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Effects of Soil Physicochemical Properties on Basal Stem Rot Disease (*Ganoderma boninense*) in Oil Palm

Evan Purnama Ramdan [1,2], Arief Hartono [3], Giyanto Giyanto [3], Sri Hendrastuti Hidayat [3] and Widodo Widodo [3*]

[1] *Graduate School, IPB University, Indonesia*
[2] *Faculty of Industrial Technology, University of Gunadarma, Indonesia.*
[2] *Faculty of Agriculture, IPB University, Indonesia*

Abstract

This study investigated soil characteristics with the most significant influence on basal stem rot (BSR). Surveys and soil sampling were carried out at the research site located in Indonesia at 105.07° to 105.27° East Longitude and 5.26° to 5.33° South Latitude with an altitude of 100 m above sea level in June 2021. The sampling was conducted on three categories of land with mild, moderate, and severe incidences of disease. A total of 20 soil-related variables, including physicochemical properties as well as disease incidence and severity were analyzed through the Pearson correlation and Lasso regression. The results showed that four soil chemical properties, namely Mg, K, Na, and base saturation, were negatively correlated with the incidence and severity of BSR, while Mn had a positive correlation. The Lasso regression equation model that affects the disease incidence is Y = 91,67-20,66Mg-6,56K+0.19Mn (%Dev = 61%), whereas the equation affecting the disease severity is Y=101,68-1,70pH-21,92Mg-2,99K-0,10KB+0.05Mn (%Dev= 57,13%). These results can be used to guide decisions regarding BSR control in oil palm plantations. To reduce the incidence and severity of the disease, oil palm fertilization recommendations must pay attention to soil chemical properties, such as an increase in the pH and cationic base factors (Mg, K, and BS) and a decrease in Mn.

Keywords: disease incidence; disease severity, soil health, suppressive soil, agroecology

1. INTRODUCTION

Ganoderma boninense is a pathogen in the ecosystem of oil palm plantations responsible for basal stem rot (BSR) (Salsabila *et al*., 2022). This disease is a serious problem in Indonesia, particularly Sumatra, where the infection rate reaches 45% (Paterson, 2019) with an estimated economic loss of up to 67.73%. (Kamu *et al*., 2021). Recently,in areas where oil palm plantations have experienced third to fourth generation replanting, the impact of *G. boninense* was reported on younger plants with earlier and more severe disease (Priwiratama *et al.,* 2020). Corley and Tinker (2016) also stated that young plants die within 1-2 years of diseases appearing, while mature plants die 3 years later. Presently, various disease control strategies, including the use of cultivation control techniques and Ganoderma-tolerant oil palm varieties, have not shown satisfactory results in suppressing disease in the field (Priwiratama *et al.*, 2020).

The continuous monoculture cultivation of oil palm over extensive periods on a large scale causes a decrease in soil quality and disruption of the ecological balance such as reduced soil microorganisms. Although high microbial population density is beneficial for pathogen suppression, this can only be achieved in fertile soil (Ramdan *et al*., 2022). This necessitates the need to find a control strategy with a bioecological approach for *Ganoderma*. Given that *G. boninense* has a complete life cycle, it is consumed by pathogens that inhabitant permanently in soil. This pathogen acts as a saprophyte decomposing plant remains in the wild, or becomes a parasite and invades the plants. Consequently, soil quality is one of the aspects that need to be investigated in developing novel management measures.

Previous research proved that soil quality directly impacts plant health and supports sustainable growth. Healthy soil depends on the physical, chemical, and biological processes within the ecosystem. The physicochemical properties directly influence disease development affecting the population, reproduction, resistance, distribution, and the ability of pathogens to infect and cause disease in plants (Bande *et al*., 2016). Meanwhile, the indirect influence is associated with plant defense enzymes (Anothai and Chairin, 2020).

According to the requirements for oil palm cultivation, suitable land does not have significant restrictions, implying that oil palm production will continue to expand. Mimboro *et al*. (2015) formulated an oil palm suitability assessment based on the physicochemical features of soil, as shown in Table 1. Ayudra *et al*. (2020) stated there were no significant variations in soil texture, nitrogen, C-organic, CEC, magnesium, calcium, salt, or K_2O between healthy and diseased oil palm trees, while P-element levels changed significantly. Diseased oil palm had lower P levels compared to the standards established by Mimboro *et al*. (2015). Furthermore, Puspika and Pinem (2018) described the physicochemical features of soil in Ganoderma-infected oil palm fields.

