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Original Research Article

Exploration of soil and weather factors on mulberry root rot incidence in the western zone of Tamil Nadu, India

Abstract

Aims: To record the occurrence of mulberry root rot disease, epidemiology, interaction of weather and soil parameters with the soil-borne pathogens in Western zone of Tamil Nadu during 2019-2020.

Study design: Survey

Place and duration of study: Surveyed in Coimbatore, Tiruppur, Erode, Dharmapuri and Krishnagiri districts of Tamil Nadu. Laboratory experiments were carried out at Department of Sericulture & Department of Plant Pathology, Tamil Nadu Agricultural University (TNAU), Coimbatore between July 2019 and Jan 2021.

Methodology: Per cent disease incidence of root rot was recorded in all surveyed gardens. To analyze the soil and weather parameters, the composite soil samples were subjected to textural analysis and weather data were collected from TNAU Agro Climate Research Centre. To predict soil temperature for all surveyed locations, the model regression equations were derived. The correlation analysis was done between per cent disease incidence, weather and soil parameters.

Results: The highest disease incidence was recorded in Nallampalli block of Dharmapuri district (54 per cent) whereas the lowest in Udumalaipettai block of Tiruppur district (0.06 per cent). The infected mulberry root samples yielded complex of soil-borne pathogens including *Macrophomina phaseolina, Lasiodiplodia theobromae, Fusarium* sp., and pathogenicity was proved. The results revealed that root rot incidence was recorded in all types of cultivars, significantly in ruling variety V1 irrespective of its age, soil type, spacing, and irrigation method. Soil parameters like texture, temperature and moisture content were found to augment the disease. Per cent disease incidence had significantly positive correlation with the weather factors like air and soil temperature whereas negative correlation with relative humidity and rainfall.

Conclusion: Synergism of abiotic stress factors hinders the mulberry plant health and increases its susceptibility to the soil-borne pathogens.

Key words: Mulberry, root rot, soil parameters, weather factors

1. Introduction

Mulberry is an astounding multipurpose woody, deciduous plant. The mulberry varieties like Victory 1 (V1), mildew resistant 2 (MR2), S36, Kanva 2 have been commercially grown in south India to meet the demand of ever expanding silk industry. In India, mulberry is cultivated around 2.47 lakh ha with silk production of 35820 metric tons [1]. Mulberry being a perennial crop can even thrive in extreme climatic conditions [2-4] and is successfully cultivated in most of the agro-climatic conditions.

In India, major mulberry cultivation is under tropical rainfed conditions. Mulberry is affected by various diseases like root rot, rust, leaf spots, powdery mildew, root knot, blight, dwarf, viral mosaic, etc. Among, root rot disease caused by soil-borne complex pathogens is a major threat to mulberry when climatic conditions are unfavourable [5,6]. The disease incidence, severity and leaf yield loss vary with conditions. Maximum leaf loss of 39 per cent and disease incidence of 55 percent was recorded in V1 in Tamil Nadu [7,8]. When compared to foliar diseases, managing root diseases in perennial crop is quite challenging. Hence, these pathogens of mulberry received an increased attention over the past decades.

Root rot infested plants had symptoms like yellowing, sudden drying, withering of leaves from bottom and decayed roots which led to weak anchorage in the soil. In addition, easy detachment of bark from roots, gummy exudation and sometimes emission of bad odour also recorded [9,10]. Generally infestation was at random and then spread throughout the field if not cared appropriately. Root rot associated pathogens produce spores, various resting structures including sclerotia, chlamydospores on the root epidermis, plant debris, etc [5, 11-13].

The root rot infection progressed quickly under physiological stress like drought, high temperature, etc. vulnerability of mulberry perennial roots to soil-borne pathogens increased by aging, physical damage, sub-soil compaction, repeated leaf harvesting along with depletion of soil nutrition [16-18]. Further variations in the virulence of pathogens resulted into unpredictable disease incidence in the mulberry gardens.

