

# Original Research Article

## Effect of Soil and Climatic Conditions on Brown Spot Occurrence in Rice Lowland Across Four Agro-climatic zones of Côte d'Ivoire

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### ABSTRACT

**Aims:** To evaluate interaction of soil pH and acidity with weather on Rice Brown spot (BS) occurrence in rice lowlands

**Study design:** Cross sectional study

**Place and Duration of Study:** Four distinct rice lowlands belonging to different climatic zones (forest, transitional and savanna) of Côte d'Ivoire during cropping seasons of 2021.

**Methodology:** BS characterization were done in different farmer fields where soil samples were also collected during dry and rainy seasons. Soil pH and acidity were determined in those samples and rice grain yield at harvest time were recorded in different sites. Weather data related to sites and seasons were used to find out correlations.

**Results:** Occurrence of BS was found in forest zones with scores of 4 and 3 compared to 1 and 2 in savanna and transitional zones, respectively, with seasonal variation. Both rice production and the occurrence of BS were explained by soil parameters in conjunction with climatic parameters. Rainfall ( $R=0.38$ ) and relative humidity ( $R=0.64$ ) led to BS occurrence and decrease of yield. Wind speed ( $R=0.62$ ) and air maximum temperature ( $R=0.63$ ) were the determinant factors affecting rice yields. Si was found to be a component of sustainable soil management that interferes with soil pH in all climatic zones.

**Conclusion:** Temperature decrease BS pathogens occurrence whereas humidity increases its spread. Those parameters combined with silicon which interferes with pH could lead to sustainable solutions in BS control. Furthermore, having a deep understanding with rice varietal considerations can significantly improve strategies related to rice cultivation and protection.

*Keywords: Precision agriculture, disease forecasting, rice; brown spot, silicon*

### 1. INTRODUCTION

Fungi, bacteria, and viruses are major crop production bottlenecks causing 20-40% yield losses in key food crops and their occurrence results from complex interactions involving climate variability, host susceptibility, crop mineral nutrition, and pathogen variability. [1]–[3]. Understanding these interactions can guide effective plant disease management. Rice Brown Spot (BS), caused by *Bipolaris oryzae*, is a major bottleneck in rice production, particularly in Africa where it widely occurs and results in yield reductions across Eastern and Western countries, albeit with varying severity across regions [4]–[6]. While this disease is predominantly found in upland ecologies, it can now also occur in lowlands and has caused yield losses of over 30% in Côte d'Ivoire due to the rapidly changing disease pressure [7], [8]. As BS is seed-borne and cannot be effectively managed with chemicals, it is crucial to identify the conditions that facilitate its occurrence [9].

For instance, while nitrogen has been shown to reduce the severity of rice blast disease, the occurrence of plant disease may still be influenced by plant genetics and climate variability [10][11]. Some studies suggest that BS is linked to soil deficiencies in silica, potassium, manganese, or magnesium, as well as the presence of hydrogen sulfide, which makes plants more susceptible to infection [12], [13]. When these conditions exist, excessive amount or lack of nitrogen with an increase for phosphorus present in soils favored BS occurrence, particularly during the late tillering [14], [15]. Moreover, the recent reemergence of BS under various conditions has been linked to climate variability, which is believed to impact the soil-plant-atmosphere system and affect how plants respond to diseases [16], [17]. The spatiotemporal variation of BS occurrence within areas and fields is still unclear, which has hindered effective disease control. Continuous research efforts are needed to identify weather parameters and nutrient combinations that can enhance plant

resistance under conditions of increasing disease pressure. Silicon (Si) improves growth, yield and disease resistance in rice plants, particularly against rice blast, highlighting its importance in plant disease regulation under toxicity conditions [18], [19]. Consequently, Si is essential for plant tolerance and resistance to abiotic stresses including lodging, temperature, and water stresses [20], [21]. Soil acidity (pH) indirectly affects also the spread of plant diseases by influencing nutrient availability and absorption. Its effects on plant disease occurrence can vary from beneficial to detrimental [22], [23]. Climatic conditions, including temperature, humidity, and wind during the cropping season, can drive the occurrence and infection ability of fungal pathogens, making seed-borne pathogens more susceptible to habitat suitability determined by these factors [24], [25]. Change in this habitat significantly affected the distribution and the spread of those pathogens [26]. Understanding these interactions could be useful for sustainable reduction of the spread of BS, especially under predicted climate changes.

This study aims to explore the impact of soil acidity and silicon concentration on BS occurrence in rice fields across various climatic zones in Cote d'Ivoire. The objectives are to (i) characterize BS occurrence in different climatic zones, and (ii) establish the relationship between BS severity and soil conditions, independent of rice genetic diversity, while considering weather factors.

