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ARTICLE

Effects of soil physico-chemical parameters on *Sclerotium rolfsii* suppressiveness

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ABSTRACT The relationship of soil physico-chemical parameters with disease suppressiveness property of soil is not well understood phenomenon. In this regard, the surveys were conducted on the occurrence of collar rot disease caused by *Sclerotium rolfsii* in two districts (North 24 Parganas and Nadia) of West Bengal Gangetic new alluvial region of India from February to March, 2016. Soil samples were screened through the disease conduciveness and suppressiveness. The physicochemical properties of soils showed that the clay loam soil dominated in new the alluvial region of West Bengal. It was found that soil suppressiveness against *S. rolfsii* significantly positively correlated with soil aggregate ratio (AR). PCA explained the closeness of the parameters with soil suppressive index (SI) and aggregate stability (AS). Mostly the exponential relationship has been observed among the selected physico-chemical parameters. From this study we found AR, AS and bulk density were most determining parameters for *S. rolfsii* soil suppressiveness. Such indicators of soil health would be very beneficial for forecasting potential risks and providing guidance on appropriate farming techniques for specific geographic areas or microclimates. However, further investigation is required to fully comprehend the impact of physical and chemical properties on soil suppressiveness.
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INTRODUCTION

Sclerotium rolfsii is one of the most dreaded soil-borne pathogens responsible for significant yield loss (Eweis et al. 2006). Fungicidal chemicals specifically designed to kill fungi are commonly employed to eradicate soil-borne illnesses such as root rot and collar rot caused by *S. rolfsii*. As the management of soil-borne diseases becomes increasingly challenging, a thorough investigation into the microbial composition and physicochemical parameters of diseased soil in comparison to healthy soil is required. For decades, plant pathologists have been intrigued by the occurrence of soils that exhibit disease suppression, which has been observed in various regions globally. Baker and Cook (1974) described suppressive soils as those that maintain a low rate of infection despite the presence of a pathogen, a susceptible host plant, and optimal conditions for disease progression.

Soil suppressiveness can be caused by a variety of mechanisms: (i) The pathogen neither establishes nor persists, (ii) It thrives but causes minimal or no damage, (iii) The pathogen establishes itself and causes disease for a certain period, but the severity of the disease decreases afterwards, despite the pathogen's persistence in the soil (Baker and Cook 1974). In this scenario, the ability of soil to suppress disease is a characteristic of a specific soil, varying from highly conducive to suppressive soils. Therefore, soils that suppress disease should be considered as healthy soils. Both soil abiotic and abiotic factors are the key functions of soil suppressiveness and conduciveness. Soil abiotic factors are primarily differentiated by means of quantitative measurements. The soil physicochemical parameters associated with soil quality and binding capacity was examined under different agro-ecological zones of West Bengal (Bandyopadhyay et al. 2011; Manik et al. 2020). In the new Gangetic alluvial region of West Bengal, India, specifically under North 24 Parganas and Nadia districts, soil suppressiveness against *S. rolfsii* has not been evident yet. In this region, no systematic research work was conducted for understanding the relationship of soil abiotic parameters with soil suppressiveness in *S. rolfsii* system. The relationships between these soil physicochemical properties and soil suppressiveness need to be evaluated using simple correlations as well as multivariant statistical approaches. Many researchers have studied the relationship between soil physicochemical properties with different disease incidence (Janvier et al. 2007) but scanty literatures are available on influence of soil physicochemical parameters with general or specific soil suppressiveness. Thus, in the current investigation were made to study the influence of soil physicochemical parameters with soil suppressiveness against *S. rolfsii*.

MATERIALS AND METHODS

Soil sample collection sites

Soil samples of 6-20 cm soil depth, collected from 23 locations of two districts (North 24 Parganas and Nadia) of West Bengal, from February to March of 2016 were used for soil physicochemical characterization and suppressiveness index analysis (Table 2 and 3). Rhizospheric soil samples were obtained from four randomly chosen locations using a soil auger over five subplots of a field and placed in clean polythene bags. To create a composite sample, each soil sample from a field was fully fixed *in-situ* conditions. In order to prevent contamination, aseptic procedures were followed at every stage of the sample collection process. Each composite sample was transported to the lab and separated into two halves, each weighing 100 g, one for the examination of the soil suppressiveness index and the other for the listing of physicochemical properties. Table 1 contains preliminary information about the locations of the collection.

Sclerotia assay from the soil

A very simple flotation and sieving technique has been used to determine the *S. rolfsii* sclerotial population using 0.75 M sucrose (having specific gravity of approx. 1.073 at 25 °C) extracting solution (Rodriguez-Kabana et al. 1974). This rapid sclerotia extraction method from rhizospheric soil was carried out by soft grinding and sieving the soil (air died) through 4 mm mesh. In an 1 l glass beaker (Borosil, India), 100 g of sieved soil and 500 ml of extraction solution was added. The mixture was stirred at 1000 rpm for 10 min and kept half an hour for settle down and decanted carefully over 60 mesh sieve and the sclerotia were collected (Rodriguez-Kabana et al. 1974).

