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EFFECTS OF SOIL PHYSICOCHEMICAL PROPERTIES ON BASAL STEM ROT DISEASE (*GANODERMA BONINENSE*) IN OIL PALM

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A B S T R A C T

This study investigated soil characteristics that have the most significant influence on basal stem rot (BSR). Surveys and soil sampling were carried out at the research site located in Lampung, Indonesia in June 2021. The sampling was conducted on three categories of land with mild, moderate, and severe disease incidences. 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 = 92,19-20,77Mg-6,93K+0.19Mn (%Dev = 60%), whereas the equation affecting the disease severity is Y=98,46-4,25pH-23,12Mg-3,32K-0,07KB+0.03Mn (%Dev=62%). These results can guide decisions regarding BSR control in oil palm plantations. To reduce the disease intensity in oil palms, fertilization recommendations must pay attention to soil chemical properties, such as an increase in pH and cationic base factors (Mg, K, and BS) and a decrease in Mn.

Keywords: disease incidence; disease severity, soil health, suppressive soil, agro-ecology.

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 severe problem in Indonesia, particularly in 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 three years later. Various disease control strategies, including cultivation control techniques and *Ganoderma*-tolerant oil palm varieties, have not shown satisfactory results in suppressing disease in the field (Priwiratama *et al.,* 2020).

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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 benefits pathogen suppression, this can only be achieved in fertile soil (Ramdan *et al.,* 2022). This necessitates finding a control strategy with a bio-ecological 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 that remains in the wild or becomes a parasite that invades the plants. Consequently, soil quality is one aspect that needs 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 ecosystem's physical, chemical, and biological processes. 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. Ayundra *et al.* (2020) stated 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 than the standards Mimboro *et al.,* established (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 and BSR is crucial due to the differences in oil palm plantations. Therefore, this research aimed to determine the effect and correlation of soil physicochemical properties on BSR intensity.

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

Soil Property	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

METHODOLOGY: Research Location and Sampling Design: This research was conducted at PT Perkebunan Nusantara VII, Rejosari-Pematang Kiwah Unit, and 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 is limited to plantation areas with similar soil types (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 m2. Hence, there were 15 sampling locations. For each plot, five sub-plots of 10 m2 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 five 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.

Measurement of Disease Incidence and Severity: Disease incidence (DI) was measured by counting the number of oil palm plants with BSR symptoms such as unopened spear leaves, dull and pale yellowish green leaves, basidiocarp appearing around the base of the stem, broken leaves, drying up and clinging to the tree, 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.