Soil-borne pathogens such as *Macrophomina phaseolina, Lasiodiplodia theobromae*, different species of *Fusarium, Helicobasidium mompa, Rhizopus oryzae, Helicobasidium mompa, Rosellinia necatrix, Armilaria mellea* have been reported as causal agents of root rot in mulberry [5, 11, 16, 19, 20]. In addition, many saprobes/ weak pathogens including *Aspergillus sp, Ovatospora sp, Talaromyces sp, Amesia sp, Gongronella sp, Myrmecridium sp, Clonostachys sp* were associated with mulberry root rot [20]. Further they act as carrier of prime pathogens into future generations [21]. These biotic factors contrive seriously when the plants suffer from stress.

Since there were no root rot resistant mulberry variety/ genotype available, disease management becomes more cumbersome. Understanding the virulence of root rot causing pathogens, their complexity, biology and epidemiology are essential to device effective disease management strategies. In the view of economic losses caused by mulberry root rot disease in silk industry, present study was carried out to document the role of the abiotic factors maneuvering the root rot disease in mulberry.

2. Materials and methods

2.1 Area surveyed and disease assessment

A survey was conducted during 2019-2020 in traditional tract of Tamil Nadu (Coimbatore, Tiruppur, Erode, Dharmapuri and Krishnagiri districts). Infected mulberry root samples were collected from four fields (two fields per block) in each district, labeled and preserved for isolation of pathogens. Soil samples were also collected randomly at different depths and preserved from all mulberry gardens. Irrigation method, cropping pattern and history, global positioning system (GPS) were recorded. Disease incidence was recorded as per cent of plants showing typical root rot symptoms, using the formula:

$$\text{Per cent Disease Incidence (PDI)} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

2.2 Weather parameters

To study interaction of weather parameters with the biotic components of root rot disease of mulberry, daily mean of maximum and minimum atmospheric temperature, relative humidity, and rainfall data were collected from TNAU Agro Climate Research Centre for all surveyed locations.

2.3 Soil parameters

To analyze the effect of soil parameters on disease incidence, the composite soil samples from 40 locations were air dried and passed through the stack of sieves with mesh size from No. 5 (4mm) to No. 200 (0.074mm). They subjected to textural analysis by following feel method [20] (Ritchey et al. 2015) and classified into hydrogenic soil groups (HSGs) [23].

2.4 Prediction of soil temperature

To predict soil temperature for all surveyed locations, model regression equations were derived for Coimbatore (GPS co-ordinates: 11.0122°N, 76.9354°E) according to Ahmad and Rasul (2008) [24]. This representative location chosen for the study has sub-tropical, humid climate and sandy clay loam soil type. Five years data of atmospheric temperature and soil temperature were collected from TNAU Agro Climate Research Centre for this study. Then, separate equations were derived for different soil depths (5cm, 10cm and 20cm) using the previous years' (2011-2015) daily mean of soil temperature as the dependent variable and air temperature as the independent variable.

2.5 Statistical analysis

The root rot incidence in different soil texture and mulberry varieties were analysed using two way ANOVA without replications [13, 14]. The correlation and regression analyses were done between PDI, weather and soil parameters [15].

3. Results and discussion

The survey was carried out to assess the distribution and incidence of the root rot disease in mulberry gardens. The results indicated that root rot disease was widespread wherever mulberry was grown. Moreover mulberry gardens had scattered infections, noticed in center and periphery as well. Root rot infected plants showed apparent wilting symptoms when most of the roots decayed. Sometimes pruned plants showed insignificant sprouting and less vigorous/ stunted growth which symbolized initial stages of infection. Completely rotten/ decayed roots were weak to hold plants firmly in the soil and could be pulled off easily. In addition, defoliated-droopy shoots, bark shredded pale coloured roots were seen and severely infested roots turn blackish due to overwintering of black sclerotial bodies (Fig 1).