Investigating the relationship between the physicochemical properties of soil, as well as BSR is crucial due to the differences in oil palm plantations. Therefore, this research aimed to determine soil characteristics with the most significant influence on BSR.

2. METHODOLOGY

2.1 Research Location and Sampling Design

This research was conducted at *PT Perkebunan Nusantara VII*, Rejosari-Pematang Kiwah Unit, Lampung, Indonesia. The sampling site is located at 105.07° to 105.27° East Longitude and 5.26° to 5.33° South Latitude with an altitude of 100 m above sea level (Figure 1). The land used is limited to plantation areas that have similarities in soil type (Inceptisols) and cropping generation. Meanwhile, the oil palm observed was the second generation, with the planting year being 2009. Surveys and sampling were conducted on land with mild, moderate, and severe disease incidence of <10%, 11-50%, and > 50% respectively. These categories were determined from previous research (Ramdan *et al*. 2023).

The sampling design used the method proposed by Sahner *et al*. (2015) with slight modifications. Each location consisted of 5 plots, measuring 50 m^2, hence, there were 15 sampling locations. For each plot, 5 sub-plots of 10 m^2 consisting of 3 oil palm trees were selected to serve as soil sampling points and to measure disease incidence and severity. Soil sampling was carried out in each sub-plot, at 5 distinct points (1 at the corner and 1 in the middle) at a depth of 30 cm. Subsequently, each sample from the same plot was combined to obtain a total of 15.

2.2 Measurement of Disease Incidence and Severity

Disease incidence (DI) was measured by counting the number of oil palm plants with BSR disease and those in the process of dying, divided by the total number in each observation plot. Disease severity (DS) was assessed from each plot by the scoring criteria in Table 2. DS was calculated using the formula in Equation 1.

$$DS = \frac{\Sigma(n_i \times v_i)}{N \times V} \times 100\% .... (1)$$

Where DS is disease severity, n_i is the number of plants with an i-score, v_i is the disease scale value, N is the number of plants observed, and V is the highest score.

2.3 Soil Physicochemical Properties

The physicochemical properties of soil samples were analyzed using the criteria from the Soil Research Institute (2009) which included soil textures namely sand, loam, and clay. Soil pH H_2O and HCl were determined using a meter with a soil-to-solvent ratio of 1:5, while total P2O5 (mg/100 g) and K_2O were examined by 25% HCl extraction. C-organic was determined by wet destruction and potassium bichromate according to the Walkley and Black method, Cation Exchange Capacity (CEC) was assessed using a saturated solution with 1 N ammonium acetate pH 7.0, and base saturation was calculated by dividing the amount of base with CEC and multiplied by 100. Each method followed analysis guidelines from the Soil Research Institute (2009).

2.4 Relationship Analysis of Soil Physicochemical Properties with Disease Incidence and Severity

Analysis of variance was used to examine differences in the physicochemical parameters of soil at the three research locations, and the Tukey test was utilized at the 5% level. Pearson's correlation analysis and the Bonferroni test at a 5% level were used to assess the linear association between soil physical attributes, disease incidence, and severity. Additionally, the Lasso method was employed in regression analysis to investigate the effect of soil physicochemical parameters on disease incidence and severity. All testing in this research was carried out using the R Studio software.

3. RESULTS

3.1 BSR disease and soil physicochemical characteristic

Based on the analysis of variance, there was no significant difference in the incidence of BSR from the 3 locations. The land with the medium category had the highest percentage of DS at 41.07%, followed by the severe at 37.0%. DS in the medium and severe category areas had no significant effect but a 20.53% difference was found in the mild area, as shown in Figure 2.

The 3 land locations exhibited low fertility as indicated by the low C-organic content in the range of 0.7%-0.8%, while CEC averaged 13.3–14.6 cmol(+)/kg. Despite the low soil fertility condition, the analysis of variance indicated a significant difference ($P<0.05$) in phosphorus, as shown in Table 3. The severe disease incidence category area had a phosphorus level of 87.5 ppm, compared to 378.6 ppm and 499.1 ppm in the medium and mild categories, respectively.

3.2 Correlation between Physicohemical Properties of Soil with Disease Incidence and Severity

Soil chemical properties have the most significant correlation with the incidence and severity of BSR in Table 4. Inverse correlations were shown by the variables Mg, K, Na, and BS with coefficients between -0.57 to -0.74 or from moderate to strong. An increase in these 4 variables caused a decrease in the incidence and severity of the disease. Meanwhile, the Mn variable exhibited a unidirectional correlation with a coefficient of 0.66 in the moderate category. An increase in the Mn content of soil led to a rise in the incidence and severity of BSR.