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

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

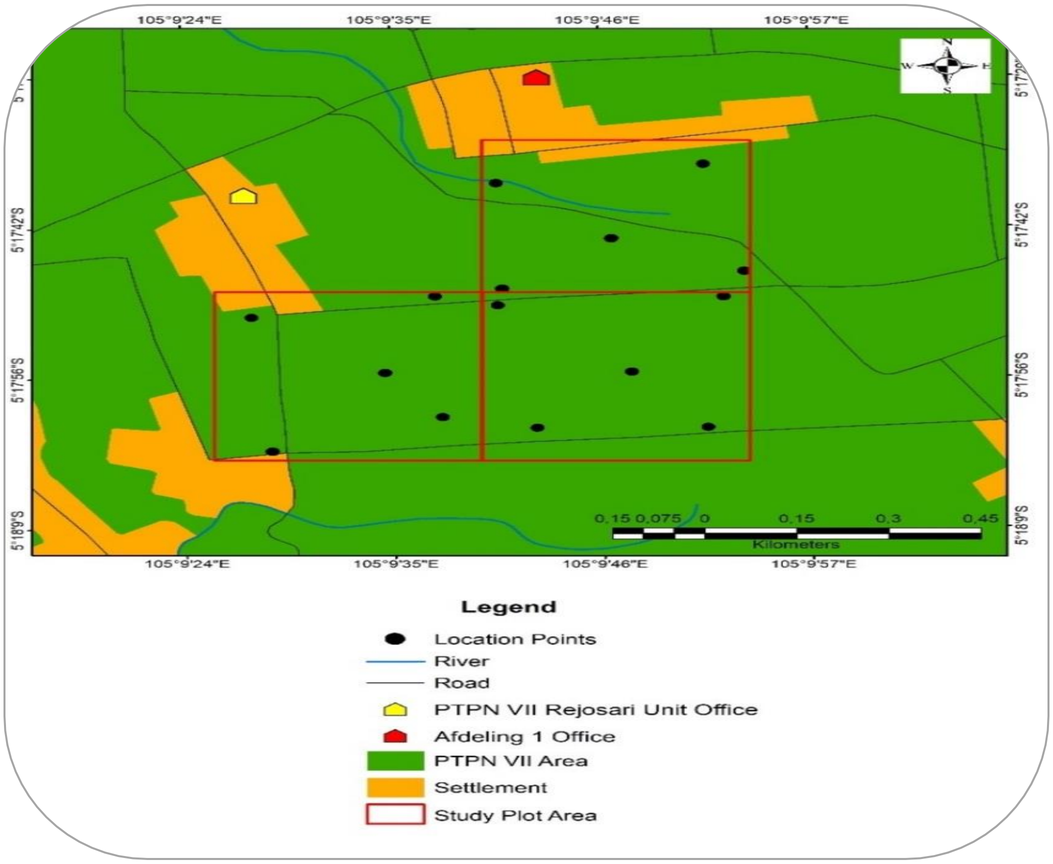

Figure 1. Field site of oil palm plantations where disease observations and soil samples were carried out. The numbers outside of the box indicate the location coordinates.

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

Score	Disease severity Level	Observed external features
0	Health	There is no existence of fruiting bodies, no foliar symptoms, and no evidence of rotting at the base of the stem
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.

Soil Physicochemical Properties: The physicochemical properties of soil samples were analyzed using the criteria from the Soil Research Institute (2009), which included soil textures, sand, loam, and clay. Soil pH H_2O and pH HCl were determined using a meter with a soil-to-solvent ratio of 1:5, while total P_2O_5 (mg/100 g) and K2O 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.

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. The correlation coefficient is the basis for assessing the proximity of the relationship between soil physicochemical attributes and BSR disease intensity. A correlation coefficient value close to 1 indicates a perfect positive correlation, meaning that if one variable increases, the other also increases. In contrast, a correlation coefficient closes to -1 indicates a perfect negative correlation, meaning that if one variable increases the other decreases.

The Lasso method was also employed in regression analysis to investigate the effect of soil physicochemical parameters (independent variables) on disease incidence and severity (dependent variables). The result of the analysis was a regression equation model with a deviance value to assess the equation model obtained. All testing in this research was carried out using the R Studio software.

RESULTS

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. However, significant differences were shown in the disease severity at these locations. The land with the medium category had the highest percentage of DS at 41.07%, followed by the severe at 37.0% and the mild at 20.53%, as shown in Figure 2.

The three 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

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 incidence categories	
		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		50.2a		48.9a	
Silt	%	25.9a	Sandy clay loam	29.5a	Sandy clay loam	25.6a	Sandy clay loam
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, nd: not detected.

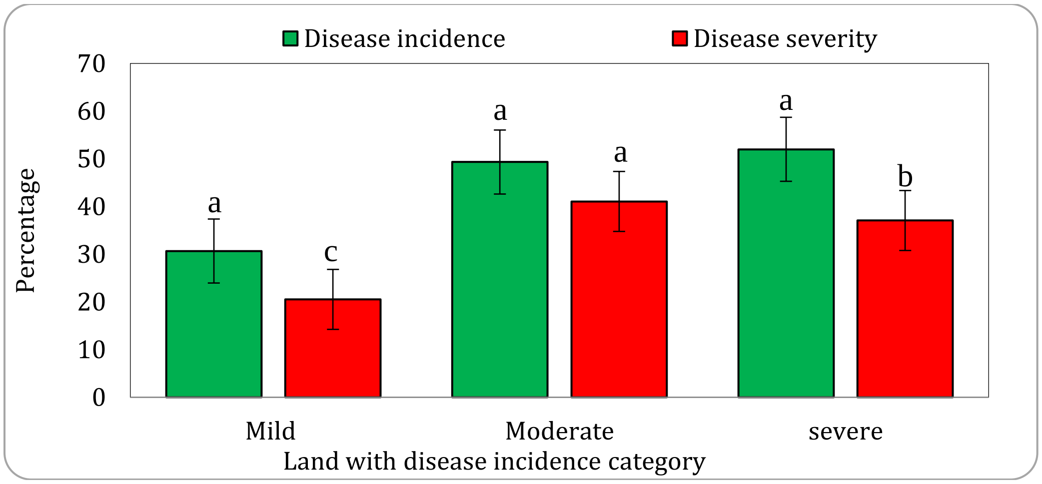

Figure 2. The incidence and severity of BSR disease on oil palm with three different categories, i.e. mild, moderate and severe disease incidence

