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Article

# Prediction of Natural Volatile Organic Compounds Emitted by Bamboo Groves in Urban Forests

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**Abstract:** After the COVID-19 outbreak, more and more people are seeking physiological and psychological healing by visiting the forest as the time of stay-at-home became longer. NVOC, a major healing factor of forests, has several positive effects on human health, and this study researched about the NVOC characteristics of bamboo groves. The study revealed that  $\alpha$ -pinene, 3-carene, and camphene were the most emitted, and the largest amount of NVOC was emitted in the early morning and late afternoon in bamboo groves. Furthermore, NVOC emission was found to have normal correlations with temperature and humidity, and inverse correlations with solar radiation, PAR and wind speed. A regression analysis conducted to predict the effect of microclimate factors on NVOC emissions resulted in a regression equation with 82.9% explanatory power and found that PAR, temperature, and humidity had a significant effect on NVOC emission prediction. In conclusion, this study investigated NVOC emission characteristics of bamboo groves, examined the relationship between NVOC emissions and microclimate factors and derived a prediction equation of NVOC emissions to figure out bamboo groves' forest healing effects. These results are expected to provide a basis for establishing more effective forest healing programs in bamboo groves.

**Keywords:** NVOC; phytoncide; bamboo grove; monoterpene; microclimate; regression analysis

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## 1. Introduction

Attention restoration theory, claimed by Stephen and Rachel Kaplan, explained that humans, who have grown tension due to continuous exposure to artificial environments, instinctively want to visit nature [1-2]. They argued that excessive "attention fatigue" caused by external environmental factors and internal psychological factors is restored by the friendly "restorative environment" of forests, which makes them feel comfortable. This theory is further highlighted by the COVID-19 pandemic. After the COVID-19 outbreak, people around the world minimized social contact through remote-working and online classes, and their time at home became significantly longer [3-4]. Also, due to the social distancing policies, spending time with family and friends was restricted, and people were not allowed to visit places where they enjoyed indoor leisure activities in the city [4]. Instead of these places, parks and forests have been spotlighted as places of recreation and healing [5-7]. As the time of staying at home becomes longer, many people are feeling more negative emotions such as depression, anxiety and loneliness, and chose forests and parks as spaces to relieves these mental stress [6,8]. Since the first half of 2019, when COVID-19 began to spread worldwide, visitors to parks and forests have increased sharply [6]. It also showed the characteristics of more diverse types of visitors, including young people and families with children, visiting forests, unlike before the COVID-19 outbreak. As such, due to the global pandemic, more and more visitors are coming to the forest and nature to promote physical and psychological health.

As previously mentioned Stephen and Rachel Kaplan argues, various studies have already demonstrated that forests can promote diverse physiological and psychological health conditions. These forest healing effects includes olfactory, visual and socio-environmental effects, among which the typical is the olfactory effects through phytoncide emitted by trees [9-13]. "Phytoncide," a complex chemical secreted by trees to protect themselves from external harmful factors, is a representative healing factor in nature. Phytoncide is also called NVOC (Natural Volatile Organic Compounds), and there is an organic compound called "Terpene" in phytoncide, which is known to benefit people's health when exposed to the atmosphere where terpenes are scattered. Phytoncide is beneficial to both physiological and psychological health [14-20]. Phytoncide enhances NK cell (natural killer cell) activities [14], has antioxidant and antibacterial effects [15], and reduces blood pressure, pulse rate and cortisol level [16-18]. Beside these physiological benefits, it also reduces stress and improve mood [16,18-20]. Since NVOC has different emissions and composition depending on the tree species, several studies have conducted experiments to find the specific tree species and natural environments with great forest healing effects.

Under these circumstances, several researchers began to pay attention to the effects of phytoncide emissions on physical health as well as the economic and environmental benefits of bamboo. Currently, more than 1,500 species of bamboo inhabit 22 million hectares of land worldwide, and research has also been conducted to find out the effects of forest healing among different bamboo species. Observation of 12 species of BVOC emissions by bamboo species showed significant differences in emissions by species [21]. In particular, according to the study which investigated steam extract of *Phyllostachys* species, it was mainly comprised of monoterpenes which are well known for various health benefits, and the study also revealed that *Phyllostachys pubescens* is said to have more significant anticancer and antioxidant effects than other species, which could be used as a natural anticancer and antioxidant factor in the future [22]. This high concentration of phytoncide emissions from bamboo groves has been proven to have a significant effect on reducing blood pressure, enhancing immune system and increasing concentration ability through activation of brain wave, and it is also effective in decreasing anxiety [23-25].