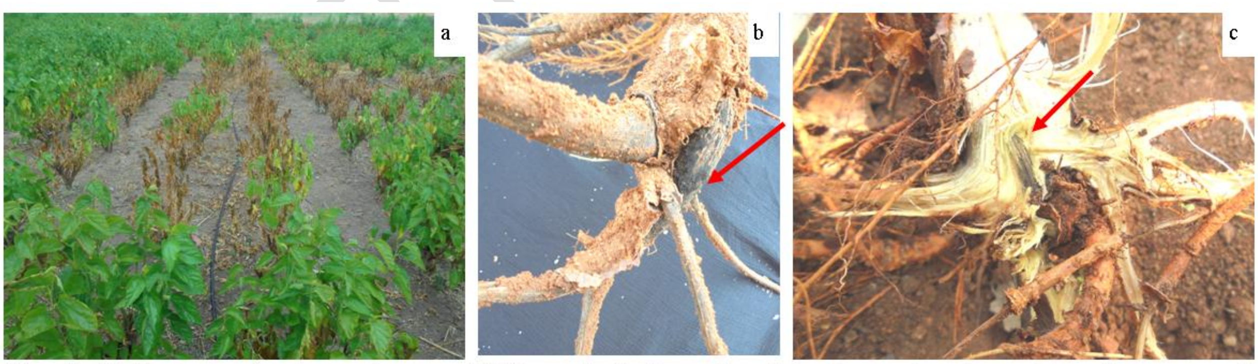

Fig. 1. Mulberry root rot symptoms a. Wilting of plants scattered in the garden (symptoms above-ground) b. Formation of resting structures c. Vascular blocking, discolouration and gummy exudates on infected roots (indicated by red arrows, symptoms below-ground)

Based on number of plants affected per cent disease incidence (PDI) was calculated for the 40 mulberry gardens during 2019-2020 survey were presented in Table 1.

Table 1. Different locations surveyed in traditional sericulture tract of Tamil Nadu

S.no	Location	Location code & Variety	DPI (%)	Soil texture	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	Rain fall (mm/y)	Predicted soil temperature (5cm) (°C)	Predicted soil temperature (10cm) (°C)	Predicted soil temperature (20cm) (°C)
1.	10.58722° N 77.16388° E	TU1-V1	1.33	SiCL	21.43	31.26	70.79	1245.39	31.27	30.76	30.06
2.	10.6925° N 76.91222° E	CP1-V1	4.00	SaCL	21.24	30.10	75.45	1712.75	30.31	29.89	29.27
3.	10.70222° N 77.02000° E	CP2-V1	13.33	CL	21.32	31.66	68.38	1054.21	31.25	30.74	30.05
4.	11.37190° N 77.08480° E	CA1-V1	5.37	LSa	21.39	32.08	66.96	997.41	31.48	30.95	30.23
5.	11.33360° N 77.08320° E	CA2-V1	8.01	SaL	21.28	31.80	68.20	983.76	31.27	30.76	30.06
6.	11.31470° N 76.98720° E	CK1-V1	11.36	SiCL	20.00	29.99	71.88	1180.40	29.57	29.23	28.67
7.	11.32370° N 76.93620° E	CK2-V1	9.89	SaCL	20.19	29.99	72.63	1310.16	29.67	29.32	28.75
8.	10.81780° N 77.02340° E	CKK1-V1	6.77	SiCL	21.53	31.60	69.43	1214.00	31.40	30.88	30.17
9.	10.87498° N 76.99507° E	CKK2-V1	10.00	SaCL	21.44	30.34	75.14	1700.09	30.55	30.11	29.47
10.	11.46638° N 77.57277° E	EA1-V1	7.50	LSa	22.16	33.61	63.57	807.03	32.74	32.08	31.27
11.	11.50111° N 77.58611° E	EA2-V1	20.00	SaL	20.93	32.80	62.56	742.21	31.62	31.08	30.35
12.	11.44083° N 77.50194° E	EB1-V1	27.00	SaL	22.11	33.76	62.30	735.40	32.80	32.13	31.31
13.	11.43000° N 77.48611° E	EG2-V1	31.00	SaCL	20.91	31.90	66.12	852.70	31.11	30.62	29.93
14.	11.32305° N 77.57805° E	EP1-V1	26.00	SaL	22.35	33.61	64.01	859.37	32.85	32.18	31.35
15.	12.15611° N 78.22916° E	DD1-V1	7.50	SaCL	20.46	32.37	64.12	815.15	31.13	30.63	29.94
16.	12.16888° N 78.23416° E	DD2-V1	14.00	SaCL	20.75	31.82	67.88	989.71	30.98	30.50	29.82
17.	11.93027° N 78.43444° E	DP1-V1	5.00	SiC	21.50	33.42	63.42	792.64	32.27	31.66	30.88
18.	11.91833° N 78.42527° E	DP2-V1	1.60	SiCL	21.76	33.18	65.28	899.29	32.28	31.67	30.89

