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ORIGINAL RESEARCH

Microclimate-based mortality analysis of the Cibodas Botanic Gardens plant collection

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Abstract. Despite the routinely conducted treatment and maintenance of garden plant collection, the monthly mortality figures of the Cibodas Botanic Gardens (CBG) plant collections remain significant. It is presumed that the microclimate has a crucial influence on plant survivorship in the field. This study aimed to analyze the effect of microclimate conditions on the mortality rate of the CBG plant collection. The study was conducted by correlating the number of mortal plants with CBG monthly microclimatic conditions from 2017 to 2018. The analyzed microclimate parameters were temperature, relative humidity, precipitation, wind velocity, and solar radiation. The multiple regression modeling, *t*-test, and Pearson correlation test (r) were utilized to measure the level of significance of the correlation ($\alpha = 0.05$). The findings were shown that the maximum wind velocity was the primary unit correlated to the number of mortality. The correlation was strong positive ($r = 68.8\%$), and significant (p-value $< \alpha$). We suggested anticipating the disadvantages influences of strong wind supported by other extreme microclimate units, such as heavy rain. These events frequently caused high damage to the tree and other plant collections. These are expected to be taken into a consideration by the CBG operator and management in order to forecast and mitigate the risks of future plant collection losses.

Keywords: *ex situ* plant conservation, plant survival, microclimate, Cibodas Botanic Gardens

INTRODUCTION

Botanic gardens' *ex situ* plant conservation has proven to be successful in preserving and enhancing plant biodiversity. Plant cultivation, seed banking, tissue culture, cryopreservation, species recovery, species conservation status assessment, assisted migration, and ecological restoration are some of the *ex situ* and *in situ* conservation strategies used by botanic gardens [1][2]. In Indonesia, botanic gardens also have some challenges in mitigating plant species extinction. Botanic gardens must immediately conduct *ex situ* conservation of plant species due to the rapid deterioration of their natural habitat [3][4]. Botanic gardens are increasingly placing plant diversity conservation at the center of their missions, initiatives, and collections [4].

Based on Presidential Decree No. 93 of 2011 [5], botanic gardens are defined as "*ex situ* plant conservation areas that are having a documented collection of plants, arranged based on taxonomic, bioregion, thematic classification patterns, or a combination of these patterns for conservation, research, education, tourism activities, and environmental services". Cibodas Botanic Gardens (CBG) is one of the Indonesian botanic gardens managed by the National Research and Innovation Agency (*BRIN*), mainly conserved plant species from tropical montane rainforests [6]. Many wild plants from these regions have been collected, acclimatized, preserved, reproduced, investigated, researched, and displayed as part of the garden collection so that the public can obtain benefit from them as a living collection [7][8][9].

However, CBG is facing many challenges to maintain these collections, specifically to ensure the plant collection's survival and health. Even with careful and routine maintenance conducted, the mortality risk of the plant collection remains significant. Many factors may cause these failures [10][11]. Microclimate condition is one of the uncontrolled elements that is thought to contribute to botanic garden plant collection mortality [12][13].

Vegetation can have a significant impact on microclimate, which is described as a small-scale pattern of climate impacted by site topography as well as local constructed forms and materials [14]. Temperature, light, wind

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velocity, and moisture are important environmental factors throughout human history, offering useful indications for habitat selection and other activities. Tree populations and associated biodiversity in the past survived due to supportive microclimates even in hostile landscape conditions would be buffering the future population against evolving environmental transformation [15]. Microclimate has a direct impact on ecological processes and reflects small shifts in ecosystem function and landscape structure at different scales [16].

Microclimates, in addition to being impacted by other biophysical factors, have a direct impact on plant growth and survival in the field [15]. The ground surface environment is dynamic, and any environmental parameter might experience huge diurnal fluctuations (temperature, humidity, solar radiation, etc.). Microclimate-biological process relationships are complicated and often nonlinear. A previous study indicated that plant survival and development can be harmed by excessive microclimate amplitudes [11].