Soil suppressive activity assay

The study of the soil's ability to suppress fungal pathogens was conducted using natural soil samples collected from the field. Petri dishes were filled with 75 g of sieved soil samples, without the addition of any extra ingredients. Soil moisture was maintained by spaying adequate sterile distilled water (sdH_2O) to achieve 70% of soil field capacity (FC). The mycelial disc (4 mm) of 3 days old *S. rolfsii* pathogen, grown on PDA medium was positioned at the center of each petri dish and incubated at 28 °C ± 1 °C for 3 days. The soil suppression level was determined by utilizing the following formula:

Suppressive index (SI) = [(Radius of fungal mycelia in conducive soil – radius of fungal mycelia in suppressive soil) / Radius of fungal mycelia in conducive] * 100

Enumeration of soil physical parameters

Field capacity (FC) of the collected soil was measured using wall hanging porous plate apparatus (Madhan Mohan and Prabhu 2019). Known volume of oven dry soil was filled in a moisture box and saturated with water. Then saturated moisture box was kept at 100 cm (0.1 bar.) from water level. After 24 h, field capacity was measured using following formula:

Weight of the moisture container (g) = Mb
Weight of moisture container + wet soil (g) = Mbws
Weight of moisture container + dry soil (g) = Mbds
Weight Percent water content = ((Mbws - Mbds)/(Mbds- Mb))*100

A bucket auger and core sampler were used to gather field damp soil samples, and bags containing the bulk samples were used to transport them to the lab. After 72 h of air drying, the samples were examined for aggregate stability (AS) and particle size. Each sample's air-dried sub-samples were then manually crushed, put through a 2-mm sieve, and stored to be examined for a variety of physical and chemical characteristics. The Boyoucous hydrometer (Bouyoucos 1962) and core sample (Black and Hertge 1986) different techniques were employed to find out bulk density and soil textural classes, respectively. Equilateral triangles with areas divided into 12 compartments, each of which represents a different textural class, are utilised in both the systems proposed by the United States Department of Agriculture (USDA) and the International Union of Soil Sciences (IUSS). Furthermore, wet sieving samples that passed through a 5.0-mm sieve but remained on a 2.0-mm sieve were obtained for aggregate stability (AS) study. The soil retained in various sieves for the untreated soil sample was collected, dried below 60 °C, and preserved for study

Table 1. Locations of the soil survey area from different vegetable crop rhizospheres

Sl. No.	Soil ID	District	Village	Latitude	Longitude	Crop
1	TOMK2	N24Pgn	Kachiara	22.88576	88.53389	Tomato
2	TOMK3	N24Pgn	Kachiara	22.88563	88.53474	Tomato
3	TOMK4	N24Pgn	Kachiara	22.88573	88.53411	Tomato
4	TOMK5	N24Pgn	Kachiara	22.88593	88.53473	Tomato
5	TOMK6	N24Pgn	Kachiara	22.88622	88.53364	Tomato
6	TOMK7	N24Pgn	Kachiara	22.8856	88.53354	Tomato
7	ONIONK	N24Pgn	Kachiara	22.88748	88.53447	Onion
8	OKRAK1	N24Pgn	Kachiara	22.88417	88.53361	Okra
9	OKRAK2	N24Pgn	Kachiara	22.88383	88.53392	Okra
10	TOMS1	N24Pgn	Santoshpur	22.77749	88.50182	Tomato
11	TOMS2	N24Pgn	Santoshpur	22.77761	88.49978	Tomato
12	TOMS3	N24Pgn	Andolpota	23.1977	88.7206	Tomato
13	TOMS4	N24Pgn	Santoshpur	22.77768	88.50248	Tomato
14	TOMS5	N24Pgn	Sekandarpur	22.94809	88.63082	Tomato
15	TOMS6	N24Pgn	Santoshpur	22.7797	88.50347	Tomato
16	TOMS7	N24Pgn	Santoshpur	22.77776	88.50175	Tomato
17	TOMS8	N24Pgn	Kaikhali	23.01012	88.72027	Tomato
18	CHIS1	N24Pgn	Santoshpur	22.78054	88.50047	Chilli
19	BRINS1	N24Pgn	Sekandarpur	22.95677	88.63478	Eggplant
20	BRINS2	N24Pgn	Andolpota	23.87763	88.72371	Eggplant
21	104	Nadia	Bhabanipur	22.92494	88.56786	Coriander
22	53	Nadia	Bhabanipur	22.92485	88.56598	Potato
23	TOMK1	N24Pgn	Kachiara	22.88528	88.53444	Tomato