The results in Table 5 showed a moderate to strong correlation between the physicochemical properties of soil. The coefficient matrix indicated that these properties indirectly influenced BSR by affecting chemical characteristics having a direct relationship with the disease. For example, the element Mn was influenced by chemical properties in the form of N, CEC, BS, H, and Fe, as well as physical properties including sand and clay fractions. The base saturation was affected by CEC, Fe, Zn, sand, and clay, while Mg was influenced by K, Na, BS, and Mn. The results also showed that K was impacted by Mg and Na, while Na was affected by Mg.

3.3 Factors of Physicochemical Characteristics of Soil Affecting Stem Rot Disease

According to the Lasso regression analysis, soil properties that affected disease incidence were Mg, K, and Mn, while pH, Mg, K, BS, and Mn influenced disease severity, as shown in Table 8. Equation 3 shows the Lasso regression model for the effect of soil physicochemical variables on disease incidence. Model equation 2 showed that increasing Mg and K alongside a reduction in Mn significantly decreased disease incidence. Meanwhile, Equation 3 shows the regression model for soil physicochemical variables affecting disease severity. The results suggested that elevating pH, Mg, K, and base saturation with decreasing Mn, reduced the severity of BSR.

$$Y = 92.19 - 20.77Mg - 6.93K + 0.19Mn \ (\%Dev = 60\%) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Y = 98.46 - 4.25pH - 23.12Mg - 3.32K - 0.07BS + 0.03Mn \ (\%Dev = 62\%) .. (3)$$

4. DISCUSSION

This research discovered that soil characteristics can be used as a new method of controlling the disease. Soil chemical properties such as Mg, K, Na, BS, and Mn correlated with the incidence and severity of BSR. The key chemical attributes that affect the DI and DS, as indicated in Table 6, include pH, Mg, K, BS, and Mn. Basic cations such as Mg, K, and BS play a role in influencing plant resistance to disease, this effect was explained in Equations 2 and 3. Potassium and magnesium have significant roles in maintaining the structural integrity of plant cell walls as well as increasing resistance to diseases. According to Anothai and Chairin (2020), potassium can stimulate the activity of polyphenol oxidase and peroxidase, both of which are involved in inducing resistance to BSR in oil palm. Mg has been reported to have an indirect impacts on plant diseases, such as its involvement in chlorophyll and enzyme systems, which are crucial for photosynthetic substrates and physiological processes relevant to plant defense mechanisms (Huber and Jones, 2013). Maintaining soil pH levels has been linked to suppressing the transmission of Ganoderma to roots by increasing the biomass. Furthermore, a pH shift toward alkaline suggests microbial activity that aids decomposition, ensuring plant nutrients are sufficient and bolstering resistance to harmful diseases (Rahman and Othman, 2020).

This study found that an increase in soil Mn significantly elevated the incidence and severity levels of BSR. This contradicts previous reports stating that increased Mn reduced disease severity by elevating tissue resistance to degradation caused by pectolytic enzymes from pathogens, causing maceration or soft rot (Huber and Jones, 2012). Mn is also a potential cofactor for phenylalanine ammonia-lyase (PAL) and the formation of lignin. Discrepancies between the results can be attributed to the different forms of Mn in soil, namely Mn^{2+} or MnO_2. This research primarily focused on the oxidized form (MnO_2), due to the sandy loam conditions (Table 3) and aerobic environment, leading to the oxidation of Mn^{2+} into MnO_2 which was insoluble and precipitated, rendering it unavailable for plants.

According to Table 3, significant differences in soil characteristics among the three oil palm fields were observed in relation to the phosphorus variable. The lower the P content, the greater the disease severity and incidence. This was consistent with the Pearson's correlation analysis results presented in Table 4. Based on the analysis, P had a weak negative correlation with disease incidence and severity, which also corresponded to the predetermined land categories. The land with medium disease incidence showed the highest severity compared to others, as shown in Figure 2. This was due to the higher sand content in the land with medium disease incidence, as depicted in Table 3. According to Susanto *et al*. (2013), several places in Indonesia have gardens adjacent to sandy soil conditions experiencing a high incidence of disease. The incidence and severity of BSR in the field were in the moderate to high range with successive percentages of 30.67% - 52.00% and 20.53% - 41.07%, respectively.