As such, several prior studies have demonstrated that more and more people are visiting forests to gain healing effects, and bamboo groves have excellent forest healing environments. However, while existing studies have been actively studying phytoncide diffusion characteristics of coniferous and broadleaf forests, analysis of the NVOC characteristics of bamboo groves is lacking. Furthermore, analysis of relationships between microclimate environments and bamboo groves is rarer, and in order to enhance the forest healing effect of visitors to bamboo groves, it is essential to understand the characteristics of NVOC emission in bamboo groves and the factors affecting its emissions. Accordingly, this study revealed NVOC emission characteristics and diurnal patterns of *Phyllostachys pubescens* groves, and proved correlation between various microclimate environment factors. In addition, to address the difficulty of regularly measuring NVOC and microclimate data over a wide range of forests for a long term, prediction equation for emissions from bamboo groves is established through regression analysis.

## 2. Materials and Methods

### 2.1. Study Site

The study was conducted at the National Institute of Forest Science's Gajwa Research Forest in southern part of Jinju City, Gyeongsangnam-do in South Korea (Figure 1). Its geographical location is 35° 9' 37.4652" N, 128° 6' 17.1504" E. The Gajwa research forest is located at 116.8m above sea level and covers an area of 27 hectares. The forest has three different kinds of bamboo groves including *Phyllostachys bambusoides*, *Phyllostachys nigra* var. *henonis* and *Phyllostachys pubescens* which is the primary species of this study. It is also

the largest bamboo variety conservation center in Korea which contains 126 different species of bamboo. It is also the only place conducting researches on bamboo groves in Korea, and it serves as an important urban forest in Jinju city. As it is shown in the Figure 1, there were three measurement points A, B, and C which were the three different experiment sites within the *Phyllostachys pubescens* grove in order to reduce measurement errors. The total length from point A to point C is about 200 meters.



**Figure 1.** Figures of study sites: (a) Gajwa *Phyllostachys pubescens* Grove; (b) NVOCs measurement points (shaded area is *Phyllostachys pubescens* groves, and points A, B and C are shown in the figure).

## 2.2. Measurement Methods

In order to proceed this research, NVOC concentrations and microclimate environment were assessed. NVOC and microclimate environment data were collected in three different points in *Phyllostachys pubescens* grove (points A, B and C) as shown in Figure 1. Samples were measured once every hour during the experimental days on April to August of 2019, three different experiment days in total. Measurement factors are shown in Table 1, and NVOCs indicators were selected based on literature research.

**Table 1.** NVOCs and microclimate environment measurement factors.

NVOCs	Microclimate Environment
3-Carene, Borneol, Bornyl acetate, Camphene, Camphor, d-Limonene, Eucalyptol, Menthol, p-Cymene, Phellandrene, Sabinene, $\alpha$ -Pinene, $\alpha$ -Terpinene, $\alpha$ -Terpinolene, $\beta$ -Myrcene, $\beta$ -Pinene, $\gamma$ -Terpinene	Air Humidity, Air Temperature, Soil Temperature, Soil Humidity, Gust Speed, PAR (Photosynthetically Active Radiation), Solar Radiation, Wind Speed

### 2.2.1. NVOCs (Natural Volatile Organic Compounds)

NVOCs were measured three different days between April to August of 2019. Of the three experimental days, one session collected NVOCs for a full 24 hours, and the other two sessions collected NVOCs from morning (9:00) to sunset (17:00), in order to gather data more about the time people visited the forest the most. The study sites were arranged in a circle at 50 meters intervals according to geographical characteristics. In consideration of the vegetation characteristics, five pumps were installed at each point of the study site.

The samples were collected using the adsorption tube process. Adsorption was performed using tubes loaded with Tenax TA (150 mg) from Markes (Sacramento, CA, USA).

The sample capture system was a mini pump (MP-30KN, Sibata, Japan), and the calibration was preceded by a measurement of the adsorption error before the flow meter was used. At a flow rate of 150 mL/min, a total volume of 9L of NVOC was collected. The sampling equipment was set up on a tripod 1.5 meters off the ground, and the average value was determined by repeating process at each site. During the experiment, disposable polyethylene gloves and antibacterial masks were used to avoid artificial errors when in contact with the tube. After sampling, the sample tubes were held at a temperature below 4°C for 48 hours before being analyzed (Table 2). In order to reduce the error, the value of the tubes collected without filling Tenax TA inside was also reflected.

