

Article

Effects of Different Site Conditions on the Concentration of Negative Air Ions in Mountain Forest Based on an Orthogonal Experimental Study

Qi Chen ^{1,2,†}, Rui Wang ^{2,3,†}, Xinping Zhang ⁴, Jianjun Liu ^{1,*} and Dexiang Wang ^{3,*}

¹ College of Landscape Architecture and Art, Northwest Agriculture and Forestry University, Xianyang 712100, China; chenqi0174@163.com

² Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention (LAP 3), Shanghai 200000, China; wangrui_nwafu@163.com

³ College of Forestry, Northwest Agriculture and Forestry University, Xianyang 712100, China

⁴ College of Art and Design, Xi'an University of Technology, Xi'an 710048, China; jhonxinping@nwsuaf.edu.cn

* Correspondence: ljj@nwsuaf.edu.cn (J.L.); wangdx6666@163.com (D.W.)

† These authors contributed equally to this work.

Abstract: The negative air ions (NAI) in a forest play an important and positive role in promoting the health of people using the forest for recreation. The purpose of this study was to explore the environmental characteristics that can effectively represent high concentrations of NAI in mountain forests to help the recreational users to seek out sites with high NAI concentrations for personal health reasons. In order to achieve this goal, we selected the mountain forest of Taibai Mountain National Forest Park, Shaanxi Province, China, as the research object and adopted an orthogonal experimental design with three factors and three levels to study the effects of terrain, altitude, and forest canopy density on the forest NAI concentrations. The results show that obvious peak–valley fluctuation occurs during 6:31 a.m. to 18:30 p.m., with the highest concentration of NAI at 8:00 a.m. (Average: 163 ions/cm³) and the lowest at 16:00 p.m. (Average: 626 ions/cm³). The altitude ($p < 0.01$) and canopy density ($p < 0.05$) were found to significantly affect NAI concentrations. The combination of site conditions in the mountain forest observed to have the highest NAI concentrations was valley topography, low altitude, and high canopy density. In addition, the highest NAI concentration was between 14:00 p.m. and 16:00 p.m., under this combination, which was thus identified as the most suitable time for health-promotion activities in mountain forests. The results provide insights into the NAI concentration characteristics and variations, along with identifying important environmental factors for the selection of health-promotion activities in mountain forests.

Keywords: mountain forest; negative air ions (NAI); terrain; altitude; crown density



Citation: Chen, Q.; Wang, R.; Zhang, X.; Liu, J.; Wang, D. Effects of Different Site Conditions on the Concentration of Negative Air Ions in Mountain Forest Based on an Orthogonal Experimental Study. *Sustainability* **2021**, *13*, 12012. <https://doi.org/10.3390/su132112012>

Academic Editor: Joana Ferreira

Received: 6 September 2021

Accepted: 27 October 2021

Published: 30 October 2021

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1. Introduction

Negative air ions (NAI) is a generic term for the negatively charged gas molecules and ions in the air [1]. Negative air ions are also known as negative oxygen ions since they form negative ions based on their ability to acquire electrons, most of which are acquired by oxygen. Numerous studies have shown that NAI has many beneficial effects on human health, both physical and psychological effects [2]. Physically, NAI have a beneficial effect on the cardiovascular and respiratory systems [3–5]. Psychologically, NAI can improve sleep quality [6], improve mood states [7], and alleviate chronic depression [8]. NAI are mainly generated by pathways involving cosmic rays [9], radiation (emitted by the radon element of minerals) [10], solar ultraviolet radiation [11], lightning [12], water shearing forces (the Lenard effect) [3] and plants [13]. Therefore, factors such as vegetation cover, flowing water bodies, and air humidity can be considered as important influencers of the anion content [14]. Forests are thought to be the environments that produce large amounts of NAI. Currently, health and wellness programs involving NAI-based forests have become

popular in China. At present, the concentration of NAI has become an important factor influencing the selection of forest healthcare sites. There are specific requirements for the concentration of NAI in the establishment of standards for relevant forest healthcare sites.

Along with the continuous increase in the attention focused on NAI, many researchers have successively conducted detailed studies on their biological effects [15], clinical efficacy [13,16–18], effects on air quality [19–23], concentration variations [24–29] and factors that influence this [27,30–32], the environment and mechanisms that produce NAI [33–35], and the development and use of NAI resources [36–38]. Studies have shown that the NAI concentrations in forests are much higher than indoors and in cities [24,31,39], with concentrations being up to 160 times higher [24].