19.	12.19750° N 78.28333° E	DH1-V1	0.10	SaCL	20.46	32.37	64.12	815.15	31.13	30.63	29.94
20.	12.18666° N 78.27194° E	DH2-V1	40.00	SaCL	20.67	32.37	65.05	867.06	31.24	30.73	30.04
21.	12.09166° N 78.15250° E	DN1-V1	10.00	CL	20.75	31.82	67.88	989.71	30.98	30.50	29.82
22.	12.19361° N 78.12333° E	DN2-V1	54.00	SiCL	20.58	32.47	64.21	845.69	31.24	30.74	30.04
23.	12.63305° N 78.24305° E	KK1-V1	4.50	SaCL	19.97	31.23	67.08	1005.51	30.23	29.82	29.21
24.	12.49472° N 78.23083° E	KK2-V1	2.50	L	20.75	31.82	67.88	989.71	30.98	30.50	29.82
25.	12.28111° N 78.27972° E	KKP1-V1	44.00	LSa	20.36	32.06	65.33	868.42	30.90	30.43	29.76
26.	12.37305° N 78.25611° E	KKP2-V1	7.50	SaL	20.47	32.27	64.59	837.81	31.07	30.58	29.90
27.	12.24277° N 78.61916° E	KU1-V1	2.35	SaL	21.47	32.25	69.21	1103.36	29.90	29.53	28.94
28.	12.27055° N 78.52944° E	KU2-V1	30.00	SaCL	21.47	32.25	69.21	1103.36	29.90	29.53	28.94
29.	12.75305° N 78.15311° E	KV1-V1	18.18	SaL	19.71	31.30	65.75	945.40	30.13	29.73	29.13
30.	12.76694° N 78.11527° E	KV2-V1	3.00	SaCL	19.71	31.30	65.75	945.40	30.13	29.73	29.13
31.	10.59611° N 77.25805° E	TU2-MR2	0.06	L	21.43	31.26	70.79	1245.39	31.27	30.76	30.06
32.	10.71083° N 77.30694° E	TG1-MR2	4.00	SaCL	21.05	31.33	68.94	1006.48	30.89	30.42	29.75
33.	10.73055° N 77.28027° E	TG2-MR2	2.00	LSa	21.53	31.60	69.43	1214.00	31.40	30.88	30.17
34.	10.93555° N 77.26833° E	TP1-MR2	0.18	CL	21.35	31.43	69.54	1179.20	31.17	30.67	29.98
35.	10.97777° N 77.29750° E	TP2-MR2	0.10	SaL	21.32	31.66	68.38	1054.21	31.25	30.74	30.05
36.	10.86083° N 77.41166° E	TK1-MR2	3.80	SaCL	21.35	31.43	69.54	1179.20	31.17	30.67	29.98
37.	10.85000° N 77.44111° E	TK2-MR2	6.36	SaL	21.43	31.26	70.79	1245.39	3.17	5.47	7.07
38.	10.81780° N 77.02340° E	CKK1-MR2	0.10	SiCL	21.53	31.60	69.43	1214.00	31.40	30.88	30.17