**Table 2.** The conditions for the operating parameters for NVOC.

Parameters		Conditions			
Column	HP-INNOWAX (60 m × 0.25 mmL Dx 0.25 μm, film thickness)				
Carrier gas flow	He at 1 mL/min				
Injection mode	Pulsed Splitless				
Injection port temp.	210 °C				
Transfer line temp.	210 °C				
Over temp. program	Initial	Rate	Final		
	40 °C	3 min	8 °C/min	220 °C	3 min 40 °C
Post run	220 °C, 5 min				

A gas chromatography-mass spectrometer (7890N-5975, Agilent, Santa Clara, CA, USA) with a thermal desorption device was used to perform qualitative and quantitative analyses on the samples (GC-MSD, Gerstel TDS, Gerstel, Germany). The substances adsorbing in the adsorption tube is concentrated in a low temperature cryofocusing system, which takes high-purity helium gas from a thermal desorption device at a rate of 1mL/min. The system desorbed the gas at 210°C for 3 minutes while maintaining a temperature of -30°C. The compounds were then heated at 220°C for 3 minutes before being injected into a GC spectrometer and detected with an MSD.

### 2.2.2. Microclimate Environment

In terms of locational environment, the site's direction and slope were calculated. The physical features of the site environment were reported at 5-minutes intervals using a portable multifunction meter (HOBO-U23 V2, Onset, Bourne, MA, USA). Solar radiation sensors (S-LIB-M003, Onset, Bourne, MA, USA) and photosynthetically active radiation sensors (S-LIA-M003, Onset, USA) were positioned in the same position and tracked during the experiment.

A wind monitoring sensor (Wind monitor O5103-45, R.N.Y., Logan, UT, USA) was also mounted in consideration of the geological features in order to obtain wind direction and velocity data at the designated site. The meter was set up in equilibrium at a height of 1.5 meters on a tripod about 5 meters from a mini pump, and the digitalized measurement results were saved and then converted for the study. The HOBO-ware Pro software was used to evaluate the findings (Onset, USA). To minimize measurement errors, the data which was saved 5 minutes before and after each measurement were excluded from the study.

### 2.3. Analysis Methods

The analysis was conducted by using R 4.0.4 and RStudio. "lmtest", "gylma", "lm.beta" and other R packages were used for the analysis. Data were collected from 17 NVOC indicators and 8 microclimate indicators shown in Table 1, with 259 and 1403 samples, respectively (Figure 2). The data were preprocessed and used for statistical

analysis and TNVOC (Total NVOC) results, which can represent 17 NVOC indicators, were also used for analysis.

To identify NVOC emission characteristics of bamboo groves, 17 NVOC substances were examined for average daily emission concentrations. Furthermore, the main NVOC emission elements of bamboo groves were identified by calculating the proportion of each substance to the TNVOC emissions. In addition, to find out the trends of TNVOC and eight microclimate elements during a day, diurnal patterns of each element were observed, and the pattern was divided by phase where the changes were significant.

In order to find out the effect of microclimate factors on NVOC emissions from bamboo groves, multiple regression analysis was conducted using the “Backward Elimination” method. The first model did not proceed with backward elimination, but performed multiple regression analysis, including a total of eight all microclimate indicators. The second model used the backward elimination method to perform multiple regression analysis. After building these two models, F-Test was conducted to prove that the removed microclimate indicators had no statistically significant effect. To verify the multicollinearity of the Model 2, the VIF (Variance Inflation Factor) was identified and shown below 10 in all indicators, proving that there is no strong correlation between independent variables. Finally, the Durbin-Watson test conducted to determine the presence of autocorrelation between the residuals. Accordingly, the result of this study was analyzed based on the Model 2 multiple regression analysis presented above.