Prior studies have focused more on monitoring the NAI concentrations in forests and analyzing the influence of different environmental factors on the dynamic change in forest NAI concentrations [26,27,29,32,39–42]. Among them, the main environmental factors considered were the influence of meteorological factors and stand structure on the NAI concentrations in forests. In the process of studying the diurnal distribution characteristics of NAI concentrations in forest parks, it was found that the law of diurnal variation would differ with different environmental conditions [27,39–41]. Although many studies have been conducted on forest NAI, current research is mainly concentrated in plains [24,27,43], and related research on mountain forests is lacking, so the influence of factors such as mountain topography and altitude has not been sufficiently considered. In addition, due to the cross-influence of terrain, altitude, ecology, and environmental factors on NAI concentrations, the research conclusions are often quite varied.

Three reasons support the study of NAI in mountain forests. Firstly, with the development of urbanization and agriculture, the land resources of plains are suitable for urban construction, and arable land is in short supply [44]. Tension due to plains land resources has caused plains forests to be continuously depleted. The area and quality of forests in plains have seriously declined [45]. Only mountain forests, having human health value, are better preserved. It is therefore necessary to study mountain forests thoroughly in order to make the most of this resource. Secondly, existing studies have only discussed the relationship between meteorological factors and NAI concentrations [27]; however, meteorological factors are relatively abstract and difficult to intuitively feel and judge, so it is necessary to determine NAI concentrations with the help of certain instruments and equipment. Moreover, it is difficult to directly observe these factors in mountain forests because of their complex terrain, large area, and poor accessibility, since it is difficult for humans to directly reach these areas. Therefore, it is necessary to explore some easy-to-observe, non-instrument modes of measurement and indirect and direct arrival factors suitable for mountain forest characterization for use in determining the NAI concentrations in mountain forests. These indicators or factors can include terrain, altitude, forest canopy density, etc. Third, the existing studies on NAI concentration were rarely carried out in mountain forests. There are no relevant or quantitative studies on factors such as terrain and altitude. Therefore, there is an obvious need for this to be conducted.

Based on the above reasons, we selected some easy-to-observe and easy-to-judge mountain forest characteristic factors to evaluate their potential in screening the forest environment with a view to promoting health. The environment we selected for study was Taibai Mountain National Forest Park, a typical mountain forest in central China with a beautiful forest environment, rich tourism resources, and high demand in terms of forest healthcare from the surrounding urban population. We studied this park during the tourist season in 2021 under different site conditions, whereby the NAI concentration variation characteristics were analyzed, and we explored the NAI concentration change rule of the park, which can serve as a reference for the study of NAI in mountain forests.

2. Materials and Methods

2.1. Study Site Selection

The study was conducted in the Taibai Mountain National Forest Park of Shaanxi Province in China. The geographical coordinates are 107°41'23"–107°51'40" E and 33°49'31"–34°08'11" N. With altitudes ranging from 620 to 3511 m, it is the national forest park with the highest point of elevation in China. It is one of the mountain forests with the richest flora in temperate China. The forest area in the district is 45,725 hectares, with a forest coverage rate of 81.2%. There are about 1800 species of seed plants, belonging to 122 families and 660 genera. The main forest vegetation includes *Quercus variabilis*, *Quercus aliena* var. *Acuteserrata*, *Quercus liaotungensis*, *Betula albosinensis*, *Betula albosinensis* var. *Septentrionalis*, *Abies fargesii*, and *Larix chinensis*. We used the Negative Air Ions monitors in the Taibai Mountain National Forest Park, which monitors the real-time concentration of NAI.

2.2. Orthogonal Experiment Design

The experimental design was an L9 (3³) orthogonal array [46], as shown in Table 1. The three factors of experimental design were terrain, altitude, and canopy density. Each factor was divided into three levels, coded as 1, 2, and 3, and a total of nine combinations were set up in this experiment, as shown in Table 2. In addition, a control sample point was set up in the square outside the mountain forest park in front of the visitor center. As the research site (Taibai Mountain National Forest Park) is located on the northern slope of the Qinling Mountains in China, all the monitoring sites in the study belong to the forests in the northern part of the terrain. A total of 10 experimental monitoring sample points were measured synchronously to study the influence of various factors on the NAI concentrations, and the results were analyzed by range, variance, and multiple comparative analyses to determine the optimal combination with the highest NAI concentration, and the optimal combination was tested and verified. The data collection period was 1–5 May 2021, during which the NAI concentrations were calculated at different sample points. According to the time of recreational activities, we chose daytime observation. The data were collected from 6:31 a.m. to 18:30 p.m. Three samples were selected for each array combination. The statistical data is the average of the three samples. Additionally, meteorological data were collected to investigate the influence of meteorological factors on NAI.