## 2. MATERIALS AND METHODS

### 2.1 Study areas

Field surveys were conducted in major rice cropping lowlands in Gagnoa, Bouaké, Agboville, and Korhogo, Côte d'Ivoire. These cities have different climatic characteristics and rainfall regimes. Gagnoa and Agboville share a bimodal rainfall regime with an average temperature of  $23.5 \pm 13.4^\circ\text{C}$ , while Bouaké has a tropical climate with a bimodal rainfall regime of around 1200 mm per year, and Korhogo has a unimodal rainfall regime of less than 1200 mm per year with high temperatures up to  $33^\circ\text{C}$ . The agro-climatic characteristics and soil properties are summarized in Tables 1 and 2.

### 2.2 BS disease on rice leaves on field

93 rice farms were surveyed during the dry and rainy seasons of 2021, with 22 in Gagnoa, 25 in Bouaké, 19 in Agboville, and 27 in Korhogo. The farms selected had farmers cultivating moderate to susceptible rice cultivars to BS, covering at least 1.24 acres, and were chosen based on the normal approximation of the binomial distribution [27].

BS characterization was evaluated on rice leaves at the onset of the reproductive stage in 2-4 randomly chosen stands of rice from different farmers' fields. Severity scores were recorded using the IRRRI (2014) scale (Table 3) on 10 plants per  $1 \text{ m}^2$  plot, designed twice per stand. The average score of each surveyed field was retained.

**Table 1. Climatic characteristics and rice growing seasons in 2021 across the sites.**

Locality	Agro climatic zone	Dry Season	Rainy Season	Rainfall pattern
Agboville	Forest Zone (Eastern)	December-March	August –November	Bimodal
Bouaké	Sudano-Guinean	February- May	September-December	Bimodal
Gagnoa	Forest zone (Western)	March-June	September-December	Bimodal
Korhogo	Sudanian	February-May	August –November	Unimodal

**Table 2. Soil of the studied sites**

Soil nutrients	Agboville	Gagnoa	Bouaké	Korhogo
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C-org (g.kg <sup>-1</sup> )	11.27	9.25	11.94	12.26
K (cmol/kg)	0.02	0.008	0.016	0.01
Total-P (ppm)	4165	5297	4004	7056
Ca (cmol/kg)	0.80	1.14	1.59	0.46
Mn (ppm)	64.08	--	112.28	100.01
Mn 36.38 %				
Fe <sub>2</sub> O <sub>3</sub> (ppm)	38511.43	29102.86	21060	59650
70% Fe				

-- Not significant values

**TABLE 3. Scale for brown spot disease of rice (IRRI, 2014).**

Disease scale	Infection
0	No incidence
01	1–5%
02	6–15%
03	16–25%
04	26–50%
05	> 50%

### 2.3. Soil analysis and rice yield

93 composite soil samples were collected per season from a depth of 0-20 cm per plot by mixing samples from different plots. After air drying, the soil samples were ground, sieved with a 2 mm sieve, and analyzed in the laboratory. The actual soil pH (pH<sub>H2O</sub>) and potential soil pH (pH<sub>KCl</sub>) were determined using a glass pH meter (HANNA) for a 1:2.5 soil-solution ratio. The total concentration of Si (SiO<sub>2</sub>) was determined by portable X-ray fluorescence spectrometry analysis using dry soil samples with less than 20% moisture. This method is accurate in determining the total elemental concentration in dry soil samples [28].

Measured Values of SiO<sub>2</sub> (MV) were converted to Silicon (Si) concentration (cmol/kg) according to following equations as below:

- (1) Determination of molar number of SiO<sub>2</sub> according to molar weight (60.08g):

$$\frac{MV}{60.08.E-3} \quad (1)$$

- (2) Determination of Si concentration (46.7%) in the molar number of SiO<sub>2</sub> as calculated above:

$$\frac{MV \times 46.7}{60.08.E-5} \quad (2)$$

During the harvest period, fresh weight of rice grains was measured and air-dried for a few days to determine the dry weight (DW). Moisture content (H) was measured by oven drying the rice grains for 24 hours at 70°C. Yield (Y) was estimated in tons per hectare using the following formula:

$$Y = DW * \left( \frac{10000}{1000} \right) * \left( \frac{100-H}{86} \right) \quad (3)$$