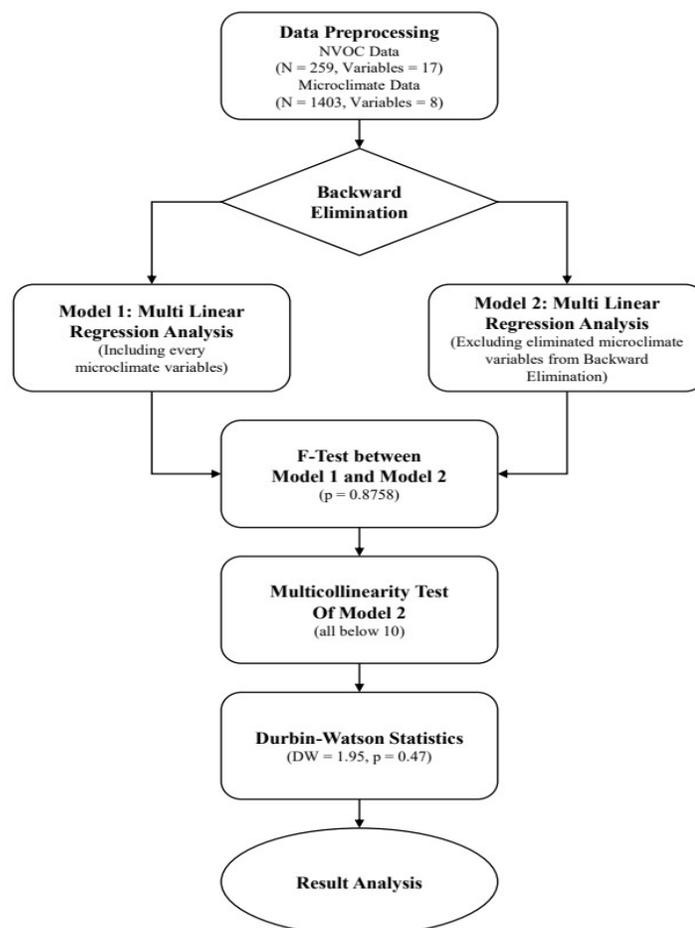
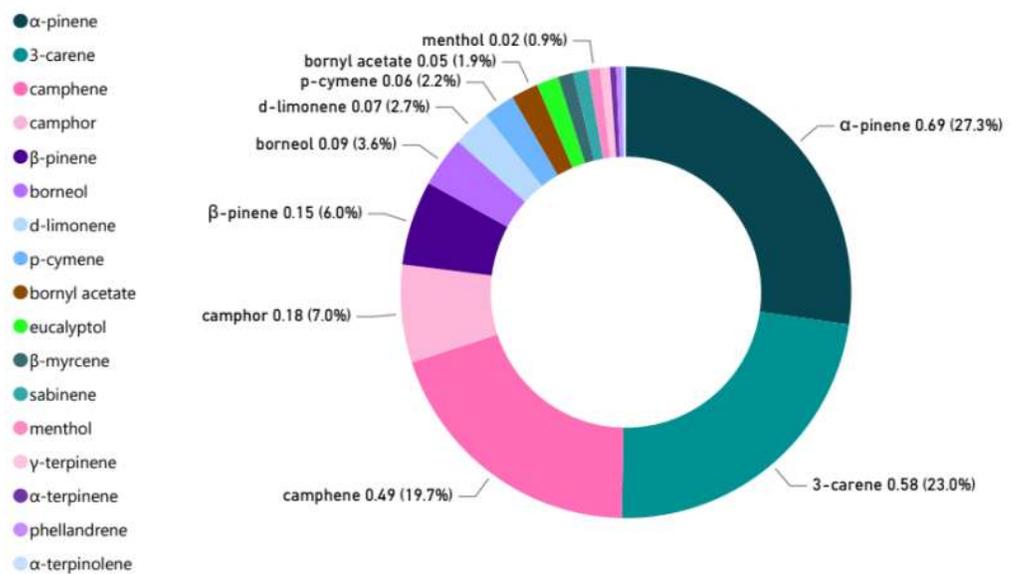


Figure 2. Flow diagram of regression analysis process.

### 3. Results

### 3.1. Characteristics of NVOCs at Bamboo Groves

The amount of emissions by NVOC components of *Phyllostachys pubescens* groves can be found in Figure 3. The most emitted NVOC is  $\alpha$ -pinene (0.69  $\mu\text{g}/\text{m}^3$ ), accounting for 27.3% of the total emissions. The second most emitted NVOC was 3-carene (0.58  $\mu\text{g}/\text{m}^3$ ) at 23%, while the third was camphene (0.49  $\mu\text{g}/\text{m}^3$ ) at 19.7%. The above three NVOCs account for 70% of the total NVOC emissions, which are overwhelmingly higher than other substances. They were followed by camphor (7%, 0.18  $\mu\text{g}/\text{m}^3$ ),  $\beta$ -pinene (6%, 0.15  $\mu\text{g}/\text{m}^3$ ), borneol (3.6%, 0.09  $\mu\text{g}/\text{m}^3$ ), d-limonene (2.7%, 0.07  $\mu\text{g}/\text{m}^3$ ), p-cymene (2.2%, 0.06  $\mu\text{g}/\text{m}^3$ ), bornyl acetate (1.9%, 0.05  $\mu\text{g}/\text{m}^3$ ), eucalyptol (1.6%, 0.04  $\mu\text{g}/\text{m}^3$ ),  $\beta$ -myrcene (1.1%, 0.03  $\mu\text{g}/\text{m}^3$ ), sabinene (1.1%, 0.03  $\mu\text{g}/\text{m}^3$ ), menthol (0.9%, 0.02  $\mu\text{g}/\text{m}^3$ ),  $\gamma$ -terpinene (0.7%, 0.02  $\mu\text{g}/\text{m}^3$ ),  $\alpha$ -terpinene (0.4%, 0.01  $\mu\text{g}/\text{m}^3$ ), phellandrene (0.4%, 0.01  $\mu\text{g}/\text{m}^3$ ) and  $\alpha$ -terpinolene (0.3%, 0.01  $\mu\text{g}/\text{m}^3$ ).