of various aggregating agents in various size fractions after aggregate stability analysis. Fresh soil samples taken from the field were weighed in the lab before being heated to 105 °C and dried there until they reached a constant weight. The Yoder apparatus was used in combination with two sets of five sieves of varying sizes (2.0, 1.0, 0.5, 0.25, and 0.1 mm) to separate the aggregates by sieving them while they were wet. The mean weight diameter (MWD) was computed as an index of aggregation using the equation from Manik et al. (2020), after adjusting coarse material content in all aggregate parts by dispersing with 0.5% sodium hexametaphosphate and screening through the same sieve size (Manik et al. 2020). By mixing aggregates of various size fractions (0.25 - 2 mm) and expressing the result as a percentage of the total weight of soil used for analysis, the water stable aggregate (WSA) was calculated (Manik et al. 2020). In addition, the aggregate stability (AS) level was determined in accordance to Gupta and Dakshinamurti 1981. Aggregate ratio (AR) was determined as proposed by Bandyopadhyay et al. 2011.

Enumeration of soil chemical parameters

The soil samples that were collected were processed by first air-drying them, then grinding and passing them through a 2-mm sieve. These samples were then used to analyze various soil properties. Techniques such as potentiometry and conductometry were used to measure the soil's pH and electrical conductivity, which were determined using a 1:2.5 soil to water ratio suspension (Jackson 1973). Organic carbon was analyzed using a wet oxidation method, as described in Walkley and Black (1934). The total nitrogen content was determined by using the micro-Kjeldahl method that involved wet digestion and distillation as outlined by Bremner and Mulvaney (1982). Available phosphorus was extracted using a modified method and available potassium was extracted using neutral normal ammonium acetate and then measured using a flame photometer (Jackson 1973).

Statistical analysis

The statistical analysis was carried out using the SPSS 21 software. Pearson's correlation coefficient and regression equations were calculated to analyze the relationships between the response variables. To understand how the soil physicochemical parameters are related on soil suppressive activity by comparing disease suppressive and conducive soils by principal component analysis (PCA) and Pearson correlation using SPSS 21.

Table 2. Soil suppressiveness and chemical parameters of 23 Gangetic new alluvial soil samples

Sl. No.	Soil ID	Suppressive index	No. Sc*	pH	EC mmhos/cm	O.C. (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
1	TOMK2	13.81	1.50	7.43	0.20	0.52	290.20	62.97	340.03
2	TOMK3	14.45	3.50	7.09	0.28	0.44	233.40	78.59	276.86
3	TOMK4	12.26	3.50	6.83	0.41	0.50	276.00	89.67	241.92
4	TOMK5	12.50	0.50	7.62	0.15	0.52	361.20	33.75	225.79
5	TOMK6	11.76	1.00	7.82	0.75	0.84	537.20	88.16	614.20
6	TOMK7	30.96	1.00	7.27	0.33	0.74	446.40	39.29	399.16
7	ONIONK	13.20	0.00	7.64	0.41	0.70	418.00	92.69	643.77
8	OKRAK1	58.79	0.50	7.49	0.26	0.76	432.50	27.20	369.60
9	OKRAK2	27.00	0.50	7.81	0.43	0.80	478.20	6.54	333.31
10	TOMS1	24.52	24.00	6.84	1.18	0.68	403.80	108.82	616.14
11	TOMS2	19.44	33.50	6.95	0.61	0.84	537.20	141.06	779.52
12	TOMS3	26.20	40.00	7.08	0.43	0.86	523.60	115.37	452.92
13	TOMS4	23.52	14.50	6.92	0.60	0.70	418.00	107.81	479.80
14	TOMS5	14.81	1.00	7.06	0.67	0.76	460.60	99.24	764.73
15	TOMS6	7.90	52.00	7.90	0.78	0.48	261.80	123.93	275.52
16	TOMS7	24.67	4.00	5.82	0.66	0.66	359.40	152.65	252.67
17	TOMS8	26.89	22.00	6.99	0.42	0.60	347.00	115.87	176.06
18	CHIS1	12.85	0.00	6.48	1.03	0.42	219.20	148.11	489.21
19	BRINS1	39.41	0.00	6.76	0.64	0.72	432.20	148.11	270.14
20	BRINS2	26.26	0.00	6.34	0.85	0.50	265.20	148.11	417.98
21	104	76.79	0.00	7.26	0.08	0.72	412.30	56.42	169.34
22	53	86.91	0.00	7.17	0.11	0.78	452.80	152.65	330.62
23	TOMK1	11.36	18.50	7.17	0.22	0.58	378.80	90.18	331.96

*No. Sc.= Sclerotial population of *S. rolfsii*/100 g soil, EC= Electrical conductivity (mmhos/cm), N= Total soil nitrogen (kg/ha), P_2O_5= Available soil phosphorus (kg/ha), K_2O= Available soil Potassium