Correlation between Physicochemical Properties of Soil with Disease Incidence and Severity: Soil chemical properties have the most significant correlation with the incidence and severity of BSR, as shown in Table 4. Inverse correlations were shown by the variables Mg, K, Na, and BS with coefficients between -0.57 and -0.74 or from moderate to strong. An increase in these four 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 directly related to the disease. For example, the element Mn was influenced by chemical properties in N, CEC, BS, H, and Fe and physical properties, including sand and clay fractions. The base saturation was affected by CEC, Fe, Zn, sand, and clay, while K, Na, BS, and Mn influenced Mg. The results also showed that Mg and Na impacted K, while Na was affected by Mg.

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

I* Significant correlation in Bartlett's test of sphericity (P<0.05).

Factors of Physicochemical Characteristics of Soil Affecting Basal 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 and reducing 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.

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

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

DISCUSSION

This research confirmed that soil characteristic should be considered as an important factor in controlling BSR disease. Soil chemical properties such as Mg, K, Na, BS, and Mn correlated with the incidence and severity of BSR. The critical 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 and increasing resistance to diseases. According to Anothai and Chairin (2020), potassium can stimulate the activity of polyphenol oxidase and peroxidase, which induce resistance to BSR in oil palms. Mg has been reported to indirectly impact 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 sufficient plant nutrients and bolstering resistance to harmful diseases (Rahman and Othman, 2020).

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

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, 2013). Mn is also a potential cofactor for phenylalanine ammonia-lyase (PAL) and lignin formation. 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 (MnO2) due to the sandy loam conditions (Table 3) and aerobic environment, leading to the oxidation of Mn2+ into MnO2, 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 regarding 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 in Table 4. Based on the analysis, P had a weak negative correlation with disease incidence and severity, corresponding 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 that are experiencing high disease incidence. 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 conditions at the research site were 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 and 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, pesticides, tillage, and 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 identifying soil characteristics that significantly influence the incidence and severity of BSR. The results can be used as a reference for control alternatives about 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 to plant nutrition and enhancing resistance to the disease.

CONCLUSIONS

Soil physicochemical properties of base cations (K, Mg, Na, and KB) and Mn were closely related to stem base rot disease incidence and severity. However, pH, Mg, K, and Mn significantly influenced disease incidence and severity. Based on the findings of this study, stem base rot disease can be reduced by increasing pH, basic cations (K, Mg, and KB), and decreasing Mn. t. Further research is needed to determine 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. Aside from being required for plant nutrition, these variables can also boost resistance to BSR.

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REFERENCES

Abdullah, F., G. N. M. Illia, M. Nelson, M. Z. Nur Aini Izzati and Y. Ummi Kalsom. 2003. Disease assessment and the efficacy of *Trichoderma* as a biocontrol agent of basal stem rot of oil palm. Research Bulletin Science Putra, 11: 31-33.

Anothai, J., and T. Chairin. 2020. Soil physicochemical properties are closely associated with fungal enzymes and plant defense enzymes in *Ganoderma*-infected oil palm orchards. Plant and Soil, 456: 99-112

Ayundra, S. D., S. Suwandi, S. Herlinda, H. Hamidson, R. Wandri and D. Asmono. 2022. Soil physicochemical properties in respect to plant health in *Ganoderma* infested oil palm plantation. Journal of Scientific Agriculture, 6: 9-13.

Bande, L. O. S, A. Wahab, H. Bambang, S. Somowiyarjo and B. H. Sunarminto. 2016. Correlation of physical and chemical soil characteristics with the intensity of foot rot disease of black pepper. Journal Penelitian Tanaman Industri, 22(2): 63-70.

Corley, R. H. V. and P.B.H Tinker. 2016. The Oil Palm 5th edition. Wiley-Blackwell, West Sussex, United Kingdom.