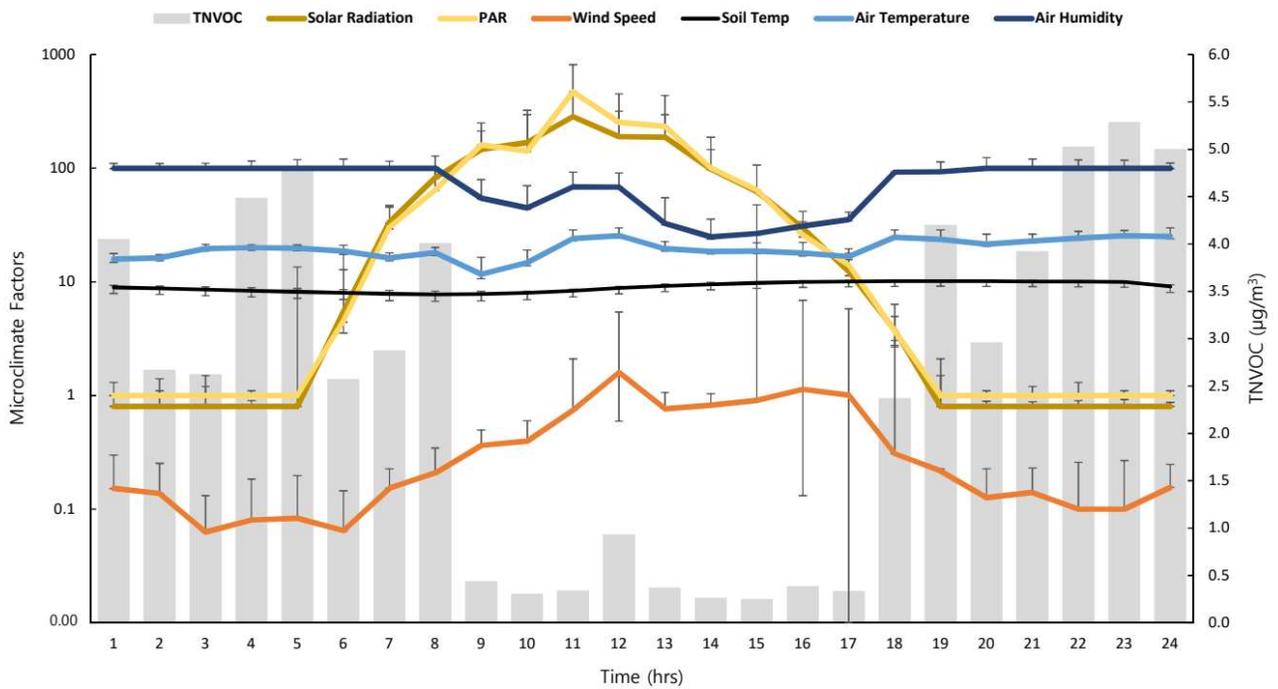
**Figure 3.** Emission analysis of bamboo groves by NVOC components. This chart used colorblind-friendly palette.