39.	11.44694° N 77.49583° E	EB2-MR2	28.00	SiCL	21.39	32.08	66.96	997.28	31.48	30.95	30.23
40.	11.43750° N 77.48388° E	EG1-MR2	48.00	LSa	21.39	32.08	66.96	997.28	31.48	30.95	30.23
41.	11.29277° N 77.51805° E	EP2-MR2	30.70	LSa	22.35	33.61	64.01	859.37	32.85	32.18	31.35
42.	11.33360° N 77.08320° E	CA2-G4	3.60	SaL	21.28	31.80	68.20	983.76	31.27	30.76	30.06
43.	11.44694° N 77.49583° E	EB2-G4	16.30	SiCL	21.39	32.08	66.96	997.28	31.48	30.95	30.23

The highest disease incidence was recorded in Nallampalli block of Dharmapuri district (54 per cent) whereas the lowest in Udumalaipettai block of Tiruppur district (0.06 per cent). While in the district-wise incidence, Erode recorded maximum incidence of 26.06 per cent followed by Dharmapuri (16.56%) and the lowest was in Tiruppur (2.23%). These variations in root rot incidence witnessed in different locations have been analysed in all possible ways to understand the pathogen behavior and to make effective management strategies.

Soil-borne pathogens including *Macrophomina phaseolina, Lasiodiplodia theobromae, Fusarium solani* and *F.oxysporum* were isolated from root samples collected from infected mulberry garden (Fig 2). Though the disease was caused by complex organisms' the frequency of *Fusarium* isolates was highest. Further pathogenicity of the isolates in mulberry was proved by following Koch's postulates.

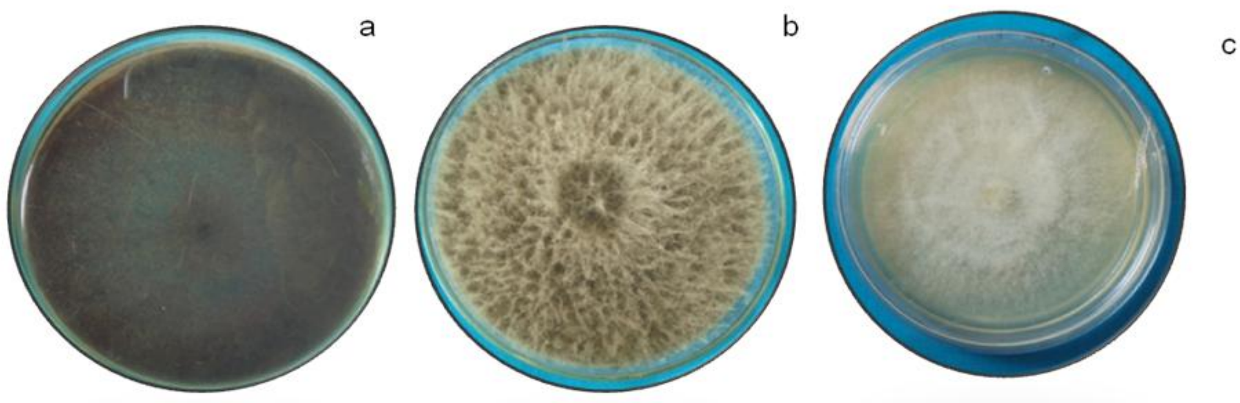

Fig. 2. Pathogens isolated from infected mulberry root samples a. *Macrophomina phaseolina* b. *Lasiodiplodia theobromae* c. *Fusarium* sp.