2.3. Instrumentation

The NAI concentrations were measured using the KEC900+II negative oxygen ion monitor (Wanyi Technology Co., Ltd., Shenzhen, China). This instrument is usually calibrated in real time and has a high measurement accuracy of $\leq 5\%$. The measuring range was 10–2,000,000 ions/cm³ and ion mobility was ≥ 0.4 cm²/(V.s). The instrument meets the requirements of the functional specifications of the China Meteorological Administration. Air temperature, relative humidity, and wind velocity were measured using the Kestrel 5500 portable meteorological instrument (Nielsen-Kellerman Instruments Ltd., Boothwyn, PA, USA). Air temperature can be measured in a range of $-10\sim 60$ °C with 0.1 °C resolution, and relative humidity is measured in the range of 0~100% with 0.1% resolution. The measurement range of wind velocity is 0.1–40 m/s with a resolution of 0.1 m/s. The atmospheric pressure was assessed using a CS106 sensor produced by Campbell Scientific, Inc., New York, NY, USA. The atmospheric pressure is measured in the range of 500~1100 hPa with a resolution of 0.3 hPa. In this test, 10 sets of monitoring instruments were used for synchronous measurement, and unified correction was performed before instrument measurement. The test time of each instrument was strictly controlled to basically ensure the synchronization of different measurement points.

Table 1. The factors of orthogonal design ($L_9 (3^3)$) and levels of site conditions.

Levels	Terrain	Altitude	Canopy Density
1	valley	high, 1501–2000 m	high, 0.7~1.0
2	slope	middle, 1001–1500 m	middle, 0.4~0.7
3	ridge	low, 620–1000 m	low, 0.1~0.4

Table 2. The orthogonal array tests ($L_9 (3^3)$) and results. The average negative air ions (NAI) concentrations of mountain forest for the three levels (level 1, 2 and 3) of the factors (terrain (T), altitude (A), and crown density (C)) and the differences between the mountain forest sample points.

Sample Point	Factors			NAI Concentration (Ions/cm ³)			
	Terrain (T)	Altitude (A)	Crown Density (C)	Forenoon Period	Noon Period	Afternoon Period	Daytime Period
S1	1	1	1	189 ± 4 d	481 ± 25 c	515 ± 33 c	395 ± 25 c
S2	1	2	2	216 ± 8 c	532 ± 34 bc	600 ± 41 b	449 ± 31 bc
S3	1	3	3	251 ± 6 b	590 ± 31 b	652 ± 35 ab	497 ± 36 b
S4	2	1	2	150 ± 8 f	361 ± 16 e	396 ± 14 e	302 ± 15 de
S5	2	2	3	171 ± 13 ef	408 ± 29 d	433 ± 18 d	337 ± 21 d
S6	2	3	1	293 ± 16 a	707 ± 49 a	734 ± 54 a	578 ± 44 a
S7	3	1	3	102 ± 12 g	243 ± 11 e	260 ± 10 f	202 ± 6 e
S8	3	2	1	210 ± 17 cd	516 ± 15 c	554 ± 63 bc	427 ± 23 c
S9	3	3	2	212 ± 9 cd	559 ± 21 b	569 ± 45 bc	446 ± 29 bc
CK				176 ± 7 e	478 ± 38 c	519 ± 39 c	391 ± 14 c

The mean values of each group were compared using Duncan's multiple range tests. Values are mean ± SE. Different letters indicate a significant difference between the means at $p \leq 0.05$. The numbers 1, 2, and 3 in the same columns for the factors (T, A, and C) represent the levels.

2.4. Statistical Analysis

A statistical analysis system (SPSS 22.0, Chicago, IL, USA) was used to analyze the data. Functional mapping software (Origin 2019, OriginLab Ltd., Northampton, MA, USA) was used to draw the data analysis diagrams. Range analysis was used to evaluate the results of the nine different combinations [47,48].