### 3.2. The Variations of NVOCs Concentration

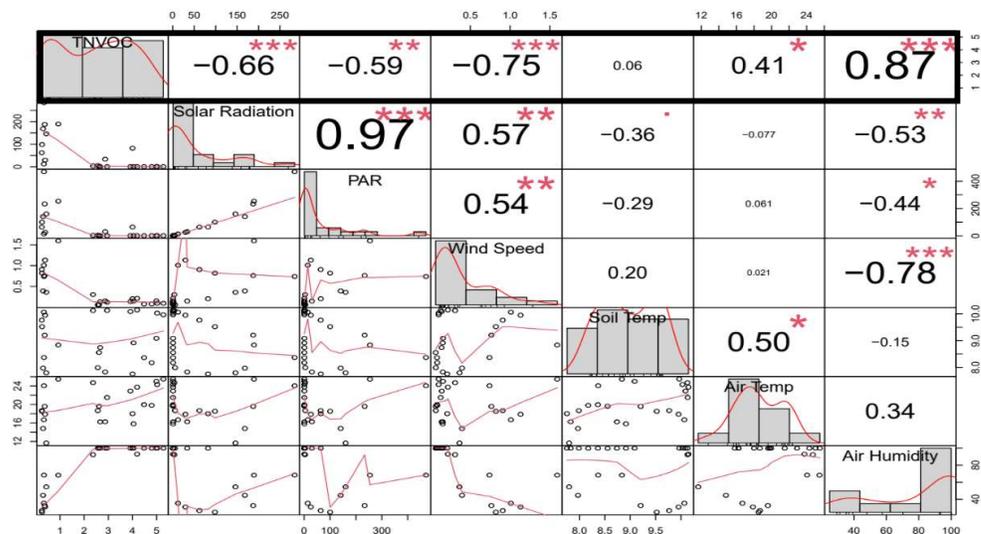
The diurnal pattern between TNVOC emissions and microclimate factors is shown in Figure 4. The grayed-out region is the TNVOC emission by time, and six broken line graphs show the change of each microclimate factors. Soil humidity and gust speed were excluded which had low significance and low tendency. The changes in time of these indicators were examined by dividing them into four phases. The first phase includes a change from 5:00 to 7:00. The TNVOC, which peaked at 5:00, decreased with a drop in temperature. Humidity, soil temperature and wind speed did not show significant changes. PAR and solar radiation tended to increase in reverse from 5:00 to 7:00 when TNVOC dropped. The conflicting trends between TNVOC and PAR and solar radiation were more pronounced in the second phase. The TNVOC increased slightly from 7:00 to 8:00, but decreased significantly from 8:00 to 10:00 in the second phase. This is in contrast to PAR, solar radiation and wind speed, which showed an increasing trend from 8:00 to 10:00. Temperature and humidity showed a downward change, such as TNVOC, and soil temperature did not show much change. At noon, before phase 3, all indicators except soil temperature showed a trend of slightly rising and then decreasing again. After 12:00, TNVOC decreased and maintained, but increased significantly from 17:00 to 19:00. This is the third phase, with temperature and humidity also showing a tendency to increase,

while PAR, solar radiation and wind speed were reduced in reverse. Soil temperature still showed minimal changes. The TNVOC peaked at 19:00 and then declined until 20:00, but rose sharply from 20:00 to 22:00 which is the fourth phase. Temperature rose slightly in the fourth phase, and other indicators showed no significant changes. Also, TNVOC recorded its highest daily emission at 23:00.

Based on this trend graph analysis, the Pearson correlation between TNVOC and the microclimate factors is shown in Figure 5. As previously identified in the trend graph, TNVOC has a strong inverse correlation with solar radiation, PAR and wind speed, and a strong normal correlation with air temperature and air humidity. However, soil temperature has not been shown to have a significant correlation with TNVOC.



**Figure 4.** Diurnal graph of TNVOC and microclimate factors. Error bar indicates standard deviation of each indicators. Units of each microclimate factors: solar radiation ( $W/m^2$ ), PAR ( $\mu E$ ), wind speed (m/s), soil temperature and air temperature ( $^{\circ}C$ ) and air humidity (% rh).



**Figure 5.** Pearson correlations between TNVOC and microclimate factors**3.3. NVOCs and Physical Environments of Bamboo Groves**

To investigate the effects of microclimate factors on NVOC emissions, multiple regression analyses were conducted (Figure 2). TNVOC was established as a dependent variable, eight microclimate factors as independent variables, and the backward elimination method was adopted. Multiple regression analysis including all eight independent variables was set to Model 1, and multiple regression analysis excluding variables removed through backward elimination was set to Model 2. Regression results from Model 1 and Model 2 can be found in Table 3. A total four microclimate factors were excluded from the backward elimination, in order of gust speed, soil temperature, solar radiation and soil humidity. As it is shown in Table 3, PAR and wind speed are shown to have a negative relationship with TNVOC, and air temperature and air humidity are shown to have a positive relationship. Among them, PAR, air temperature and air humidity have been shown to be significantly related to TNVOC emissions. The significance probability of Model 2 is .000, indicating that the regression model is suitable, and the adjusted R<sup>2</sup> is 0.829, which has sufficient explanatory power. Furthermore, multicollinearity tests demonstrate that all indicators have below 10 on VIF (variance inflation factor), and all explanatory variables in Model 2 are not highly linearly related. Finally, D-W value obtained from the Durbin-Watson statistics was 1.95, indicating that no autocorrelation exists between the residuals and that they are independent to each other (Table 4).