Soil fertility condition at the research site was in the low category, indicated by C-organic values below 1%, as shown in Table 3. The reduced nutrient availability can disrupt soil physical properties and the survival of microorganisms. The connection between low C-organic content decreased soil fertility was reported by Ramdan *et al*. (2023). Susanto *et al*. (2013) also discovered that low soil nutrient levels reduced plant resistance to pathogenic infections. This was further exacerbated by excessive use of inorganic fertilizers and pesticides, tillage, as well as biomass loss due to harvesting (Guillaume *et al*., 2016). Therefore, a long-term reduction in C-organic can diminish plant fitness (Goh *et al*., 2017).

This research contributed to ecological investigations of BSR, focusing on the abiotic soil environment. The novelty lies in the identification of soil characteristics with the greatest influence on the incidence and severity of BSR. The results can be used as a reference for control alternatives in relation to plant nutrition manipulation. Further research is needed to determine the effective dose of potassium factor (K, Mg, and Na) in suppressing BSR disease. This method could serve as a recommendation for fertilization, contributing not only to plant nutrition but also enhancing resistance to the disease.

5. CONCLUSIONS

In conclusion, the incidence and severity of BSR in the field ranged from moderate to high categories with values of 30.67% - 52.00% and 20.53% - 41.07%, respectively. Soil characteristics that were negatively correlated included K, Mg, Na, and KB, while Mn had a positive correlation. Based on the Lasso regression equation model, Mg, K, and Mn had a significant impact on disease incidence, as denoted by the equation: Y = 92.19-20.77Mg-6.93K+0.19Mn (%Dev = 60%). Similarly, the Lasso regression equation for disease severity prediction was Y = 98.46-4.25pH-23.12Mg-3.32K-0.07KB+0.03Mn (%Dev = 62%), with pH, Mg, K, KB, and Mn all having a substantial effect. Further research is needed to determine both the optimal pH level and the effective dose of the basic cations (K, Mg, and BS) along with Mn. This determination is crucial to enable their inclusion in fertilization recommendations. These variables aside from being required for plant nutrition, can also boost resistance to BSR.

6. ACKNOWLEDGEMENTS

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Table 1. The suitability of oil palm land based on the physicochemical properties of soil

Suitable Land Criteria	Unit	Value
Sand	%	37,4-75
Clay	%	11,8-36,8
CEC	cmol (+) / kg	>3,8
pH	-	4,9-6,5
C-organic	%	>1,1
BS	%	>16,3
Al	%	<39,4
N total	%	>0,06
P-Ols	Ppm	>16,8
K	cmol (+) / kg	>0,1

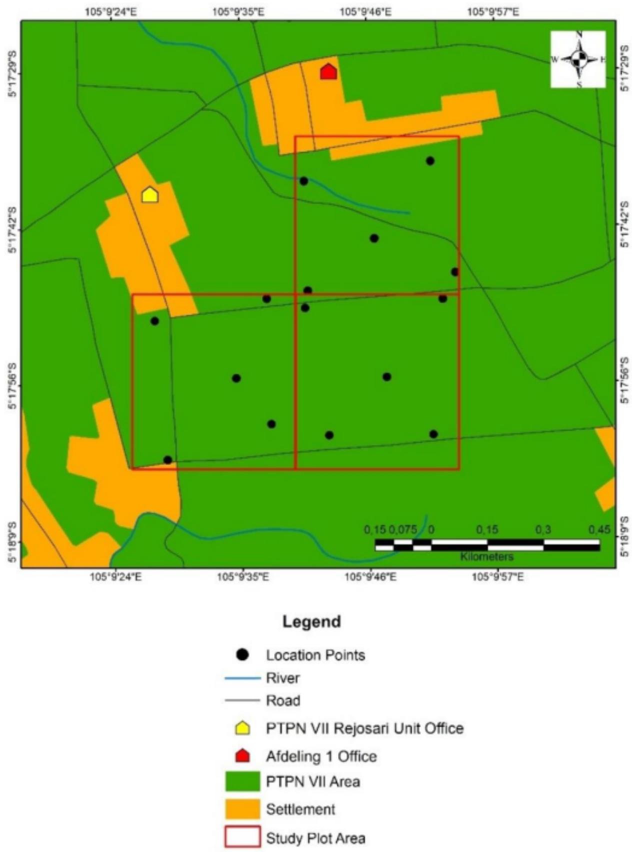

Figure 1. The coordinate point for measuring the incidence and severity of the disease and for soil sampling.

