1} to 1.6×10^3 cfu g^{-1} within a month and remained stationary thereafter.

Unlike *Foc* levels, the populations of total bacteria, fungi and actinomycetes at 0– 5 cm soil depth varied in different months (Fig. 3a). There was a sudden upsurge in total bacteria and fungi at this depth during the rainy season months, which declined in subsequent months, but at the end of the test in March the final population of all three groups of microbes was still two or three times what it had been at the start. None of the factors was significantly correlated with *Foc* population levels. In path coefficient analysis, the minimum soil temperature had the greatest negative direct effect on the *Foc* population, followed by maximum soil temperature (Table 2). A high residual factor (0.80) was calculated for this depth.

At a 6–15 cm soil depth fluctuations in all three groups of microbes were much like those in the topsoil layer. Total bacteria and total fungi were again at maximum levels during the rainy season months, but total actinomycetes were highest in the winter months (Fig. 3b). However, a 200% increase in the total bacteria and fungi was calculated at the end of the experiment, while total actinomycetes remained almost at their initial level. No correlation of any of these factors with the *Foc* population was found. In path coefficient analysis, total bacteria had the highest direct effect on the *Foc* population while the total microbial population had the highest negative direct effect (Table 2). At this depth the residual factor was also high (0.75).

At the lowest soil depth (16–25 cm), relatively high soil moisture led to an increase in total bacterial and fungal populations, so that in the rainy season the total bacterial population increased fourfold. The total actinomycetes population remained stationary during this period (Fig. 3c), but in the later winter months it suddenly increased, and in the final samples, populations of all the three groups of microbes were significantly higher than they had been at the start of the test. At this depth also, none of the studied factors were significantly correlated with the *Foc* population. In path coefficient analysis, total bacteria had the highest negative direct effect on the *Foc* population, followed by the total microbial population. However, maximum indirect effects of total bacteria and microbial populations were also produced by microbial population and total bacteria respectively. This depth also had high residual factor (0.93). The multiple regression equations (step-wise) were (P= <0.05):

0–5 cm: $\hat{Y} = -2.22 - 0.04x_1 - 0.03x_3 - 1.72x_4 - 0.02x_5 - 0.15x_6 + 0.17x_7$ (R^2=0.57)

6–15 cm: $\hat{Y} = -1.08 + 0.01x_1 + 0.18x_3 + 0.32x_4 + 0.01x_5 + 0.05x_6 - 0.03x_7$ (R^2=0.40)

16–25 cm: $\hat{Y} = -2.33 + 0.02x_1 - 0.02x_2 - 0.10x_3 + 0.05x_4 + 0.01x_5 - 0.01x_7$ (R^2=0.13)

Thus at the 0–5 and 6–15 cm soil depths almost 57 and 40% of all variations in the population of *Fusarium* were accounted for by the test factors, whereas at a depth of 16–25 cm these factors accounted for only 13% of variation.

Discussion

Factors influencing the population dynamics of *Foc* in soils with and without a cumin crop are vital to understanding the ecology of this important *Fusarium* in aridisols. A single cumin crop led to a 2.5-fold increase in *Fusarium,* a second crop to a 3.7-fold increase. This explains why wilt incidence increases with the number of years when a susceptible crop has been grown in a given field: each year the *Foc* population in the field increases and this increase is correlated with a rise in wilt incidence (Mawar and Lodha, 2002). Lodha (1995) also reported a 1.4-fold increase in *Foc* population levels after two successive crops of cumin. The still greater increases found in the present study are probably to be attributed to the high initial inocu-

Table 2. Direct and indirect effects of certain factors influencing *Fusarium oxysporum* f. sp. *cumini* populations at different soil depths in fallow fields.