Y= Yield in tons/ha; DW= Dry weight in Kg; H=Humidity rate in %

## 2.4. Climate data

Daily data for Maximum (Tmax), Mean (Tmean), and Minimum temperature (Tmin), Relative humidity (RH), Rainfall (Precip), and Wind speed (WS) were download from [POWER | Data Access Viewer \(nasa.gov\)](https://power.larc.nasa.gov/) for different locations with a spatial coverage of  $1/2^{\circ} \times 1/2^{\circ}$ . Monthly averages were generated and adjusted for each cropping season

## 2.5. Statistical analyses

Statistical analyses used R software (Version 4.1.0) to calculate means and perform comparisons at  $\alpha = .05$  using Kruskal-Wallis and Dunn's test. ANOVA was used to analyze site and season effects on BS severity and rice yield. Spearman correlation determined correlations between BS severity/rice yield and climate/soil parameters. Regression models were established with significant explanatory variables ( $P = .05$ ) for dependent variables. Confusion matrix evaluated model accuracy.

## 3. RESULTS

### 3.1. Weather conditions for cropping seasons.

Weather variation during wet and dry seasons is presented in Figure 1. Rainfall was highest in the first semester in Gagnoa and Korhogo, while Bouaké and Agboville had more dispersed peaks. RH was more stable in the wet season than the dry season, with the lowest average recorded in Korhogo during the dry season.

In the dry season, temperature and wind speed were high. Table 4 shows weather parameter means for wet and dry seasons across localities. Korhogo and Bouaké had the highest average temperatures, reaching 28.8 and 28.1°C, respectively, while Agboville and Gagnoa had the highest rainfall amounts of 736 mm to 980 mm and RH above 80% during the rainy season.

### 3.2. Soils acidity and silicon content in areas

Soil across the studied areas had almost neutral active acidity (pH 6.6-6.7), with the lowest value observed at Korhogo (pH 6.3). Exchangeable acidity was stable (6.3) except for Korhogo (6.0). Similar  $\Delta$ pH values were observed between Agboville and Korhogo (0.3) and Bouaké and Gagnoa (0.4), respectively. Soil silicon concentration (2.13-2.28 cmol/kg) was higher in the forest zone (Agboville and Gagnoa) compared to transitional and savanna zones (Bouaké and Korhogo).

### 3.3. BS trough rice cropping seasons.

BS severity varied significantly across the studied areas, with the highest severity in Agboville and the lowest in Korhogo. Seasonal variability was observed, with higher severities during the rainy season. Altitudinal decreasing of BS severity was observed, with the highest occurrence in the forest zone and the lowest in the savanna, regardless of the season.

### 3.4. BS with climatic parameters

Meteorological parameters, especially RH and rainfall, strongly influenced the severity of BS in rice. The correlation between BS severity and climate parameters is shown in Table 8. Higher RH and rainfall correlated positively with higher BS severity, while higher Tmax and Tmean with WS correlated negatively. Minimum temperature had no significant effect.

**Table 4. Weather during rice cropping seasons in year 2021.**

	Mean Temp (°C)		Max Temp (°C)		Min Temp (°C)		Rainfall (mm)		Relative Humidity (%)		Wind speed (m/s)	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Agboville	26.75 ±0.77	25.61 ±0.54	31.59 ±.56	29.41 ±0.94	23.1 ±.76	22.66 ±0.77	346.32 ±4.21	980.76 ±22.3	82.08 ±4.35	88.66 ±2.91	1,50 ±0.35	1.57 ±0.48
Bouaké	28.1 ±1.31	25.61 ±0.77	33.5 ±2.45	29.90 ±1.13	23.5 ±1.12	21.85 ±1.30	394.2 ±4.70	435.60 ±8.79	70,27 ±10.5	82.93 ±7.05	1,73 ±0.38	1.28 ±0.33
Gagnoa	25.9 ±0.79	25.48 ±0.64	29.9 ±1.49	29.50 ±1.36	22.9 ±0.65	22.31 ±0.63	557.1 ±5.5	736.65 ±14.19	86,38 ±3.77	87.40 ±5.12	1,01 ±0.16	0.88 ±0.21
Korhogo	28.8 ±1.35	26.25 ±1.19	35.7 ±2.33	31.69 ±2.83	22.8 ±4.9	21.82 ±0.71	257.6 ±4.9	488.21 ±8.40	54,68 ±15.8	76.50 ±9.03	2,02 ±0.43	1.68 ±0.41