Table 2. BSR disease severity score (Abdullah *et al*., 2003)

Score	Disease severity Level	Observed external features
0	Health	Unopened leaves, rotting stems, and fungal fruiting bodies are all diseases of healthy plants.
1	Mild	Spear leaves not opening, and stunted growth at the top, resulting in a flat surface of the leaf crown and leaves at the top shorter in shape than those below.
2	Moderate	The leaves are dull and pale yellowish green; the lower midrib and leaflets on the fifth and sixth circles have dried up.
3	Severe	When the plant is dry, the crown is shortened, the fruit is small or non-existent, the three spear leaves do not open, and the plant is nearly dead.
4	Death	When the basidiocarp grows around the base of the trunk or palm tree, all of the leaves will break, dry up, and cling to the tree.

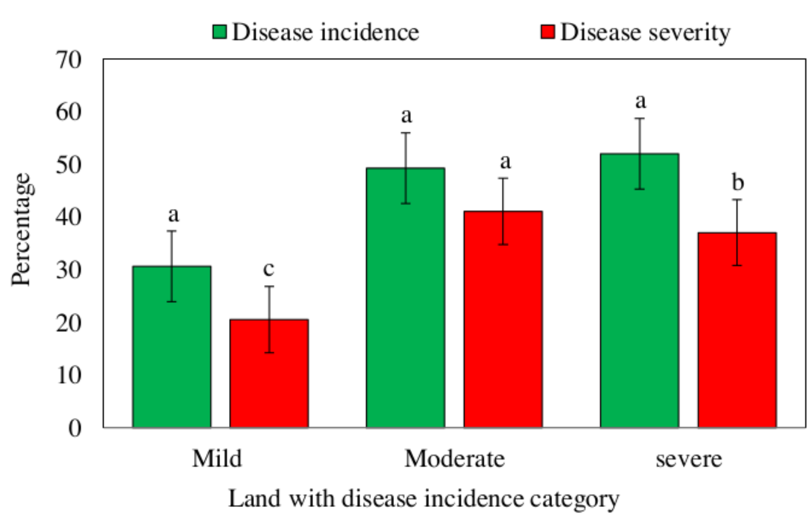

Figure 2. The incidence and severity of oil palm BSSR disease on land are classified as mild, moderate, or severe.

Table 3. Physicochemical properties of soil on site

Soil properties	Unit	Location					
		Field with mild disease incidence categories		Field with moderate disease incidence categories		Field with severe disease incidengories	
		Value	Status	Value	Status	Value	Status
pH H_2O	1:05	6.7a	N	6.6a	N	6.8a	N
pH KCl	1:05	6.2a	N	6.1a	N	6.3a	N
C-organic	%	0.7a	VL	0.7a	VL	0.8a	VL
N total	%	0.1a	L	0.1a	L	0.2a	L
P olsen	ppm	54.2	VH	42.9a	VH	50.3a	VH
P HCl	ppm	499.1b	VH	478.6b	VH	87.5a	VH
Ca	cmol(+)/kg	4.3a	L	3.6a	L	4.6a	L
Mg	cmol(+)/kg	2.5a	H	2.2a	H	2.2a	H
K	cmol(+)/kg	1.6a	VH	1.4a	VH	1.2a	VH
Na	cmol(+)/kg	0.7a	M	0.6a	M	0.6a	M
CEC	cmol(+)/kg	13.3a	L	13.9a	L	14.6a	L
BS	%	71.6a	H	57.5a	M	58.8a	M
Al	cmol(+)/kg	nd	-	nd	-	nd	-
H	cmol(+)/kg	0.1a		0.1a		0.1a	
Fe	ppm	73.3a	VH	47.8a	H	78.7a	VH
Cu	ppm	1.3a	H	0.8a	H	1.6a	H
Zn	ppm	2.6a	H	2.3a	H	2.3a	H
Mn	ppm	38.9a	VH	37.9a	VH	60.5a	VH
Sand	%	49.6a	Sandy clay loam	50.2a	Sandy clay loam	48.9a	Sandy clay loam
Silt	%	25.9a		29.5a		25.6a	
Clay	%	24.4 a		20.3a		25.5a	

On the Tukey test, different numbers in the same row indicate a significant effect (P<0.05). N: neutral, VL: very low, L: low, M: moderate, H: high, VH: very high, and; not detected.