The rate of plant growth and development is influenced by the surrounding temperature, and each species has its temperature range, which is represented by a minimum, maximum, and optimal temperature [16]. Unfortunately, heat waves, also known as severe air temperature occurrences, are expected to grow more powerful, more frequent, and persist longer than they have in recent years. These severe occurrences would have the greatest impact on plant productivity if they occurred during the summer [17].

As a result of these crucial effects of microclimate on plant growth and development, it is necessary to investigate the effect of CBG microclimate with CBG plant collection mortality. The aim of this study was to analyze the impact of microclimate on the plant's monthly mortality rate which indicate CBG plant collection survivorship. The findings were supposed to be used as a consideration strategy in plant collection management actions of botanic gardens to reduce the impact of unpredictable future microclimate conditions.

METHODOLOGY

Study site

The study was conducted in Cibodas Botanic Gardens (CBG), Cianjur, West Java. CBG covers an area of 84.99 hectares on the eastern slope of Mount Gede and Mount Pangrango, at an altitude of approximately 1,300-1,425 meters above sea level. CBG is located around 100 kilometers from Jakarta and 80 kilometers from Bandung. The climate of CBG was classified as type C to B, or less wet to wet, by Schmidt-Ferguson, and it may be classified as tropical rainy climates or wet tropic 'Af' by Koppen [18].

Data acquisitions

The data were consisted of two main parts: the CBG microclimate series data (i.e., temperature, humidity, rainfall, average wind velocity, and solar radiation) and the monthly number of mortal CBG plant collections. The data were recorded from 2017 to 2018.

The microclimate series data was gathered from CBG Registration Unit monthly report of the CBG weather conditions [19]. The weather station *Precision Weather Station Davis Instruments Vantage Pro2 Plus*^{TM} that captured the weather data was established in front of the CBG management office and used to collect these microclimate data. The device delivers real time data on CBG's microclimate conditions to the server on a continuous time basis. The microclimate data then obtained from saved data in the server.

The number of plant mortality was collected based on field census inventory conducted weekly by CBGs' Registration Unit staff and reported monthly. The plants included in the assessment were only outdoor plants influenced by direct microclimate conditions and excluded indoor plants. These data processed into the dynamic of CBG plant collection data, including the plant mortality figures which are documented as a monthly report by the Registration Unit [20].

Data analysis

Except for precipitation, all other units were assessed in the value of minimum, average, and maximum. Precipitation was the accumulative volume of rainfall in a month. To analyze the variety of each microclimate data, we were conducted standard deviation assessment through normalized the data by using a log-transformation due to varied in their ranges and unit. Minimum wind velocity and minimum solar radiation were excluded from the analysis since there are only contained "0" values.

We have also modeled the linear correlation between the number of plant mortality and the microclimate units using a multiple regression model. The number of plants mortality (Y) was only described as the total number of dead plants each month, and not considering other characteristics.

Thus, we conduct data analysis based on the following model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + error$$

where Y refers to the number of mortal plants, β refers to the coefficient of the predictor, and X_1 = minimum temperature, X_2 = average temperature, X_3 = maximum temperature, X_4 = minimum relative humidity, X_5 = average relative humidity, X_6 = maximum relative humidity, X_7 = precipitation, X_8 = minimum wind velocity, X_9 = average wind velocity, X_{10} = maximum wind velocity, X_{11} = minimum solar radiation, X_{12} = average solar radiation, X_{13} = maximum solar radiation. To test the degree of significance, we also conducted a t-test (α = 0.05).

We also performed Pearson correlation (r) tests to check the correlation between Y and analyzed variables (X_i) which detected have a correlation based on the regression test, with the following formula:

$$r_{xy} = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}\sqrt{n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2}}$$

The r-value will not exceed |1|. When the r value approaches -1, it indicates a negative linear relationship, and when it approaches 1 indicates a positive linear relationship. If $r \neq 0$ and p-value < α (α = 0.05), the correlation between two variables is significant, but, if p-value > α, the correlation between two variables is insignificant [21].