2.5. Validation of the Improved Protocol

The results of the orthogonal test were used to establish an improved scheme consisting of the optimal levels of site conditions to evaluate the effectiveness of the orthogonal test method. Verification tests were then conducted during 7–12 May 2021. Two combinations were compared: (a) the improved combination based on the orthogonal array test results, and (b) the best of the nine combinations tested in the orthogonal array matrix.

3. Results

3.1. The Variation Characteristics of NAI Concentrations in Different Time Periods

The mean NAI concentration of mountain forests at different time periods was analyzed, and the diurnal variation was shown in Figure 1. For data statistics, we chose the data from half an hour before and after each hour for average calculation. We clearly found that the diurnal variation in the average NAI concentration shows obvious troughs and peaks. The average NAI concentration showed a gradual decreasing trend from 7:00 a.m. to 8:00 a.m. with a minimum (163 ions/cm³) at approximately 8:00 a.m., then a rapid increase from 9:00 a.m. to 16:00 p.m., with a maximum (626 ions/cm³) at approximately 16:00 p.m., and then a rapid decrease from 16:00 p.m. to 18:00 p.m. until the end of our observation window.

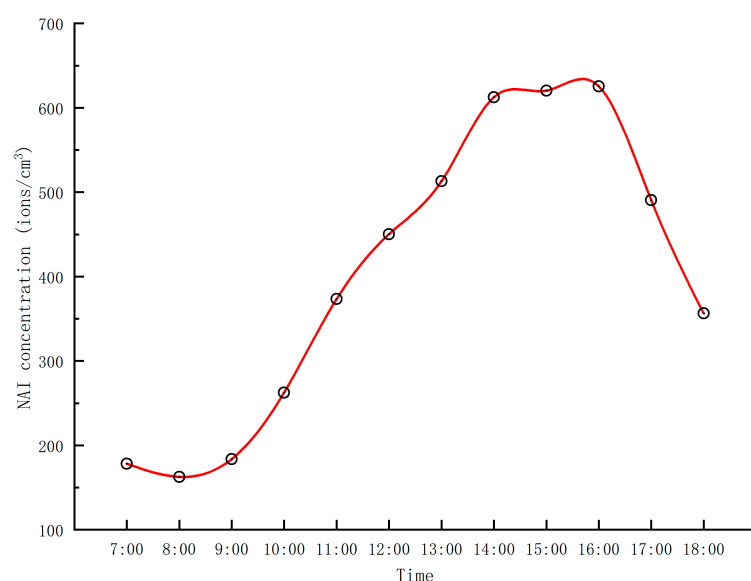


Figure 1. The variation characteristics of NAI concentration in different time periods.

Analyzing the hourly data of NAI concentrations, we found that NAI concentrations from 14:00 p.m. to 16:00 p.m. were much higher than during the other time periods, whereas NAI concentrations were low from 7:00 a.m. to 13:00 p.m. and 17:00 p.m. to 18:00 p.m. Dividing the sampling day into three periods, we found that the average mountain forest NAI concentration trajectory is first steady, then increases, and then decreases. The average of NAI concentration in each period is 197 ions/cm³ from 6:31 a.m. to 10:30 a.m., 487 ions/cm³ from 10:31 a.m. to 14:30 p.m., and 523 ions/cm³ from 14:31 p.m. to 18:30 p.m. Therefore, the NAI concentration in the daytime leisure period was divided into three periods, namely morning period, noon period, and afternoon period, for subsequent analysis.

3.2. The Variation Characteristics of NAI Concentrations at Different Mountain Forest Sample Points

Table 2 provides the average NAI concentration of the mountain forest for the three levels (level 1, 2, and 3) of the terrain (T), altitude (A), and crown density (C) factors, and the differences between the mountain forest sample points. Figure 2 more intuitively shows the NAI concentration at the different sample points under different factor combinations in the mountain forest.