Factor		Soil temperature		Soil moisture	Bacteria	Fungi	Actinomycetes	Microbial population
		Max	Min					
0–5 cm								
	Max	0.75	0.62	-0.09	0.09	-0.06	-0.08	0.08
Soil temperature								
	Min	1.10	1.32	0.27	-0.52	0.07	0.58	-0.46
Soil moisture		0.01	0.01	-0.07	0.00	-0.01	-0.00	0.00
Bacteria		0.04	0.14	-0.03	0.35	0.22	-0.04	0.35
Fungi		0.06	0.00	-0.01	-0.04	-0.07	-0.03	-0.04
Actinomycetes		0.01	0.05	-0.00	-0.01	-0.05	-0.13	-0.02
Microbial population		0.02	0.09	-0.02	0.26	0.17	0.05	0.02
Residual factor = 0.80								
6–15 cm								
	Max	0.21	0.19	-0.10	0.09	0.13	-0.04	0.09
Soil temperature								
	Min	0.21	0.23	-0.14	0.12	0.17	-0.06	0.12
Soil moisture		-0.09	0.11	0.19	-0.08	-0.09	0.01	-0.08
Bacteria		-2.60	3.18	-2.75	6.08	2.31	1.51	6.06
Fungi		0.16	0.19	-0.13	0.10	0.27	-0.00	0.10
Actinomycetes		-0.18	-0.25	0.07	0.22	-0.01	0.90	0.26
Microbial population		-2.67	-3.25	2.85	-6.29	-2.53	-1.89	-6.31
Residual factor = 0.75								
16–25 cm								
	Max	0.77	0.76	-0.37	0.04	-1.48	-0.20	0.45
Soil temperature								
	Min	-0.83	-0.84	0.41	-0.51	1.27	0.22	-0.48
Soil moisture		0.13	0.13	-0.28	-0.12	0.09	-0.00	0.09
Bacteria		6.07	5.86	-3.28	-20.16	9.58	0.56	9.50
Fungi		0.00	0.00	-0.02	-0.21	0.02	0.08	0.03
Actinomycetes		-0.31	-0.32	0.01	1.06	0.07	1.20	0.22
Microbial population		-5.94	-5.72	3.39	19.77	-9.98	-1.91	-10.06
Residual factor = 0.93								

lum levels (the most important factor affecting *Fusarium* wilt) and to subsequent increases in the fungal population. In general, a higher initial inoculum level of a soil-borne wilt pathogen hastens wilt onset and increases severity (Elmer and Lacy, 1987; Ben-Yephet *et al*., 1996). Hall and Philips (1992) likewise found that after seven successive bean crops the population density of *F. solani* f. sp. *phaseoli* increased from <1.7 cfu g^{-1} to about 660 cfu g^{-1}, a more than 300-fold increase.

Since the highest *Foc* levels were in the topmost soil layer, and since the fungus population size was positively correlated with the highest soil temperature and with total bacteria in the present study, it is clear that there was less competition from actinomycetes and total fungi, and this enhanced the survival of *Foc* propagules. Soil bacteria can lyse the hyphae (Huber and Anderson, 1966) and may stimulate the formation of new chlamydospores (Ford and Trujillo, 1967). A release of chlamydospores from decaying infected tissues, a low soil moisture and less organic matter, with consequently smaller population of some microbes competing with *Foc* propagules could account for the greater density of *Foc* in the top layer of soil. Burke *et al*. (1972), on *F. solani* f. sp. *phaseoli*, re-

ported that the density of this fungus also tended to decline with soil depth.

In aridisols, the highest density and survival of *Macrophomina phaseolina* also occurred at 0–5 cm soil depth (Lodha *et al*., 1990). However, the positive correlation of *Foc* density with maximum as well as minimum soil temperature at a 6–15 cm soil depth in cumin-planted fields accounted for earlier findings that wilt incidence was greatest between the third week of January and the first week of February, since it is precisely at this period that the roots reach a depth of 10–15 cm (Mathur and Mathur, 1966). The negative correlation of soil moisture with *Foc* propagules at this depth suggested that soil moisture induced changes in the soil microbial population, and that this in turn affected the *Foc* propagules. The low residual factor at both these soil depths (0–5 and 6–15 cm) suggested that no other factor was of greater importance in influencing the survival of *Foc* propagules. However, the absence of a significant correlation of *Foc* density with any of the factors studied, along with the high residual factor found in path coefficient analysis, indicated that survival of *Foc* propagules at the 16–25 cm soil depth was not influenced by these factors. In general, a stationary *Foc* population in the absence of a wilt-susceptible cumin crop was a clear indication that the soils had only low levels of antagonists making them susceptible to severe forms of the wilt. Conducive soils had high levels of *F. o.* f. sp. *niveum* because populations of general bacteria, actinomycetes and fluorescent *Pseudomonads* tended to be greater in suppressive soils than in conducive soils (Larkin *et al*., 1993).