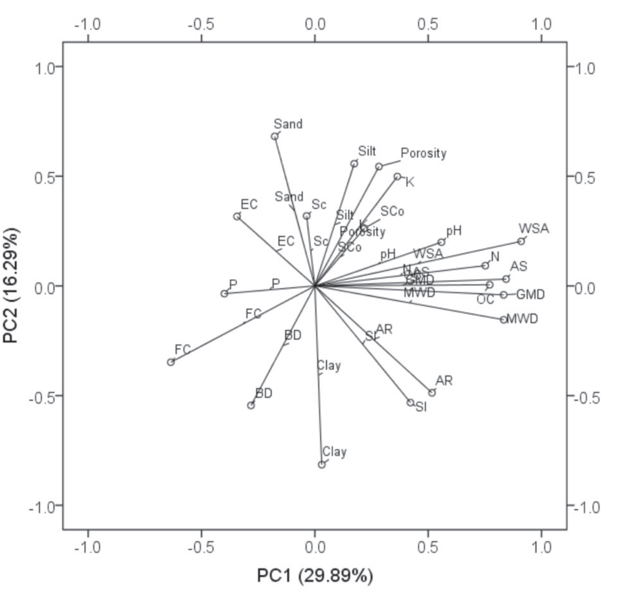

Figure 1. PCA of soil physicochemical parameters including SI and Sc represented through 2-D plot consider first two principal component PC1 and PC2.

RESULTS AND DISCUSSION

Soil suppressiveness of surveyed area

The survey was conducted during February-March, 2016 under 23 surveyed locations, including six villages under two different districts of W.B. (Table 1). Tomato crop was found most cultivated crop followed by eggplant, okra, onion, coriander, potato and chilli during *Rabi* (October to December) and post-*Rabi* season. Two soil samples named, 53 and 104 were found to be the most suppressive soil against *S. rolfsii* disease with 86.91% and 76.79% suppressive index, respectively. Potato and coriander were the field crops during the time of the survey in soil ID of 53 and 104. Among 23 soil samples only one (OKRAK1) was showing moderate level of suppressiveness which was 58.79% and the crop was okra during the time of survey. Twenty of soil samples were found conducive and the most conducive soils were TOMS6 (7.90) and TOMK1 (11.36). During the survey, tomato crop was present in most of the conducive soil locations. Number of sclerotial population of *S. rolfsii* per 100 g of rhizospheric soil were high in conducive soil, whereas no sclerotial population was observed in suppressive soils (Table 2).

Table 3. Soil physical properties of the 23 Gangetic new alluvial soils

Sl. No.	Soil ID	FC*	BD	Porosity	%WSA	AR	AS	SCo	MWD	GMD	Sa%	C%	Si%	Texture
1	TOMK2	31.82	1.441	0.460	69.280	25.851	5.841	0.497	1.141	0.974	40.20	34.10	25.70	Clay loam
2	TOMK3	29.49	1.373	0.486	38.120	1.668	1.561	-0.301	0.670	0.704	41.50	30.10	28.40	Clay loam
3	TOMK4	30.16	1.471	0.449	51.660	2.542	1.152	0.672	0.696	0.739	37.90	34.20	27.90	Clay loam
4	TOMK5	29.57	1.461	0.453	37.480	2.085	3.013	-0.537	0.725	0.734	39.80	32.20	28.00	Clay loam
5	TOMK6	34.69	1.505	0.436	69.180	12.717	5.499	-0.255	1.085	0.950	40.80	31.20	28.00	Clay loam
6	TOMK7	33.95	1.618	0.394	65.440	4.661	4.190	-0.244	0.933	0.853	35.10	36.80	28.10	Clay loam
7	ONIONK	35.42	1.515	0.433	68.900	7.074	3.973	0.199	1.020	0.901	39.20	34.30	26.50	Clay loam
8	OKRAK1	34.97	1.395	0.478	74.340	31.500	4.759	0.295	1.424	1.093	35.20	42.00	22.80	Clay
9	OKRAK2	33.46	1.461	0.453	80.700	6.993	1.965	1.673	1.628	1.129	40.20	28.70	31.10	Clay loam
10	TOMS1	27.54	1.525	0.429	78.700	7.397	2.431	0.898	1.475	1.066	40.80	32.20	27.00	Clay loam
11	TOMS2	26.33	1.334	0.501	69.380	13.876	6.389	-0.036	1.233	1.000	38.90	34.20	26.90	Clay loam
12	TOMS3	27.41	1.324	0.504	79.040	6.006	3.580	0.039	1.319	1.008	45.20	27.50	27.30	Sandy Clay loam
13	TOMS4	25.59	1.495	0.440	86.620	8.576	7.846	-0.128	1.583	1.122	35.60	34.20	30.20	Clay loam
14	TOMS5	25.37	1.289	0.517	88.620	24.617	7.679	0.163	1.471	1.122	39.70	32.80	27.50	Clay loam
15	TOMS6	35.10	1.376	0.485	18.060	1.311	0.596	0.071	0.551	0.644	38.20	37.40	24.40	Clay loam
16	TOMS7	37.63	1.608	0.398	15.700	2.322	0.970	-0.435	1.318	0.934	34.80	42.20	23.00	Clay
17	TOMS8	34.88	1.451	0.456	28.200	67.143	2.133	-0.310	1.417	1.097	37.93	38.50	23.57	Clay loam
18	CHILLIS1	36.43	1.500	0.438	33.260	3.538	0.783	0.031	0.815	0.764	42.10	32.80	25.10	Clay loam
19	EGGPLANTS1	41.05	1.623	0.392	5.260	1.520	0.170	0.223	0.594	0.678	41.80	30.50	27.70	Clay loam
20	EGGPLANTS2	40.47	1.441	0.460	5.320	1.060	0.201	0.199	0.587	0.664	42.90	30.40	26.70	Clay loam
21	104	29.24	1.362	0.490	75.260	45.786	6.544	0.125	1.234	0.948	42.20	33.50	24.30	Clay loam
22	53	27.25	1.557	0.417	81.660	56.540	5.282	0.224	1.464	0.869	37.20	35.60	27.20	Clay loam
23	TOMK1	31.48	1.443	0.460	40.380	10.614	0.428	0.084	0.658	0.706	38.20	34.20	27.60	Clay loam