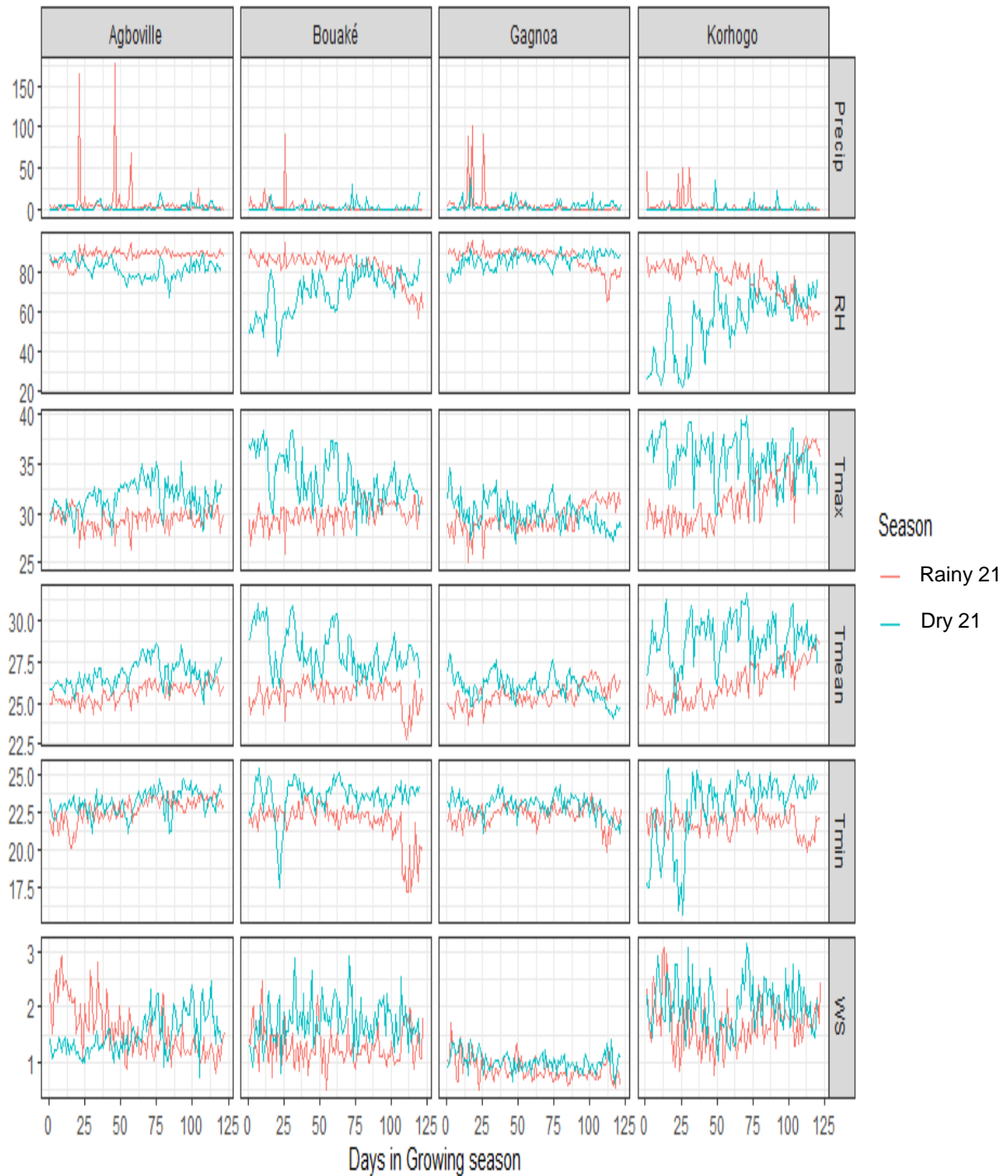
\*Mean Temp= Mean temperature; Max Temp= Maximum temperature; Min Temp= Minimum temperature.  
Data presented are the means ± standard deviations (Sds) for different regions

**Table 5. Soil characteristics**

Variables	Study areas				Significance
	Agboville	Bouaké	Gagnoa	Korhogo	p-value
pH <sub>Water</sub>	6.6 <sup>a</sup>	6.7 <sup>a</sup>	6.7 <sup>a</sup>	6.3 <sup>b</sup>	**
pH <sub>KCl</sub>	6.3 <sup>a</sup>	6.3 <sup>a</sup>	6.3 <sup>a</sup>	6 <sup>b</sup>	**
Δ Ph	0.3	0.4	0.4	0.3	-
Si (cmol.kg <sup>-1</sup> )	2,22 <sup>ab</sup>	2.13 <sup>b</sup>	2,28 <sup>a</sup>	1,94 <sup>c</sup>	**

Different letters indicate significant differences between mean values within comparison done with Kruskal-Wallis with Dunn's test, \*\* P < .001

## Climate variation during rice cropping season



**Fig.1. Climate conditions for different study areas during the wet and dry seasons**

*Precip*=Rainfall; *RH*= Relative humidity; *Tmax*=Maximum temperature; *Tmean* =Mean Temperature; *Tmin* =Minimum temperature, *WS*= Wind speed.