Goh, Y.K., C. K. Lim, C. R., Cheng, S. Y. Tan, L. W. Cheah, P. G. Ah Tung, Y. K. Goh and K. J. Goh. 2017. Effects of chemical properties of different soil in *Ganoderma* disease in oil palm (*Elaeis guineensis*). Oil Palm Bulletin, 75: 17-26.

Guillaume T., A. M. Holtkamp, M. Damris, B. Brummer and Y. Kuzyakov. 2016. Soil degradation in oil palm and rubber plantations under land resource scarcity. Agriculture, Ecosystems, & Environment, 232: 110-118.

Huber, D.M. and J. B. Jones. 2013. The role of magnesium in plant disease. Plant and Soil, 368: 73-85.

Kamu, A., K. P. Chong, A. S. Idris, G. Darmesah, and C. M. Ho. 2021. Estimating the yield loss of oil palm due to *Ganoderma* basal stem rot disease by using Bayesian model averaging. Journal of Oil Palm Research, 33(1): 46-55.

Mimboro, P. 2015. Development of Land Suitability Criteria for Oil Palm (*Elaeis guineensis* jacq.) In the area of Pt. Perkebunan Nusantara-III, North Sumatra (Doctoral dissertation, Bogor Agricultural University (IPB).

Paterson, R. R. M. 2019. *Ganoderma boninense* disease of oil palm to significantly reduce production after 2050 in Sumatera if Projected Climate Change Occurs. Microorganisms, 7: 24.

Priwiratama, H., A. E. Prasetyo and A. Susanto. 2020. Incidence of basal stem rot disease of oil palm in converted planting areas and control treatments. IOP Conf. Series: Earth and Environmental Science, 468: 012036.

Puspika M. A. and M. I. Pinem. 2018. The physical and chemical soil properties of the soil are suppressive to the existence of *Ganoderma boninense* on the oil palm. Journal Online Agroekoteknologi, 6(2): 356-361.

Rahman, H.S., H.H. Othman, N.I. Hammadi, S.K. Yeap, K.M. Amin, N.A. Samad and N.B. Alitheen. 2020. Novel drug delivery systems for loading of natural plant extracts and their biomedical applications. International journal of nanomedicine, 2: 2439-2483.

Ramdan, E.P., A. Afriani, A. Hanif, C. Wati, N. Nurholis, D. Astuti, and W. Widodo. 2022. Role of soil solarization on the growth of soil-borne pathogens and soil microbial populations. Agrotechnology

Research Journal, 6(1): 27-31.

Ramdan, E. P., A. Hartono, G. Giyanto, S. H. Hidayat and W. Widodo. 2023. The relationship between soil fertility and basal stem rot disease in oil palm plantations. Agrosainstek: Jurnal Ilmu dan Teknologi Pertanian, 7(1): 32-29.

Sahner J., S. W. Budi, H. Barus, N. Edy, M. Meyer, M. D. Corre and A. Polle. 2015. Degradation of root community traits as an indicator for the transformation of tropical lowland rain forests into oil palm and rubber plantations. PLoS ONE, 10(9): 1-19.

Salsabila, A., E.P. Ramdan, P. Asnur and H. Hidayat. 2022. Survey of oil palm basal stem rot in Cikasungka Estate, PT Perkebunan Nusantara VIII, Bogor. Agrosains Jurnal Penelitian Agronomi, 24(1): 1-5.

Soil Research Institute. 2009. Petunjuk Teknis Analisis Kimia Tanah, Tanaman, Air, dan Pupuk. Soil Research Institute, Bogor, Indonesia.

Susanto, A., A.E. Prasetyo and S. Wening. 2013. The infection- the rate of *Ganoderma* at four soil texture classes. Jurnal Fitopatologi Indonesia, 9(2): 39-46.

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Evan P. Ramdan	:	Preparation and creation of the published work, particularly authoring the initial draft (including substantial translation)
Arief Hartono	:	Methodology development or design; model creation
Giyanto Giyanto	:	Verification, either as a proof of the action, or of the overall experiment
Sri H. Hidayat	:	Critical review, criticism, and modification publishing, covering the pre- and post-publication stages
Widodo Widodo	:	ideas, articulation of research goals and objectives, management and leadership responsibilities for research activity planning and implementation