Table 2: Root rot incidence in different mulberry varieties and soil textures

Mulberry variety	Hydrogenic soil group A		Hydrogenic soil group B	Hydrogenic soil group C	Hydrogenic soil group D		
	Loamy Sand (LSa)	Sandy Loam (SaL)	Sandy Clay Loam (SaCL)	Loam (L)	Clay Loam (CL)	Silty Clay Loam (SiCL)	Silty Clay (SiC)
V1	18.90	15.57	13.99	2.50	11.67	15.01	5.00
MR2	26.90	3.38	3.90	0.06	0.18	14.05	0.00
G4	0.00	3.60	0.00	0.00	0.00	16.30	0.00

Table 3. Summary table for the analysis of two factor ANOVA without replication

Sources of value	Sum of squares	Degrees of freedom	Mean square	F calculated	F tabulated	P value at 5%
Between varieties	281.86	2	140.93	4.08	3.88	0.04
Between soil textures	632.69	6	105.44	3.05	2.99	0.04
Residual	413.91	12	34.49	-	-	-
Total	1328.47	20	-	-	-	-

Survey revealed mulberry varieties V1 and MR2 were predominant among sericulturists exceptionally a few have young G4 plantations. The disease was prevalent irrespective of the crop age, from one to fifteen years old plantations (maximum age observed during the survey). The root rot pathogens affected all the varieties corroborated with results of Mallikarjuna et al. (2010) [16]. But the variety V1 was found to be more susceptible and recorded maximum average disease incidence (14.19%). And also from the summary table (Table 3), it was statistically clear that the F calculated value is greater than F table value at 5% level of significance and we conclude that the root rot disease incidence between mulberry varieties and soil textures differ significntly.

Soil-borne pathogens survive and their virulence expression depends on soil receptivity [25,33]. Classification into HSGs is crucial for soil and water conservation efforts, which, intern, play an important role in devising disease management strategies. Survey revealed that mulberry could be grown in wide range of soils with varied cultural practices. The frequency of root rot incidence was high in sandy soils (hydrogenic group A & B) (Table 2). Loamy sand had high proportion of sand and recorded maximum incidence of 22.93 per cent whereas loam soils recorded minimum incidence of 1.28 per cent. Reduction in *Fusarium* wilt of banana was reported in soils with clay component might be due to suppressive role of clay on pathogens by altering oxygen diffusion, pH buffering and nutrient availability [26, 27]. This clearly showed that soil texture has significant role in disease occurrence.

Higher PDI in some gardens with SiC and SiCL soil types could be explained based on the irrigation methods and poor nutrient management. Continuous depletion of soil nutrients resulted severe charcoal rot in mulberry [26]. Serrano et al. (2011) [29] also studied the calcium fertilizers suppressed root rot disease incidence in *Quercus*. Similarly irrigation reduced *M. phaseolina* colonization on soyabean roots than in non-irrigated crop system [30]. Significant number of farms had year round silkworm rearing and continuous harvesting of mulberry leaves while the management of nutrient depletion was unsatisfactory. Prolonged nutrient deficit made the mulberry plants susceptible to soil-borne pathogens, especially root rot disease incidence was reported high in areas where low organic matter (<0.6%) and moisture content (<40%) [5].

In addition, soil texture significantly influences the soil moisture content followed by vegetation and climatic conditions. When compared to other soil textures, sandy soils have poor water and nutrients holding capacity due to large pore sizes. So the mulberry roots grew longer to absorb enough water favouring soil-borne pathogens to find host easily and initiate infections. Further, the viability of pathogen propagules (*M. phaseolina*) was unaffected at low water potential of sandy soils and also enhanced colonization of the roots [31, 32]. Moreover with the fewer populations of other microbes to compete for resources, desiccation tolerant pathogens like *Fusarium* were ten times higher than in regular [33]. The temperature increases quickly in sandy soils, aggravate the root rot by physiological stress to mulberry roots and decreasing photosynthetic efficiency [34].