Backward regression identified Maximum and Mean temperature as significant variables affecting BS severity occurrence, with Rainfall also initially identified. These parameters can predict severity with 56% accuracy. However, removing Rainfall from the model decreased  $R^2$  to 48%, with low RMSE and MAE, as shown in the confusion matrix in Figure 3. Thus, the regression model developed is indicated in the following equation:

$$\text{Severity} = 1.44 T_{\text{mean}} - 1.13 T_{\text{max}} \quad (4)$$

$$R^2 = 0.48$$

### 3.5. BS with soil properties

Lowland rice cultivation's BS is affected by soil  $\text{pH}_{\text{Water}}$ ,  $\text{pH}_{\text{KCl}}$ , and  $\text{SiO}_2$  content (Table 9), positively correlated to its progress. BS has negative effects on grain yield ( $R = -0.43$ ) by reducing paddy.  $\text{SiO}_2$  rate in soil was found as the main predictor for recorded BS severity at 17% through regression analysis. The linear equation was as follows:

$$\text{Severity} = 9.70 \times 10^{-4} \text{SiO}_2 \quad (5)$$

$$R^2 = 0.17$$

**Table 6. BS severities through seasons**

	Brown Spot severity	
	Dry Season	Rainy Season
Agboville	4.29±1.20	3.32±0.67
Bouaké	2.52±0.82	2.96±0.75
Gagnoa	3.22±1.35	3.48±1.06
Korhogo	1.06±0.36	1.62±0.56

Data presented are the means  $\pm$  standard deviations (Sds) for different regions.

### 3.6. BS with soil and climate.

From regression analysis, three (Relative humidity, Rainfall, and Wind speed) of the six significant predictors for BS were removed due to strong correlation with Maximum temperature. The final regression equation used three variables (Total  $\text{SiO}_2$ ,  $\text{pH KCl}$ , and Maximum temperature) and had an  $R^2$  value of 53%. Thus, the regression equation obtained is presented as follows:

$$\text{Severity} = 1.42 \text{pH KCl} + 5.04 \times 10^{-4} \text{SiO}_2 - 0.24 T_{\text{max}} \quad (6)$$

$$R^2 = 0.53$$

### 3.7. Rice yield and effects of season and/or site on yield

Paddy yields ranged from 4.5 to 6.5 t.ha<sup>-1</sup> with the highest yield at Korhogo, followed by Bouaké and Agboville, and the lowest at Gagnoa (Figure 2). Yield varied significantly across sites and seasons, with Korhogo consistently producing the highest yields and Gagnoa the lowest. Dry season yields were significantly higher than rainy season yields ( $P < .05$ ) (Table 10).

### 3.8. Rice yield and climate parameters

From results Temperature (Mean, Maximum, and Minimum) and Wind speed positively affected rice yield during the growing season, while high humidity (rainfall and relative humidity) decreased yield ( $p < .05$ ) (Table

**Table 7. ANOVA table summarizing effects of seasons and sites on BS occurrence and rice yield.**

Source	DF	Sum of Squares	Mean Square	F ratio	Pr(>F)
<b>Brown Spot severity</b>					
Season	1	5.82	5.82	10.452	0.00146
Site	3	154.65	51.55	92.648	< 2e-16
Interaction	3	13.62	4.54	8.162	4.03e-05
Residuals	178	99.04	0.56		
Total	185	273,13			
<b>Rice paddy yield</b>					
Season	1	56.66	56.66	54.021	8.11e-12
Site	3	80.95	26.98	25.728	9.26e-14
Interaction	3	13.16	4.39	4.181	0.00693
Residuals	169	177.26	1.05		
Total	176	328,03			

11). Five climate parameters including Minimum and Mean temperature, Relative humidity, Wind speed and Rainfall were found to be significant predictors of rice paddy yield. These parameters can predict rice yield with 43% accuracy and low RMSE and MAE. Due to collinearity with relative humidity, Rainfall, and wind speed and mean temperature were removed (Figure.4). The regression model is presented as follows based on low correlation between Minimum temperature and Relative humidity:

$$\text{Yield} = 0.46 T_{\min} - 6.02 \cdot 10^{-2} RH \quad (7)$$

$$R^2 = 0.37$$

**Table 8. Correlation between climate parameters and BS severity**

Climatic parameters	Brown Spot Severity	
	R	P-value
Tmax **	-0.58	< 2.2e-16
Tmin	0.10	0.1608
Tmean **	-0.49	1.1e-12
Rainfall **	0.38	7.2e-08
Relative humidity **	0.66	<2.2e-16
Wind speed **	-0.42	1.90e-09

\*\* Variable affected significantly Brown spot severity

### 3.9. Rice yield and soil parameters

Silicon content and acidity of soil impacted significantly rice grain yield obtained as presented in Table 11. Those parameters affected negatively rice grain yield as expressed soil pH<sub>Water</sub> (-0.35), pH<sub>KCl</sub> (-0.22) and soil content of SiO<sub>2</sub> (-0.15).