Accordingly, the variables that have the greatest impact on TNVOC emissions have been found to be PAR, air temperature and air humidity. The regression equation for Model 2 is shown below.

$$\text{TNVOC} = -1.704 + -0.004 * (\text{PAR}) - 1.075 * (\text{Wind Speed}) + 0.135 * (\text{Air Temperature}) + 0.029 * (\text{Air Humidity}) \quad (1)$$

**Table 3.** Multiple regression results of Model 1 and Model 2

	Indicators	Estimate	Std. Error	t	p <sup>2</sup>	Adjusted R <sup>2</sup>	F	p <sup>3</sup>
<b>Model 1</b>	(Intercept)	8.920	20.254	0.440	0.666			
	Solar Radiation	0.008	0.016	0.510	0.618			
	PAR	-0.010	0.009	-1.095	0.291			
	Wind Speed	-1.078	1.154	-0.934	0.365			
	Gust Speed	-0.039	1.300	-0.030	0.976	0.796	12.240	0.000 ***
	Soil Temp.	0.022	0.672	0.033	0.974			
	Soil Humidity	-80.648	174.771	-0.461	0.651			
	Air Temp.	0.183	0.087	2.093	0.054			
	Air Humidity	0.026	0.022	1.163	0.263			
<b>Model 2</b>	(Intercept)	-1.704	0.986	-1.729	0.100	0.829	28.930	0.000 ***
	PAR	-0.004	0.002	-2.682	0.015*			

Wind Speed	-1.075	0.720	-1.493	0.152
Air Temp.	0.135	0.051	2.626	0.017*
Air Humidity	0.029	0.011	2.761	0.012*

<sup>1</sup> \* p < .05, \*\* p < .01, \*\*\* p < .001

<sup>2</sup> Calculated probability of each independent variable.

<sup>3</sup> Calculated probability of each model.

**Table 4.** Variance Inflation Factor (VIF) and Durbin-Watson statistics results of Model 2

Model	Variance Inflation Factor				Durbin-Watson Statistics			
Model 2	PAR	Wind Speed	Air Temp.	Air Humidity	Lag	Auto-correlation	D-W	p
	1.43	3.60	1.49	3.76	1	-0.03	1.95	0.50

#### 4. Discussion

This study is aimed to discover the NVOC emission characteristics of bamboo groves and to build a model to predict the effects of microclimate elements on NVOC emissions of bamboo groves. Prior studies have already demonstrated that microclimate factors affect NVOC emissions in various types of forests, especially on the NVOC emission characteristics of broadleaf forests and coniferous forests. However, not many studies have analyzed the NVOC distribution characteristics of bamboo groves and their association with microclimates, which are widely distributed in East Asia, and researches regarding predicting NVOC emissions of bamboo groves are even rare. According to the existing prior studies mentioned earlier, bamboo grove provides diverse psychological and physiological health benefits including enhancing immune system and cytotoxic effect [21,23,25]. Therefore, an investigation into the effects of microclimate elements on NVOC emissions of *Phyllostachys pubescens* grove, a type of bamboo groves, is necessary to understand the positive effects of bamboo grove on humans in more detail. However, even though several studies have already demonstrated the effect of microclimate on NVOC emissions in forests, there is a need for a model to predict them as it is difficult to regularly measure NVOC emissions and microclimate changes across forests that change over time and season. Accordingly, this study identified the type of monoterpene that is mainly emitted from the bamboo grove, and the relationship between NVOC and microclimate factors in the bamboo groves. Lastly, this study established the NVOC emission prediction model through the regression analysis.

In this study, a total of 17 NVOCs were detected in the *Phyllostachys pubescens* grove, it was detected high in the order of  $\alpha$ -pinene, 3-carene, camphene, camphor and  $\beta$ -pinene. The above five substances have also been shown to be the main components of NVOC in several prior studies. In particular,  $\alpha$ -pinene, 3-carene and camphene accounted for 70% of the total emissions, with  $\alpha$ -pinene known to have anxiolytic, anti-inflammatory, antioxidant, and antiproliferative effects, and 3-carene is known to improve inflammatory conditions [13,26-29]. Finally, camphene was found to have an antiproliferative, antioxidant, antinociceptive, and antihyperlipidemic effects, and also can enhance metabolism activities [30-32]. As such, it has been revealed that major NVOCs emitted from bamboo groves have various healing effects. In addition, when checking diurnal patterns of NVOC emissions and microclimate factors in bamboo groves, TNVOC was the highest at 1:00 to 8:00 and 18:00 to 24:00, excluding daytime hours, and peaked at 23:00. Considering that the study period is from April to August, this is consistent with prior studies proved that NVOC is produced the most in the morning and late afternoon in spring and summer [2,36,38]. In addition, given the graph of diurnal pattern and Pearson correlation results, NVOC emissions showed strong inverse correlation with solar radiation, PAR and wind speed, and strong normal relationship with temperature and humidity. This is also matched with previous studies that claimed correlation of radiation, wind speed, temperature, humidity and NVOC emissions [32,33,35-38]. Based on these