*FC= Field capacity, BD= Bulk density, %WSA= Percent water stable aggregate, AR= Aggregate ratio, AS= Aggregate stability, SCo= Stability coefficient, MWD= Mean weight diameter, GMD= Geometric mean diameter, Sa%= Sand percentage, C%= Clay percentage, Si%= Silt percentage

Soil aggregation

The textural class of the surveyed soil mainly belonged to clay to clay-loam (Table 3). According to physical parameters of soil, the soil aggregation indices were depicted as field capacity (FC), bulk density (BD), porosity, % water soluble aggregates (%WSA), aggregate ratio (AR), aggregate stability (AS), stability coefficient (SCo), geometric mean diameter (GMD) and mean weight diameter (MWD). These parameters were significantly varied among the different suppressive and conducive soils. There were no significant relations observed in BD and porosity with soil suppressiveness in accordance to this study (Table 4). It was observed that AR, AS and MWD were high in two suppressive soil 53 and 104 in comparison to the moderate suppressive OKRAK1 and most conducive TOMK1

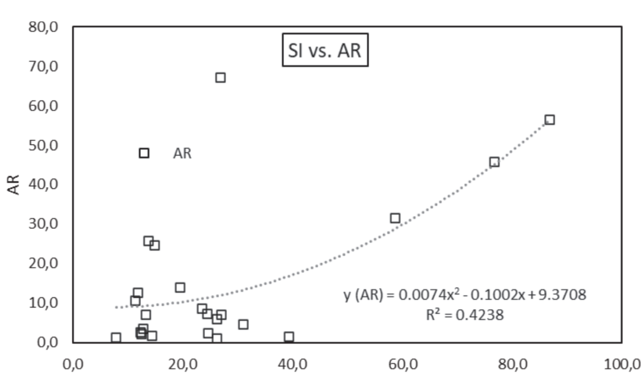

Figure 2. Polynomial relationship between soil suppressive index (SI) against *S. rolfsii* and aggregate ratio (AR).

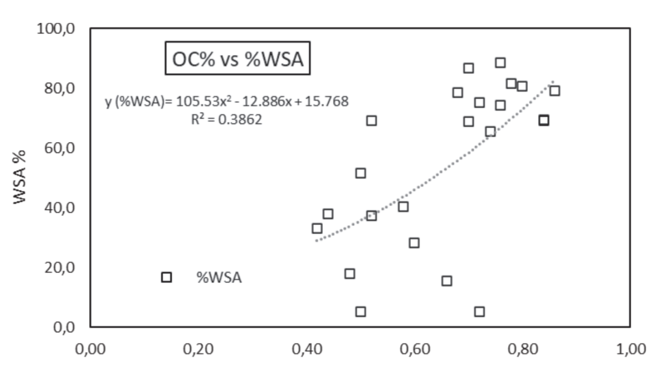

Figure 3. Polynomial relationship between soil OC% and %WSA.

Table 4. Two-tailed Pearson correlation coefficient among the selected soil parameters