The three site condition factors significantly impacted the NAI concentrations in mountain forest at different time periods (Figure 2, Table 2). The results demonstrate that NAI concentration increased with crown density and decreased with increasing altitude, and that NAI concentration was also influenced by terrain factors (Table 3). The highest NAI concentration at different sample points were observed during the afternoon period at sample point S6 (734 ions/cm³), which was 41.4% higher than that of the control group (519 ions/cm³) (Figure 2). The lowest NAI concentration amongst the different sample points was observed during the morning period at sample point S7 (102 ions/cm³), which was 42.0% less than that of the control group (176 ions/cm³) (Figure 2). The highest NAI concentration (S6, during the afternoon observation period, 734 ions/cm³) was 7.2 times that of the lowest NAI concentration (S7, during the morning observation period, 102 ions/cm³). The highest NAI concentration at sample point S6 was related to mountain forest with the highest crown density and lowest altitude. Conversely, the lowest NAI concentration at sample point S7 was related to the mountain forest having the lowest crown density and the highest altitude. Among the three mountain forest factors, altitude had the greatest impact on NAI concentrations at different time periods, crown density had the second greatest impact on NAI concentration at different time periods and

the least impact on NAI concentration during the morning and afternoon periods, and terrain had the least impact on NAI concentrations and the second strongest impact on NAI concentration during the afternoon period (Table 3).