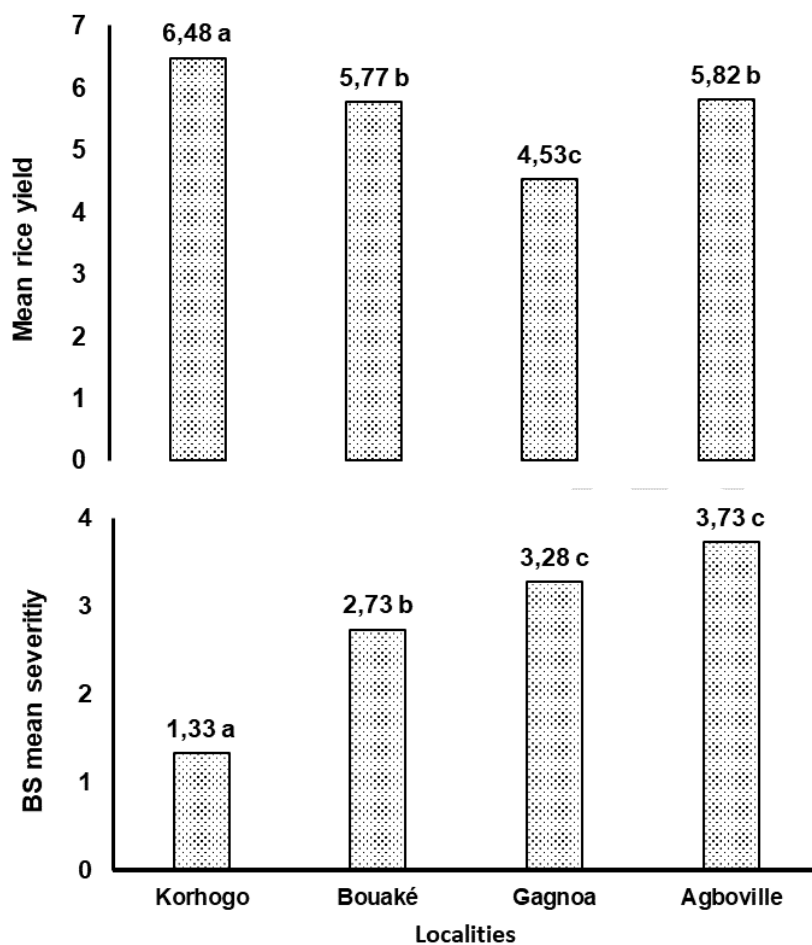


Fig. 2. Mean BS severity and Rice yield for different sites.

Table 9. Correlation between BS severity, soil properties and rice grain yield

Soil parameters	Brown spot Severity	
	R	P-value
pH <sub>Water</sub> **	0.44	1.49e <sup>-10</sup>
pH <sub>KCl</sub> **	0.52	2.58e <sup>-14</sup>
ΔpH	-0.05	0.44

SiO <sub>2</sub> **	0.40	1.20e <sup>-8</sup>
Yield	-0.43	1.44e <sup>-09</sup>

\*\* Variable affected significantly Brown spot severity

### 3.10. Rice yield with soil and climate parameters

The best variables describing the yield of rice with the lowest AIC (21.21%) were Maximum and Minimum temperature, Rainfall, Wind speed, and Relative humidity. However, Relative humidity, Rainfall, Wind speed, and Maximum temperature were highly correlated. When they were associated separately with Minimum temperature, which appeared as the main predictor, the R<sup>2</sup> value dropped to 0.37 except for Rainfall (0.27). Eq. 8 was presented as the best predictor of rice grain yield.

$$\text{Yield} = - 6.02 \text{ } 10^{-2} \text{ RH} + 0.46 \text{ Tmin} \quad (8)$$

$R^2 = 0.37$

Table 10. Rice yield for different areas

Cropping seasons	Yield (t/ha)			
	Agboville	Bouaké	Gagnoa	Korhogo
Dry Season	6.45±1.50	6.51±0.48	4.58±0.99	7.09±1.48
Rainy Season	5.58±0.96	5.03±0.84	4.51±0.70	5.87±1.09

Data presented are the means ± standard deviations (Sds) for different regions.