For the better understanding of disease-temperature interactions, soil temperature also taken into account. Soil temperature is difficult to monitor and data availability is limited as compared to data of atmospheric temperature, rainfall and relative humidity. Hence the scientists came with an alternative of developing an empirical equation to predict soil temperature [24, 35].

Soil temperature is influenced by air temperature, solar radiation, vegetation, rainfall and could hold heat better than air does [36, 37]. Likewise, the observed soil temperature was higher than air temperature (2011-2015) and wide fluctuations' was observed in soil temperature at depths of 5cm (upto 20°C), 10cm (upto 7°C) while beyond 20cm, the differences were insignificant (Fig 3).

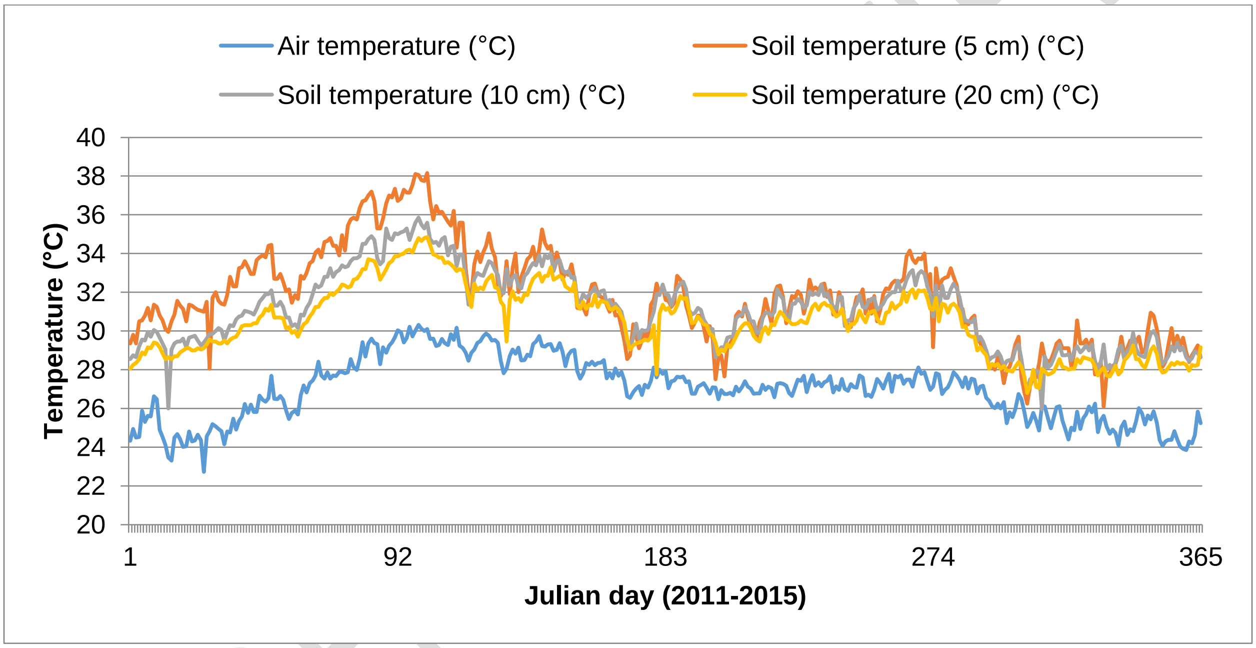

Figure 3: Julian day graph (2011 to 2015) - Daily average air temperature and soil temperature at 5cm, 10cm and 20cm depths of the representative block (CBE); Soil type-Sandy clay loam

The Pearson's correlation analysis between daily average air and soil temperature at 5cm, 10cm and 20cm depth of representative site indicated the strong R^2 value (0.77, 0.85, 0.91) as per Dancey and Ready's (2004) [38] categorization and the positive relationship. Using these available data, separate model regression equations were derived to predict soil temperature.