In our experiment, variations in the population levels of specific antagonists in different months of the study were not examined. A significant increase in actinomycetes antagonistic to *Foc* was found in cruciferous-residue-amended soil of our region (Sharma *et al*., 1995). Similarly the finding that cruciferous-residue-amended heated soils, contained enhanced populations of *Aspergillus versicolor* that were strongly antagonistic to *Foc* propagules (Israel and Lodha, unpublished data) is another sign that certain biocontrol agents specific to a hot and dry arid climate can be exploited by incorporating them as organic amendments into nutrient-deficient sandy soils. The possible role of specific antagonists to counter survival of *Foc* propagules opens up a new avenue of research in conducive aridisols.

Literature cited

Ben-Yephet Y., M. Reuven, A. Zviebil and D. Stienberg, 1996. Effects of initial inoculum and cultivar resistance on incidence of *Fusarium* wilt and population densities of *Fusarium oxysporum* f. sp. *dianthi* on carnation and soil. *Phytopathology* 86, 751–756.

Burke D.W., L.D. Holmes and A.W. Baker, 1972. Distribution of *Fusarium solani* f. sp. *phaseoli* and bean roots in relation to tillage and soil compaction. *Phytopathology* 62, 550–554.

Dewey D.R. and K.H. Lu, 1959. A path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal* 51, 515–518.

Dryden P. and N.K. Van Alfen, 1984. Soil moisture, root system density and infection of pinto beans by *F. solani* f. sp. *phaseoli* under dry land conditions. *Phytopathology* 74, 132–135.

Elmer W.H. and M.L. Lacy, 1987. Effects of inoculum densities of *Fusarium oxysporum* f. sp. *apii* in organic soil on disease expression in celery. *Plant Disease* 71, 1086–1089.

Ford E.J. and E.E. Trujillo, 1967. Bacterial stimulation of chlamydospores production in *Fusarium solani* f. sp. *phaseoli*. *Phytopathology* 57, 811 (abstract).

Hall R. and L.G. Phillips, 1992. Effect of crop sequence and rainfall on population dynamics of *Fusarium solani* f. sp. *phaseoli* in soil. *Canadian Journal of Botany* 70, 2005–2008.

Hopkins D.L., R.P. Larkin and G.W. Elmstrom, 1987. Cultivars-specific induction of soil suppressiveness to *Fusarium* wilt of watermelon. *Phytopathology* 77, 607–611.

Huber D.M. and A.L. Anderson, 1966. Necrosis of hyphae of *F. solani* f. sp. *phaseoli* and *Rhizoctonia solani* induced by a soil-borne bacterium. *Phytopathology* 56, 1416–1417.

Larkin R.P., D.L. Hopkins and F.N. Martin, 1993. Ecology of *Fusarium oxysporum* f. sp. *niveum* in soils suppressive and conducive to *Fusarium* wilt of watermelon. *Phytopathology* 83, 1105–1116.

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

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.

Mathur B.L. and R.L. Mathur, 1966. Fusarium wilt of cumin: Influence of certain factors on disease incidence. *Proceedings of National Academy of Sciences, India* 36, 33–38.

Mawar R. and S. Lodha, 2002. *Brassica* amendments and summer irrigation for the control of *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *cumini* in hot arid regions. *Phytopathologia Mediterranea* 41, 55–62.

Nash S.M. and W.C. Synder, 1962. Quantitative estimation by plate counts of propagules of the bean root rot *Fusarium* in field soils. *Phytopathology* 52, 567–572.

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

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

Singhal V., 1999. Cumin seed. In: *Indian Agriculture*. Indian Economic Data Research Center, New Delhi, India, 432–434.

Snedecor G.E. and W.J. Cochran, 1967. Statistical methods, Oxford and IBH publishing Co., Calcutta, India, 258–298.

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