findings, this study conducted a multi-regression analysis to establish a model for NVOC prediction through microclimate factors. There are a total of four microclimate factors affecting TNVOC emission forecasts, including PAR, wind speed, air temperature, and air humidity. Air temperature, air humidity, and wind speed are also included in prior studies that derive TNVOC prediction regression for different types of forests, meaning that this study found the effect of PAR on TNVOC prediction in addition to the above three factors, and is expected to be useful for bamboo groves' TNVOC prediction [7,39].

However, this study has several limitations. First, this regression is derived from data measured from a *Phyllostachys pubescens* grove in Jinju, South Korea, and the threshold remains that predictive accuracy can be reduced in areas with different climates and different physical elements. Second, as many other factors besides microclimate elements can affect NVOC emissions of *Phyllostachys pubescens* groves, outside factors are also needed to be considered. Third, there is a limitation that the NVOC and microclimate data of *Phyllostachys pubescens* groves were not measured continuously for a long time, but only measured three times in a short period of time. Thus, in subsequent studies, data collection on bamboo groves in different regions and long-term and periodic observations will allow to expand the study. Furthermore, since this study identified four major weather factors affecting NVOC emissions in bamboo groves, it is expected that further studies will be able to specifically consider these four microclimate factors in their research, not the whole microclimate factors. Lastly, researching about how these four microclimate factors affect other types of forests will be able to expand this research also.

In COVID-19 pandemic situation, people stay in their homes longer than before, interests in health care is rapidly increasing, and more and more people are trying to find healing elements in parks and forests near their homes as mentioned earlier. Therefore, forests and the natural environments which provide various forest healing elements and promote health conditions are drawing significant attention. However, there is still a lack of research on the specific mechanisms of what factors in forests and green areas affect health improvement. Therefore, this study could be used as a basis for identifying forest healing mechanisms, as it identified the relationship between NVOC, one of the forest healing elements, and microclimate factors, and derived a regression equation to predict NVOC emissions in bamboo groves.

## 5. Conclusions

This study was conducted to identify the NVOC emission characteristics of bamboo groves with abundant forest healing elements and their relationship to microclimate factors, and to build a prediction equation of NVOC emissions from bamboo groves. This study, conducted in *Phyllostachys pubescens* groves in Jinju, Gyeongsangnam-do, South Korea, was analyzed based on a total of 259 NVOC samples and 1403 microclimate data. A total of 17 types of NVOC were detected, and the relationship with 8 microclimate factors was examined. Of the 17 NVOCs detected,  $\alpha$ -pinene, 3-carene and camphene were found at high level, with these three monoterpenes accounting for 70% of the total NVOC emissions. A review of diurnal NVOC emission pattern in the bamboo groves confirmed that the amount of TNVOC was detected high in the early morning and late afternoon. These patterns of TNVOC emissions showed strong normal correlations with air temperature and air humidity, and strong inverse correlations with solar radiation, PAR and wind speed. Soil temperature has not been shown to have much correlation with TNVOC emissions. Finally, to establish a model for predicting NVOC emissions from bamboo groves, multiple regression analyses were conducted based on changes in NVOC emissions and microclimate factors. The selected regression equation included a total of four microclimate factors and was found to have a high explanatory power of 82.9%. The above findings and prediction equation will be able to give insights regarding NVOC emissions of bamboo groves, spaces for forest healing, and these results could be used as a basis for providing better forest healing services to citizens.

**Author Contributions:** Conceptualization, Y.C. and G.K. and S.P.; methodology, E.K.; software, Y.C.; validation, Y.C., E.K. and S.K.; formal analysis, Y.C.; investigation, E.K. and S.K.; resources, G.K. and S.P.; data curation, G.K.; writing—original draft preparation, Y.C.; writing—review and editing, G.K. and S.P.; visualization, S.K.; supervision, G.K.; project administration, S.P. All authors have read and agreed to the published version of the manuscript.

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