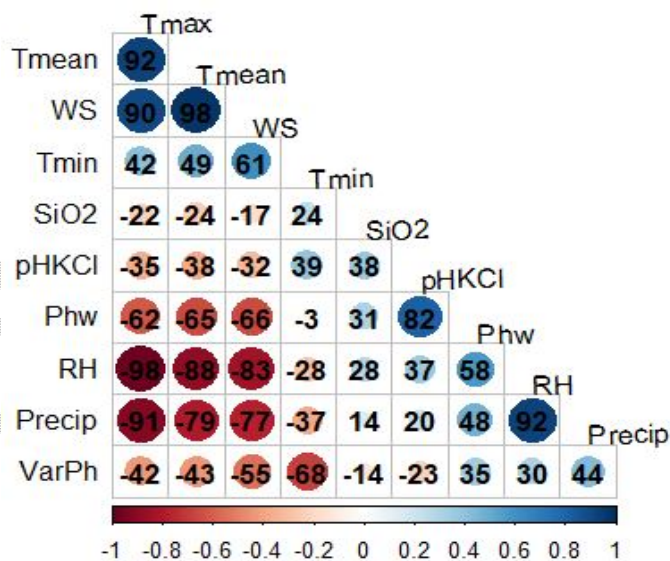


Fig. 3. Confusion matrix between soil and climate parameters

## 4. DISCUSSION

### 4.1. Rice production across Brown spots occurrence agro-ecology

Soil conditions influence plant growth thereby the expression of many important traits, especially grain yield. Soil pH values between 6.0 and 7.0 are considered neutral whereby most plant nutrients remain available [29]. In this study, the actual soil acidity (soil pH<sub>water</sub>) from savanna to forest zone ranged from 6.3 to 6.7, neutral values suitable for soil micronutrient availability [30]. Similarly, silicon increased from the savanna zone to the forest zone, ranging from 1.94 to 2.22 cmol.kg<sup>-1</sup> respectively, reflecting the positive correlation between soil silicon and acidity (R = 0.38) [31]. The practical importance of that correlation is maintaining optimal soil pH level is crucial for achieving high rice yields, as silicon plays a significant role in the growth and defense system against fungal attacks and other biotic stresses [32], [33]. However, at sites with the same soil pH, rice yields varied (5.8 t. ha<sup>-1</sup> and 4.5 t. ha<sup>-1</sup> respectively at Bouaké and Gagnoa) despite similar BS scores (3) due to differences in silicon availability and utilization, indicating the importance of maintaining soil conditions that favor silicon availability. Therefore, when soil conditions favor silicon availability, silicon release for crop use remains dependent on soil temperature, soil pH, and redox potential, which is affected by weathering rates. In tropical soils, silicon release is generally low due to high weathering, mostly in rice soils [31]. High levels of precipitation in the forest zone may decrease the release of silicon for rice cultivation use, thereby increasing the susceptibility of rice to BS pathogens. Haynes & Zhou[34] and Vander Linden & Delvaux[35] reported in tropical rice soils that extractable silicon decreases with increasing precipitation and weathering, highlighting the interaction between weather variations and nutrient availability in the soil.

High temperatures reduce BS pressure in the fields with the availability of nutrients that interact better with the released Si enhances and promotes better growth of rice plants for good yield [36]. In the savanna zone, the combination of rainfall and high temperatures led to Si availability, reduced BS pressure, and mobilization of nutrients such as phosphorus, iron associated with soil organic matter, resulting in a yield of around 6.5 t/ha. Higher humidity in the forest zone led to BS occurrence in both rainy and dry seasons, preventing rice plants from effectively absorbing nutrients and resulting in lower yields despite the high Si content of the soil, which also had lower fertility[37]. Another nutrient contributing to the observed difference in grain yield between sites was the soil potassium content, which was low (0.008 - 0.02 cmol/kg) compared to the optimal level of 0.10 cmol/kg defined by [38] for rice nutrition. This implies that potassium (K) is a key soil component to support the effect of silicon in controlling the occurrence and yield of BS.