Pearson correlation coefficient, r (2-tailed)																				
	SI#	pH	EC	OC	N	P	K	Sc	Clay	Silt	Sand	FC	BD	Porosity	WSA	AR	AS	SCo	MWD	GMD
SI	1	0.057	-0.406	0.405	0.293	-0.017	-0.287	-0.259	0.211	-0.229	-0.11	-0.082	0.12	-0.119	0.261	0.627**	0.283	0.101	0.377	0.19
pH		1	-0.500*	0.34	0.425*	-0.743**	0.099	-0.154	-0.243	0.357	0.055	-0.255	-0.196	0.197	0.564**	0.204	0.420*	0.229	0.177	0.263
EC			1	-0.092	-0.118	0.520*	0.487*	0.262	-0.134	-0.027	0.204	0.238	0.133	-0.134	-0.231	-0.421*	-0.267	0.119	-0.037	0.006
OC				1	0.974**	-0.101	0.431*	0.052	-0.058	0.193	-0.072	-0.271	-0.007	0.008	0.618**	0.238	0.559**	0.151	0.651**	0.633**
N					1	-0.147	0.462*	0.081	-0.126	0.281	-0.047	-0.322	-0.027	0.028	0.605**	0.18	0.557**	0.087	0.571**	0.576**
P						1	0.193	0.299	0.042	-0.239	0.129	0.156	0.161	-0.162	-0.419*	-0.019	-0.235	-0.281	-0.151	-0.264
K							1	0.116	-0.215	0.237	0.109	-0.31	-0.21	0.211	0.473*	-0.193	0.458*	0.078	0.283	0.372
Sc								1	0.023	-0.134	0.073	-0.255	-0.395	0.397	-0.045	-0.073	-0.099	-0.071	0.003	0.03
Clay									1	-0.695**	-0.828**	0.183	0.217	-0.215	-0.127	0.347	0.055	-0.304	0.166	0.138
Silt										1	0.172	-0.346	0.082	-0.082	0.327	-0.393	0.12	0.313	0.013	0.008
Sand											1	0.019	-0.362	0.358	-0.081	-0.169	-0.168	0.172	-0.238	-0.195
FC												1	0.477*	-0.478*	-0.728**	-0.216	-0.637**	-0.039	-0.460*	-0.424*
BD													1	-1.000**	-0.269	-0.157	-0.305	-0.033	-0.092	-0.198
Porosity														1	0.27	0.154	0.305	0.033	0.092	0.197
WSA															1	0.29	0.800**	0.34	0.719**	0.721**
AR																1	0.414*	-0.045	0.503*	0.437*
AS																	1	-0.094	0.618**	0.651**
SCo																		1	0.281	0.264
MWD																			1	0.949**
GMD																				1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

#SI= Soil suppressive index, Sc.= Sclerotial population of *S. rolfsii*/100 g soil, EC= Electrical conductivity (mmhos/cm), OC= Soil organic carbon (%), N= Total soil nitrogen (kg/ha), P= Available soil Phosphous (kg/ha), K= Available soil Potassium FC= Field capacity, BD= Bulk density, Porosity= soil porosity percentage, %WSA= Percent water stable aggregate, AR= Aggregate ratio, AS= Aggregate stability, SCo= Stability coefficient, MWD= Mean weight diameter, GMD= Geometric mean diameter, Sa%= Sand percentage, C%= Clay percentage, Si%= Silt percentage

Table 5. Total variance explained from the selected components

Total Variance Explained			
Component	Initial Eigenvalues	% of Variance	Cumulative %
1	5.977	29.885	29.885
2	3.258	16.291	46.176
3	2.435	12.175	58.351
4	2.382	11.908	70.26
5	1.396	6.979	77.238
6	1.186	5.931	83.17
Extraction Method: Principal Component Analysis			

and TOMS6 soil. Soil suppressiveness against *S. rolfsii* significantly positively correlated with soil aggregate ratio (AR). PCA explained the closeness of the parameters with soil suppressive index (SI) and aggregate stability (AS) according to the rotated matrix of PCA2.

Table 6. Rotated component matrix of Principal Component Analysis

Rotated Component Matrixa		
	Component	
Soil parameters	1	2
SI#	0.422	-0.532
pH	0.558	0.199
EC	-0.343	0.317
OC	0.771	0.005
N	0.752	0.092
P	-0.399	-0.035
K	0.364	0.499
Sc	-0.036	0.319
Clay	0.03	-0.815
Silt	0.174	0.557
Sand	-0.177	0.682
FC	-0.635	-0.348
BD	-0.282	-0.545
Porosity	0.282	0.544
WSA	0.91	0.203
AR	0.517	-0.487
AS	0.843	0.031
SCo	0.218	0.263
MWD	0.833	-0.154
GMD	0.833	-0.041
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization, a Rotation converged in 3 iterations		

#SI= Soil suppressive index, Sc.= Sclerotial population of *S. rolfsii*/100 g soil, EC= Electrical conductivity (mmhos/cm), OC= Soil organic carbon (%), N= Total soil nitrogen (kg/ha), P= Available soil Phosphous (kg/ha), K= Available soil Potassium FC= Field capacity, BD= Bulk density, Porosity= soil porosity percentage, %WSA= Percent water stable aggregate, AR= Aggregate ratio, AS= Aggregate stability, SCo= Stability coefficient, MWD= Mean weight diameter, GMD= Geometric mean diameter, Sa%= Sand percentage, C%= Clay percentage, Si%= Silt percentage

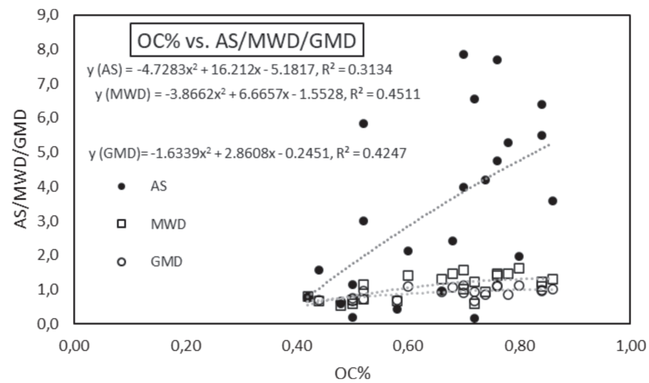

Figure 4. Polynomial relationship among soil OC% and AS/MWD/GMD.