Table 4. The coefficient of correlation between soil physicochemical properties and BSR disease

No	Location	Disease Incidence (%)	Disease Severity(%)
1	pH H_2O	-0.36	-0.40
2	pH KCl	-0.24	-0.35
3	C-organic	0.18	0.03
4	N tot	0.17	0.21
5	P Ols	0.24	0.17
6	P HCl	-0.41	-0.33
7	Ca	-0.20	-0.29
8	Mg	-0.74*	-0.74*
9	K	-0.64*	-0.58*
10	Na	-0.65*	-0.63*
11	CEC	0.30	0.37
12	BS	-0.57*	-0.63*
13	H	0.34	0.36
14	Fe	0.23	0.26
15	Cu	-0.24	-0.21
16	Zn	-0.10	-0.22
17	Mn	0.66*	0.60*
18	Sand	-0.32	-0.26
19	Silt	0.12	0.09
20	Clay	0.30	0.26

Significant correlation with $p < 0.05$ on Bartlett's test of sphericity

Table 5. Pearson's correlation coefficient between soil physicochemical properties

Soil properties	pH H_2O	pH KCl	C org.	N Tot.	P Ols	P HCl	Ca	Mg	K	Na	CEC	BS	H	Fe	Cu	Zn	Mn	Sand	Silt	Clay
pH H_2O	1	0.8*	0.1	-0.2	-0	-0	0.7*	0.3	-0	0	-0.6*	0.7*	-0	-0.6*	0.1	0.2	-0.6*	0.5	-0	-0
pH KCl		1	0.4	-0.4	-0.3	-0	0.4	0.1	0.1	0.1	-0.3	0.5	-0	-0	0	0.1	-0	0.3	-0	-0
C org.			1	-0.1	0.28	-0	0.2	0.1	-0	-0	0.1	0	0.3	-0	-0	0.2	0.1	-0	0	0
N Tot				1	0.15	0.1	-0	-0	-0	-0	0.2	-0	0.6*	0.5	0.2	-0.4	0.5*	-0	0	0.3
P Ols					1	0.2	0.1	0.1	-0	-0	0	0	0.2	0.2	0.1	0.3	0.3	-0	-0	0.3
P HCl						1	-0	0.3	0.4	0.4	-0.4	0.3	-0	0	0	0.1	-0	0.2	0	-0
Ca							1	0.4	-0	-0	-0.3	0.7*	-0	-0	0.3	0.7*	-0	0.4	-0	-0
Mg								1	0.6*	0.7*	-0.2	0.6*	-0	-0	0.3	0.4	-0.5*	0.3	-0	-0
K									1	0.9*	0	0.2	-0	0.1	0.2	-0.1	-0	0.1	-0	0
Na										1	-0.1	0.4	-0	-0	0.3	0.1	-0	0.3	-0	0
CEC											1	-0.8*	0.5*	0.4	0.1	-0.1	0.6*	-0.6*	0	0.7*
BS												1	-0	0.5	0.2	0.4	-0.7*	0.7*	-0	-0.6*
H													1	0.2	-0	-0.3	0.5*	-0.5*	0	0.5
Fe														1	0.4	-0.2	0.8*	-0	-0	0.8*
Cu															1	0.5	0.1	0.1	-0	0.3
Zn																1	-0	-0	0	0
Mn																	1	-0.6*	-0	0.8*
Sand																		1	-0.7*	-0.7*
Silt																			1	-0
Clay																				1

In Bartlett's test of sphericity, numbers with gray backgrounds show significance ($P<0.05$).

Table 6. Lasso regression coefficient between soil physicochemical properties with BSR disease

Variables	Disease Incidence	Disease Severity
Intersep	92.19	98.46
pH H_2O	0.00	0.00
pH KCl	0.00	-4.25
C-organic	0.00	0.00
Total N	0.00	0.00
P Olsen	0.00	0.00
P HCl	0.00	0.00
Ca	0.00	0.00
Mg	-20.76	-23.12
K	-6.49	-3.32
Na	0.00	0.00
KTK	0.00	0.00
BS	0.00	-0.07
H	0.00	0.00
Fe	0.00	0.00
Cu	0.00	0.00
Zn	0.00	0.00
Mn	0.19	0.03
Sand	0.00	0.00
Silt	0.00	0.00
Clay	0.00	0.00

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