To complete the information regarding the family of the mortal plants and the types of mortality causes, then the data would be only presented descriptively. However, these would not be conducted a further statistical test or analysis.

RESULTS AND DISCUSSION

Microclimate conditions of Cibodas

The surrounding microclimate of CBG was dynamically changing based on the 2017 to 2018 circumstances. However, based on the temperature, relative humidity, and solar radiation were tend to be stable throughout the month and year (Figure 1 (a), (b), and (e)). Only the minimum temperature and relative humidity, and average solar radiation were slightly varied over time.

Furthermore, Figure 1(c) also described that precipitation has the most dynamic value among the microclimate units. The data showed that the volume of rainfall is high in the early part of the year, then gradually decreases from April to July and August. The volume difference between the wettest month and the drought month is also clearly shown in each year. In both years, November has the most rainfall, with 362 and 309 mm month^{-1} and the most drought months are in August 2017 and July 2018.

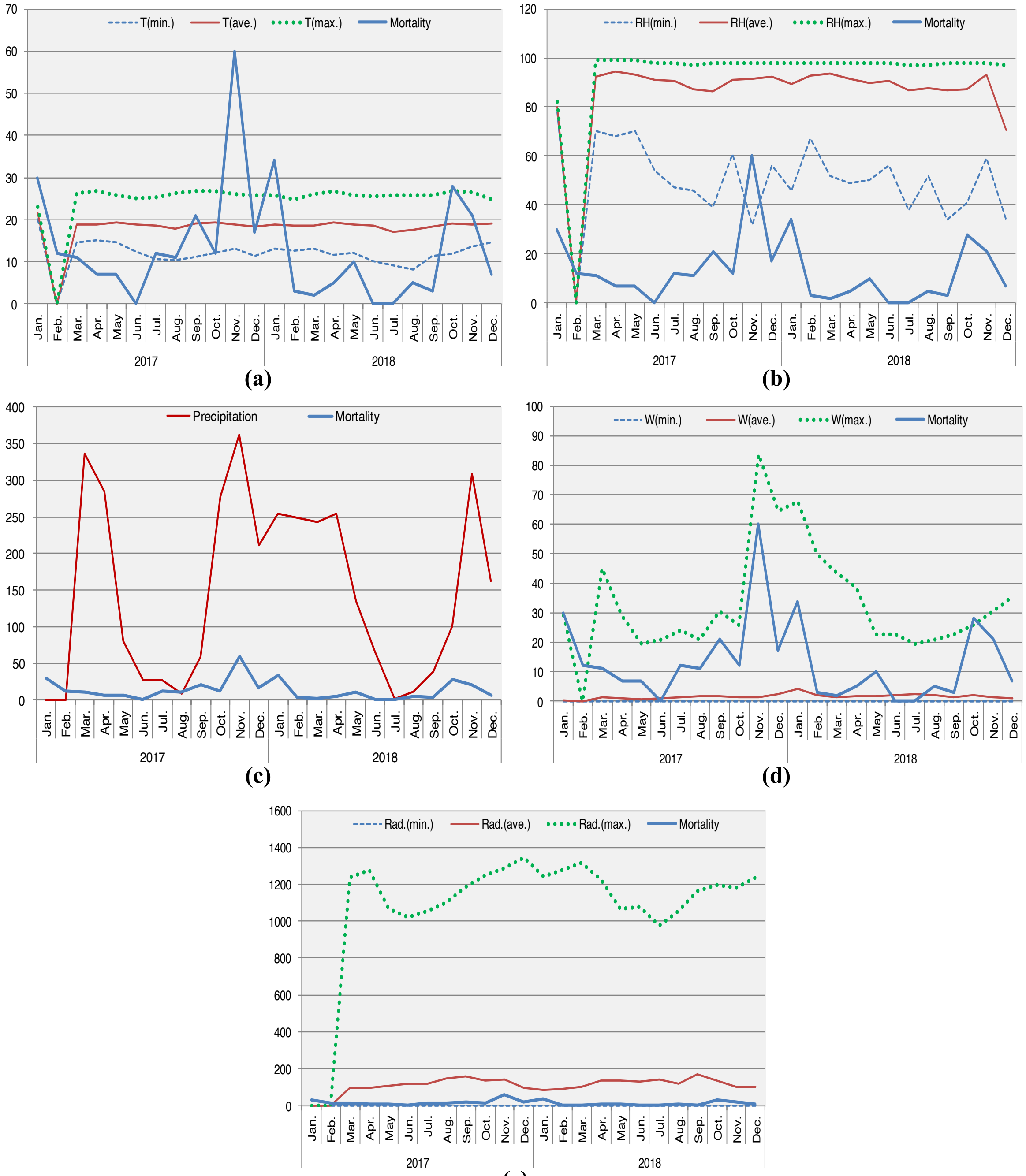
Next, wind velocity has distinct properties than the preceding units (Figure 1 (d)). Although the average was nearly stable, the maximum value was extraordinarily high. March 2017, and from November 2017 to March 2018, the maximum wind velocity was above 40 kph. This was included to strong breeze to severe gale wind which might cause the trees uprooted, branches to break from trees [22].