Soil physicochemical constraints and their relationship with soil suppressiveness

The soil physicochemical parameters had been examined together with soil suppressiveness activity (SI). North 24 Parganas and Nadia districts of West Bengal had the dominance of clay loam soil. In this study we found positive relation of clay with disease suppressiveness against *S. rolfsii*. Some research found that there was a positive relation of SI with clay texture (Höper et al. 1995; Duffy 1997). However, some reports found that there was negative relation with clay (Workneh et al. 1993) or no relation (Hamel et al. 2005; Pérez-Piqueres et al. 2006) with SI. In new alluvial zone the higher clay contain was observed which associated with soil organic carbon (OC) and other organic binding agents such as the crop residues, root exudates, microbial decompositions and some other inorganic binding agents to maintain the AS of the soil (Manik et al. 2020).

According to the Pearson correlation study soil suppressive index was significantly correlated with (AR) with 1% level of significance. It was also observed that soil suppressiveness had slight positive correlation with

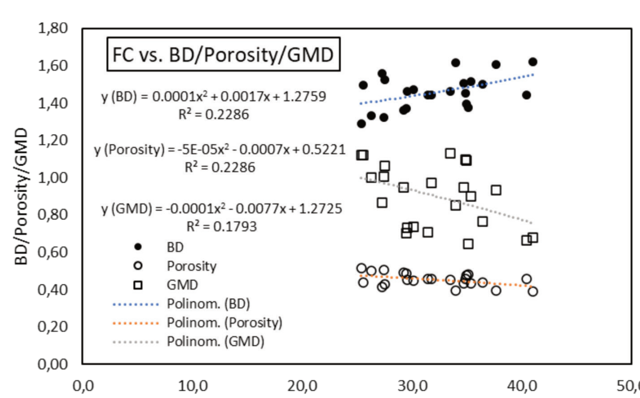

Figure 5. Polynomial relationship among soil FC and BD/Porosity/GMD.

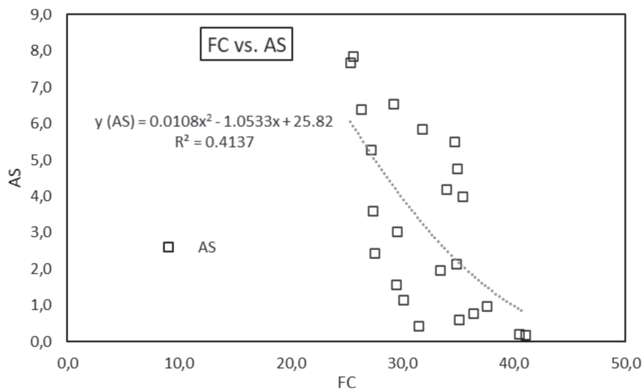

Figure 6. Polynomial relationship between soil FC and AS.

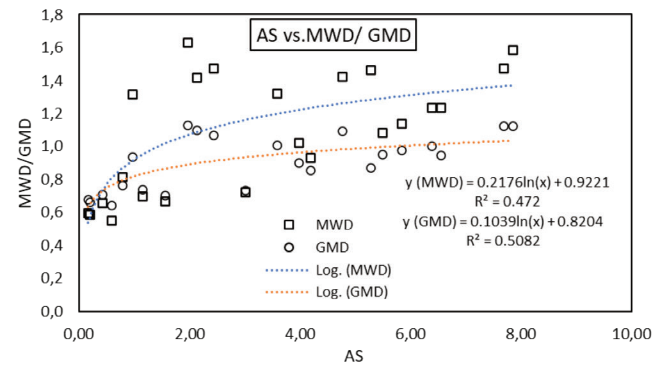

Figure 8. Logarithmic relationship among soil AS and MWD/GMD.