**Table 11. Correlation between rice yield, temperature, rainfall, and relative humidity**

		Yield	
		Coeff Corr	P-value
Weather parameters	T <sub>max</sub>	0.63	< 2.2e-16
	T <sub>mean</sub>	0.62	< 2.2e-16
	T <sub>min</sub>	0.33	5.81e-06
	Rainfall	-0.43	2.76e-09
	Relative humidity	-0.60	< 2.2e-16
	Wind speed	0.62	< 2.2e-16
Soil parameters	pH <sub>Water</sub>	-0.35	1.66 e-6
	pH <sub>KCl</sub>	-0.22	3.46 e-3
	ΔpH	-0.24	1 e-3
	SiO <sub>2</sub>	-0.15	0.04

Temperature and humidity, which are part of ecological variance, have been shown to impact rice plant growth under various diseases such as bacterial blight, sheath blight, and blast pressure in several studies [39], [40]. Temperature, precipitation, and soil conditions are the primary determinants of crop growth and yield, confirming decrease in rice yield observed from the hot savanna zone to the humid forest zone along

the altitudinal gradient [37] [41]. High humidity and low temperatures increase the prevalence of rice brown spot disease, which is seed-borne. Conversely, maximum temperature and wind speed negatively impact its occurrence ( $R = -0.58$  and  $R = -0.42$  respectively) [42], [43]. Rice grain yield was affected by high levels of rainfall and relative humidity, which have a strong positive relationship with air temperature [44], [45]. Temperature also plays a significant role as fungal pathogens' prevalence is higher at lower temperatures, with a decrease observed outside the optimal range. Environmental factors must be managed to prevent crop damage as disease occurrence had a negative relation with rice grain yield.

This study found that weather and soil conditions are important factors in the occurrence of BS in Côte d'Ivoire, with regression models predicting over 50% of BS occurrence. However, the variation of the reaction among the rice varieties grown by farmers in the surveyed areas needs to be further explored for additional insights.

#### 4.2. BS control by Silicon

The surveyed sites were found to have Si levels ranging from 1.94 to 2.28 cmol/kg and potential Si content per hectare ranging from 1717 to 2035 kg Si/ha, exceeding the recommended rate of 1000 kg Si/ha to increase soil pH by 0.29-0.47 units in all soils [46] leading no significant variation in pH. The pH only rose by 0.4 units between Bouaké and Korhogo for a difference of 0.19 cmol Si/kg and by 0.1 units between Agboville and Gagnoa for a difference of 0.06 cmol Si/kg. Moreover, the Si content of surveyed soils (0.859 mg.dm<sup>-3</sup> - 1.02 mg.dm<sup>-3</sup>) was much lower than the required critical concentration of 10-20 mg.dm<sup>-3</sup> for achieving maximum yield with low BS occurrence in rice crops [47]. This may have contributed to the increase in BS occurrence ( $R = 0.40$ ) and the reduction in rice grain yield ( $R = -0.15$ ) observed in this study. Available Si can substitute C in shoot tissues, increase photosynthesis, and strengthen C:N:P stoichiometry leading to enhanced biomass production through N and P uptake. It also provides bioenergetic benefits due to altered C:N stoichiometry, particularly in low N conditions as varieties with high N responsiveness were found to be less susceptible to BS [48]. Si uptake indirectly promotes the absorption of other nutrients for plant physiological and BS resistance independently of classic immune hormones like salicylic and jasmonic acid during BS attack [49], [50]. More research is needed to understand the relationship between silicon and other soil metabolites and their effects on rice plants to develop effective approaches for controlling brown spot disease.

Considering multiple regression, contribution of Si was positive but lowest ( $R=0.40$ ), which was unexpected based on previous studies [49], [51] that suggested a negative coefficient. We hypothesized a polynomial relationship between soil Si content and BS occurrence, taking into account soil pH, rainfall, minimum temperature, and relative humidity, where higher Si levels would reduce BS occurrence. However, we found that Si had limited effectiveness in controlling BS, as the optimal rate for limiting iron toxicity in rice was only 371 kg Si/ha [19]. Max temperature significantly contributed to BS occurrence during the crop season, indicating rice susceptibility to injury under projected temperature increases (by 99.5% of current value) and reduced rainfall amount [52]. Furthermore, Regression analysis showed that soil pH, Si concentration, and maximum temperature were significant predictors of BS occurrence.

### 5. CONCLUSION

This study revealed evidence of climate associated with edaphic conditions in predicting BS occurrence and rice production in different agro-climatical zones. More humidity increased BS occurrence whereas high temperature and wind speed decreased its effects, promoting the final rice yield. In addition, soil pH and Si effect appeared as components of an integrated soil sustainable management when they are associated to hot conditions on BS across studied areas. Therefore, further research for deep understanding of the effect on Si on other nutrients and new methods of silicon application combined with humidity management are required in BS control for better rice production in future.

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