Table 1. Standard deviation (SD) value of the normalized microclimate units.

Microclimate unit		SD
Temperature	Minimum	0.187
	Average	0.041
	Maximum	0.033
Relative humidity	Minimum	0.252
	Average	0.063
	Maximum	0.038
Precipitation		1.436
Wind velocity	Average	0.665
	Maximum	0.429
Solar radiation	Average	0.205
	Maximum	0.091

All previous microclimate data describe that the varying value of these units occurs in a daily cycle but less in months and years [18]. It might be caused by CBG's position in the mountainside with wet tropical zone characteristics [18].

These data are consistent with the results of the variety test. Precipitation has the highest value of the variety than all units. The difference was occurred especially between the dry and wet seasons. The second biggest is wind velocity, and the remaining units are less varied (Table 1).



(a) **(b)** **(c)** **(d)** **(e)**

Figure 1. The graphical comparison between the number of mortality (*n*) with microclimate conditions surrounding Cibodas from 2017 to 2018: **(a)** mortality (*n*) and temperature (°C); **(b)** mortality (*n*) and relative humidity (%); **(c)** mortality (*n*) and precipitation (mm month^{-1}); **(d)** mortality (*n*) and wind velocity (kph); **(e)** mortality (*n*) and solar radiation (Wm^{-2}). (*Note*: precipitation and solar radiation in January 2017, and all microclimate units in February 2017 were not included in the charts due to the equipment's error).

The microclimate conditions surrounding CBG are significantly influenced by high annual rainfall that occurs both early and late in the year (wet season). Every year, wet months outnumber dry months by seven to eight months, with an annual rainfall of more than 1,000 mm [18][23].

The variety of the plants

Based on the assessment, the number of mortal plants in 2017 and 2018 was 200 and 118 specimens. These annual mortality rates were included as a significant amount (>100 specimen year^{-1}). However, the numbers would be only explained descriptively, and the variety of the mortal plants is only outdoor plants.

Table 2. The number of mortal plants based on families in 2017 and 2018.