OC, N, clay, BD, AS, %WSA, MWD and GMD. It was observed that soil OC (Workneh et al. 1993; Pankhurst et al. 2002) and soil N (Hamel et al. 2005; Pankhurst et al. 2002; Hiddink et al. 2005) have positive relation with disease suppressiveness. As OC was the soil binding agent it was positively correlated with %WSA, AS, MWD, GMD, N and K (Fig. 3, 4 and Table 4). The SI vs. AR, OC vs. WSA%, OC vs AS/MWD/GMD, FC vs. BD/porosity/GMD, %WSA vs. AS/MWD/GMD, AS vs. MWD/GMD and MWD vs. GMD relationship curve depicted about mostly their polynomial or in some case logarithmic relationship (Fig. 2-9). In our statistical data analysis, we used principal component analysis (PCA), a data reduction method that took into account all of the soil microbiological parameters, soil microbial enzymatic activity, suppressive index, and disease incidence as variables. The PCA was carried out through the rotation of varimax with Kaiser normalization which converged in 6 iterations. In this extraction process KMO and Bartlett's test was carried out. The first two components were used to generate the 2-D plot (Fig. 1). Component 1 had an eigenvalue of 5.997 and accounted for 29.89% of the variance, while component 2 had an eigenvalue of 3.258 and accounted for 16.29% of the variance, as shown in Table 5. As indicated by the rotated matrix of components, PCA1 we did not obtain clear relation but as per PCA2, soil SI Index (-0.532) was closely related to BD (-0.545) and distantly related to K (0.499) and porosity (0.544) fulfil the 95% redundant cut off criteria (Table 6, Fig. 1). Few reports suggested that soil K had negative relation with SI (Oyarzun et al. 1998; Rimé 2003), whereas, many reports suggest that there was no relation (Duffy et al. 1997; Pérez-Piqueres et al. 2006; Pankhurst et al. 2002). Additionally, with AS (0.843) the closest parameters were MWD (0.833) and GMD (0.833) with 95% redundancy cut off that obtained from PCA1. Rice-vegetable cropping system had significantly higher AR, AS, GMD and MWD than rice-fallow cropping system (Manik et al. 2020). Again, the application of natural fertilizers in these soils for vegetable cultivation may be held responsible for increased soil AS (Manik et al. 2020). Changes in management approaches, according to Kay and Dexter (1990), affect both the surface area of aggregates exposure and

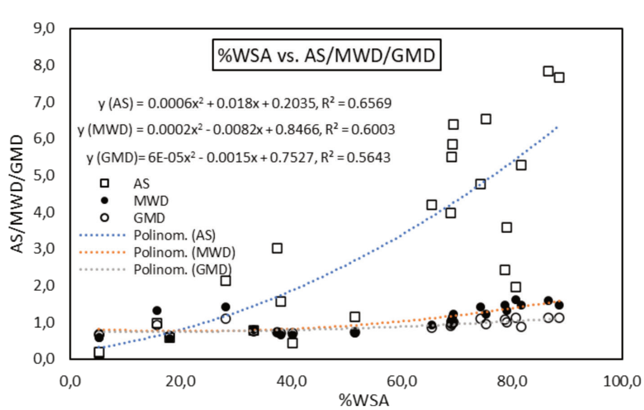

Figure 7. Polynomial relationship among soil %WSA and AS/MWD/GMD.

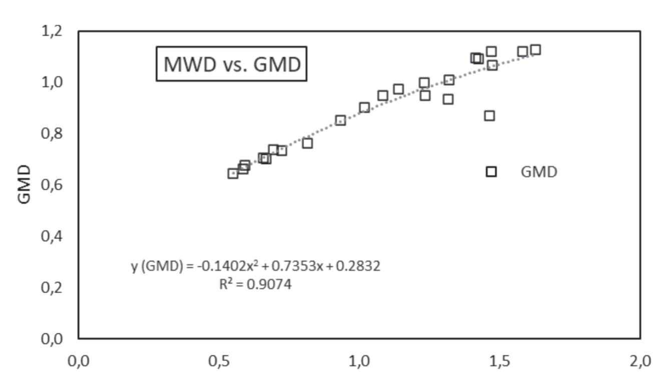

Figure 9. Polynomial relationship between soil MWD and GMD.

the miscibility of the clay for AS (Kay and Dexter 1990). Above all, plant roots, exudates, microbial biomass, crop residual management and organic manures endure the binding capacity of soil aggregates and increase the soil microbial diversity and abundance which perhaps allow the soil suppressiveness. Additionally, high compactness and maximized AS of soil hinder the optimum growth of pathogenic fungus *S. rolfsii* under soil environment even after encounter with susceptible crops.

CONCLUSION

Diseases in plants that are caused by pathogens present in the soil are the consequence of various and complex interactions between pathogens and plants, as well as soil components that are living and non-living. The deciding soil functions that lead to the underlying mechanisms of plant diseases are not fully comprehended, or hardly all of the mechanisms were associated with soil suppressiveness (Janvier et al. 2007). From this study we found AR, AS and bulk density were most determining parameters for *S. rolfsii* soil suppressiveness. Such indicators of soil healthiness would be extremely advantageous for risk prediction and technical assistance for good farming approaches. The holistic approach seems to be obvious to relate the potential key soil health abiotic and biotic indicators on a global scale. Though, the regional study has limitations to understand the universal key indicator of soil suppressiveness but is very much suitable for specific zonal or micro-climatic conditions. To achieve the suitable supervisory tools following the soil health indicators of soil sustainability and soil conservation will remain an ambitious task unless we do not consider more and more region-specific studies as well.

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