Empirical model equation for deriving soil temperature at 5cm, 10cm and 20cm depths

$y5cm=1.10x+2.07$

$y10cm=0.99x+4.48$

$y20cm=0.90x+6.17$

Where y is the average soil temperature (dependent variable) and x is the average air temperature (independent variable)

These equations were applied for estimating average soil temperature at different depths 5cm, 10cm and 20cm (Table 4). Thus soil temperature had been derived for all surveyed locations and correlation matrix was worked out between disease incidence per cent and weather data. The results revealed significantly positive interaction of maximum temperature while relative humidity and rainfall had negative interaction with PDI. However, the disease incidence established positive interaction with soil temperature (Table 4). This was strengthened by the fact that, suppressive soil turned to conducive for pathogens when exposed to prolonged drought and water deficit conditions [33, 39]. Further sudden outbreaks of root rot in mulberry gardens might be due to prolonged drought followed by showers.

Table 4: Correlation analysis to study the interaction between PDI, weather parameters and predicted soil temperature

Parameters	Minimum air temperature	Maximum air temperature	Relative humidity	Rain fall	Predicted soil temperature		
					5cm	10cm	20cm
PDI	-0.012	0.326*	-0.385**	-0.359**	0.102	0.102	0.102

*Significance at 5%   ** Significance at 1%

Soil temperature has exponential correlation with soil respiration and determines the state of water in the soil [40]. The correlation study depicted the influencing role of temperature on the host plant, soil beneficial and pathogenic organisms in disease incidence. Increase in atmospheric temperature has direct impact on soil temperature increase up to 20cm depth (except in some extreme conditions) resulting in higher root rot incidence. The soil temperature elevations from 24°C to 34°C had significant role in banana fusarial wilt severity in almost all soil types [41, 43]. The spores and other resting structures of soil-borne pathogens survive for years in soil without hosts [5, 43]. Pathogenic propagules mostly remain in the top layer of soil (30cm) and may reach up to 1.5m deep over years of cultivation to eliminate themselves from adverse conditions [44]. Root rot is alarming for perennial crops like mulberry since it can destroy vaguely, irrespective of crop's age and number [45].

4. Conclusion

Variations in the disease incidence and severity could be well attributed to the pathogens virulence and cultural practices followed by the farmers as well. Under optimum soil, weather and climatic conditions plants can overcome the pathogen infections. Unfortunately the susceptibility of the mulberry plants to pathogens greatly influenced by weather and soil conditions. In addition, root rot pathogens are necrotrophic and have wide host range with higher surviving ability even under extreme conditions.

Through the correlation studies, the impacts of weather parameters and soil temperature on mulberry plants and soil-borne pathogens were well understood. A small change in the properties of soil has influence on the host health and pathogen multiplication as well. The developed empirical model equation to predict soil temperature is reasonably effective at a large scale. However deviations in the derived soil temperatures might be due to the site specific seasonal variations. This could be reduced and gave better prediction by modifying/ developing individual equations. By conclusion if the high atmospheric and soil temperature occur simultaneously with poor nutrient, low relative humidity and rainfall will increase the susceptibility of mulberry plants to root rot disease.

Soil is the common arena/ dome where all the host, antagonists and pathogens interact. Hence, the present study was carried out to throw light on key factors manipulating mulberry root rot disease incidence, intensity and yield losses. It is clear that the disease incidence was prominent and difficult to manage in sandy soils during prolonged dry spell. It is paramount important to improve the soil texture and moisture content through cultural interventions like mulching, cover crops and spreading compost over soil. These processes encourage soil organic content and prevent evapo-transpiration to minimise root rot incidence in mulberry.

Disclosure Statements

The manuscript is approved by all the co-authors and I assure that the submitted manuscript or any part of it has not been under consideration or published elsewhere. All the authors declared that there is no conflict of interest.

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