2017		2018	
Family	*n*	Family	*n*
Myrtaceae	28	Cupressaceae, Myrtaceae	13
Casuarinaceae	17	Araucariaceae	8
Lauraceae	16	Casuarinaceae, Lauraceae	6
Arecaceae	11	Arecaceae, Leguminosae, Melastomataceae	5
Cupressaceae	8		
Lamiaceae	7	Araliaceae, Gentianaceae	4
Araliaceae, Ericaceae, Leguminosae, Proteaceae	6	Apocynaceae, Magnoliaceae, Malvaceae, Primulaceae, Sapindaceae	3
Fagaceae, Malvaceae, Melastomataceae	5	Acanthaceae, Compositae, Fagaceae, Moraceae, Rubiaceae, Salicaceae, Zamiaceae	2
Araucariaceae, Asparagaceae, Elaeocarpaceae	4	Actinidiaceae, Anacardiaceae, Asparagaceae, Boraginaceae, Burseraceae, Ebenaceae, Elaeocarpaceae, Euphorbiaceae, Meliaceae, Oleaceae, Phyllanthaceae, Pinaceae, Podocarpaceae, Polygalaceae, Ranunculaceae, Rosaceae, Rutaceae, Sabiaceae, Staphyleaceae, Styracaceae	1
Anacardiaceae, Cusiaceae, Pandanaceae, Pinaceae, Pittosporaceae, Rutaceae, Thymelaeceae	3		
Apocynaceae, Araceae, Cannabaceae, Crassulaceae, Elaeagnaceae, Moraceae, Phyllanthaceae, Podocarpaceae, Rosaceae, Rubiaceae, Xanthorrhoeaceae	2		
Actinidaceae, Berberidaceae, Cyatheaceae, Gunneraceae, Lythraceae, Magnoliaceae, Pentaphylacaceae, Piperaceae, Polygalaceae, Primulaceae, Sapindaceae, Schisandraceae, Solanaceae, Stemonuraceae, Styracaceae, Symplocaceae, Theaceae Urticaceae, Zamiaceae	1		

There is a slightly similar trend in both years: the highest rates of mortality occur at the start of the year (especially in January) and at the end of the year (from September or October to December) (Figure 1). This mortality trend was almost likely with the precipitation and wind velocity, especially the maximum wind velocity pattern. Those indications would be further exploring in the next chapter.

Based on the family, the most plant collection loss was Myrtaceae (Table 2). In 2017, as many as 28, and 13 specimens in 2018. Myrtaceae is a widespread family found in tropical rainforests in sub-montane and montane zones [24]. Thus, Myrtaceae s is one of the most important collections in the CBG. Some of these species were *Eucalyptus deanei*, *Eucalyptus saligna*, *Eucalyptus pauciflora, Syzygium antisepticum*, and *Melaleuca nodosa*. All of those trees were perished in 2017. *Eucalyptus camaldulensis*, *Eucalyptus robusta*, *Melaleuca phoenicea*, *Syzygium nigricans*, and *Corymbia citriodora* were died in 2018.

Apart from Myrtaceae, in both years, the next families that experienced big losses were Casuarinaceae, Cupressaceae, Lauraceae, and Arecaceae. In 2018, Araucariaceae also experienced the second-most losses, with eight specimens. According to the CBG location's features, the family's plant collections in the garden are typical plants of mountainous tropical rainforests. The tropical mountain forests' characteristic vegetation includes the Annonaceae, Fagaceae, Lauraceae, Meliaceae, Myrtaceae, Rubiaceae, and Sterculiaceae

Table 3. The coefficient (β), standard errors (SE), *t*-stat, and *p*-value of the full model ($\alpha = 0.05$). Detected correlations are marked by asterisks (*).

Predictor	β	SE	*t*-stat	*p*-value
Intercept	-26.430	765.230	-0.035	0.973
Minimum Temperature	0.655	3.315	0.198	0.847
Average Temperature	8.017	6.837	1.173	0.268
Maximum Temperature	12.693	5.990	2.119	0.060
Minimum Relative humidity	-0.306	0.439	-0.698	0.501
Average Relative humidity	0.072	0.926	0.077	0.940
Maximum Relative humidity	-3.795	9.174	-0.414	0.688
Precipitation	-0.026	0.048	-0.531	0.607
Minimum Wind velocity	0.000	0.000	65535	Undefined
Average Wind velocity	-1.596	4.483	-0.356	0.729
Maximum Wind velocity$^{*)}$	0.900	0.320	2.814	0.018$^{*)}$
Minimum Solar radiation	0.000	0.000	65535	Undefined
Average Solar radiation	-0.063	0.201	-0.313	0.761
Maximum Solar radiation	-0.072	0.039	-1.836	0.096

families [24]. In a previous study in Mount Tanggamus, Lampung has described that the most species in the sub-montane zone are Myrtaceae, Clusiaceae, and Lauraceae [25]. Most of these deceased collections were collected by CBG through various *ex situ* conservation efforts. These collections are gathered from Sumatra tropical rainforests mountains [20].

However, some families were introduced or exotic plants to CBG, such as Araucariaceae, Casuarinaceae, Cupressaceae, and few others [26]. Only *Agathis borneensis* and *Casuarina junghuhniana* were recorded its seedlings from domestic. Even all Cupressaceae collections are exotic plants [26]. The exotic plants came from seeds exchange and foreign grants. These are also the other form of *ex situ* conservation efforts conducted by CBG.

Correlation between plants survival and microclimate conditions

Based on the test, the result of the regression model was valid with significance F (0.043) < α, and R^2 was 79.1%. However, only maximum wind velocity has a significant correlation with the number of plants mortality, and the value was positive (Table 3). It means that when the wind speed is reaching above 40 kph, then possibly a plant to die is bigger.

Then the Pearson correlation test was only conducted to maximum wind velocity. The result showed that the correlation between the number of plants mortality and maximum wind velocity was a significant strong positive (r = 68.8%; p-value (0.000) < α) [21]. Based on this result, then it can be explaining the reason that when the maximum wind velocity occurred, the number of mortal plants tended to increase, as shown in Figure 1 (d).

Wind's direct mechanical effects include uprooting plants when the wind's power exceeds the stem or root/ soil energy [27]. The power of the wind can lodge the plant as it grows taller, either shattering stems or causing the soil and roots to collapse. The wind is frequently associated with other microclimate factors that might amplify or limit the damages [28]. Due to the added power of rainfall and the increased weight of the canopy owing to interception, wind and rain events are more damaging [29].

Extreme weather events in November 2017 demonstrated this as well (Figure 1 (d)). The highest wind velocity reached 83.7 kph, destroying many plants [19][20]. Furthermore, a high plant mortality rate phenomenon occurs in conjunction with a high volume of rainfall at the beginning and end of the year.

From 2017 to 2018, the strong wind effects on the plants' survivorship have also been shown in the dead cause data (Table 4). We have recorded that he fallen plant was the primary death cause to CBG collections. Fallen plants were contributed 37% in 2017, and 19% in 2018, and the total loss of 31% in both years.

Table 4. Causes of plant mortality in 2017 and 2018.

Cause of dead	2017	2018
Broken stem	4	1
Dried	10	7
Eaten by wild boar	1	8
Fallen	74	23
Fungus	32	13
Hit by fallen tree	5	12
Old age	19	10
Pest	11	12
Relocation	-	1
Rotten root	13	17
Rotten stem	11	4
Struck by lightning	1	2
Termites	10	5
Undefined	9	3

Heavy rains not only limited the capacity of plants to survive but also increase the number of illnesses spreading [29][30]. Rotten roots, stems, or other parts of plants, as well as fungal stroked, increased throughout this period [30]. External variables like increased precipitation loading, lower shear strength in wet soils, and disease-induced weakening of plant stem increases the risk of falling [27]. The effect of soil saturation due to rainfall infiltration may also cause the additional weight of the water in the soil to compensate for any loss of soil strength and finally weakening the tree strength [30].

We suggest to the CBG operator to conduct some steps to mitigate these disadvantages in the future. Including the trimming to the crown canopy and branches that might be jeopardized trees' survivorship and also for public safety, regular pest and disease management, tree health assessment, and concrete reinforcement of the garden's hillside. These efforts hopefully are able to minimize the effects of strong wind and heavy rain would occur at any time.

CONCLUSIONS

Based on microclimatic occurrence in the CBG, the volume of precipitation was the most dynamic unit, followed by maximum wind velocity throughout the year. The others are more likely to show a difference between a day's maximum and minimum. Based on the test, the findings showed that maximum wind velocity was the primary microclimate unit effect on number plant mortality. The correlation was a significant strong positive. Supported by other microclimate units, such as heavy rain, a strong wind could enlarge the effects on the weakening of plant survivorship in the garden. These results are supposed to be used as a consideration for the CBG operator to anticipate and to eliminate the risks of a bigger loss of plant collections in the future.

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