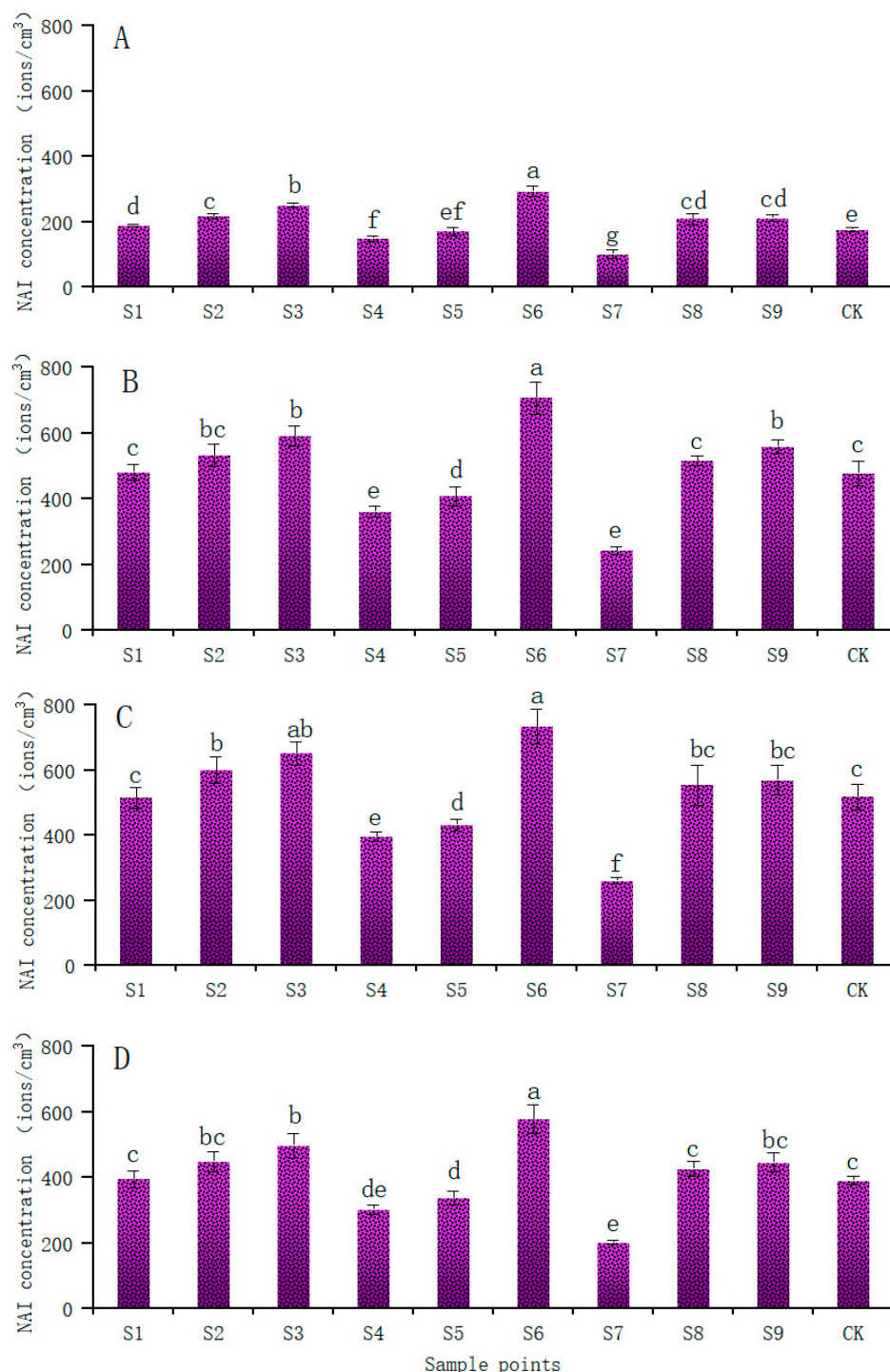


Figure 2. Orthogonal array tests ($L9(3^3)$) and the results. The mean values of each group were compared using Duncan's multiple range tests. Different letters indicate a significant difference between the means at $p \leq 0.05$. Values are means $\pm$ SE and vertical bars represent the SE. NAI concentrations at different sample points during the (A) morning period, (B) noon period, and (C) the afternoon period; (D) NAI concentration at different sample points during the daytime period.

Table 3. Results of range analysis on NAI concentration (morning, noon, afternoon, and daytime periods) in a mountain forest of three levels of three factors: terrain (T), altitude (A), and crown density (C).

Indicator	Terrain (T)			Altitude (A)			Crown Density (C)		
	K ₁	K ₂	K ₃	K ₁	K ₂	K ₃	K ₁	K ₂	K ₃
Morning period (ions/cm ³)	219	205	175	147	199	252	231	193	175
Noon period (ions/cm ³)	534	492	439	362	485	619	568	484	414
Afternoon period (ions/cm ³)	589	521	461	390	529	651	601	522	448
Daytime period (ions/cm ³)	447	406	358	300	404	507	467	399	345

The subscript numbers 1, 2, and 3 next to the letters indicate levels. K₁, K₂, and K₃ are the average values of level 1, 2, and 3, respectively.

3.3. Orthogonal Analysis of NAI Concentrations in Mountain Forest

Two mountain forest factors, altitude (A) and crown density (C), had significant effects ($p \leq 0.01$) on the NAI concentrations in all the studied periods, but terrain (T) had no significant effects ($p \geq 0.05$) on the NAI concentrations (Table 4). However, the combination of the three factors (T*A*C) in the mountain forests had a significant ($p \leq 0.01$) effect on NAI concentrations during all periods. The site condition combination T₂A₃C₁ (sample point S6) resulted in the highest NAI concentrations among all sample points tested in the orthogonal array design, and the NAI concentration (578 ions/cm³) during the daytime period was significantly higher compared with the other sample points (Table 2, Figure 2). The NAI concentration (578 ions/cm³) with combination T₃A₁C₃ (the sample point S7) during the daytime period was significantly lower compared with the other combinations.

Table 4. Variance analysis was performed on the mountain forest sample points, and orthogonal comparisons were conducted at the terrain (T), altitude (A) and crown density (C) levels to test the F ratio and probability of the NAI concentration in mountain forests.

Factor	Morning Period		Noon Period		Afternoon Period		Daytime Period	
	F	P	F	P	F	P	F	P
T	2.768	0.079	2.694	0.084	2.917	0.070	2.193	0.117
A	15.186	0.000 **	19.456	0.000 **	12.249	0.000 **	11.944	0.000 **
C	4.536	0.019 *	7.049	0.003 **	4.178	0.025 *	4.076	0.020 *
T*A*C	5.483	0.000 **	6.882	0.000 **	4.598	0.001 **	6.071	0.000 **

* Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$.

3.4. Correlation Analysis between Micrometeorological Environment and NAI Concentration in Mountainous Forest

Meteorological factors such as temperature and humidity had a significant effect ($p < 0.01$) on the NAI concentration in this mountainous forest, but meteorological factors such as wind velocity and atmospheric pressure had no significant effect ($p > 0.05$) (Figure 3). In sunny and breezy weather conditions, the NAI concentration of the mountainous forest increased with the temperature between 8.6 and 36.2 °C, and decreased with the humidity between 12.7% and 53.9%. The wind velocity, with a change between 0 and 2.8 m/s, and atmospheric pressure, with a change between 849.5 and 992.9 hPa, had no significant effect on the NAI concentration in the mountainous forest (Figure 3).

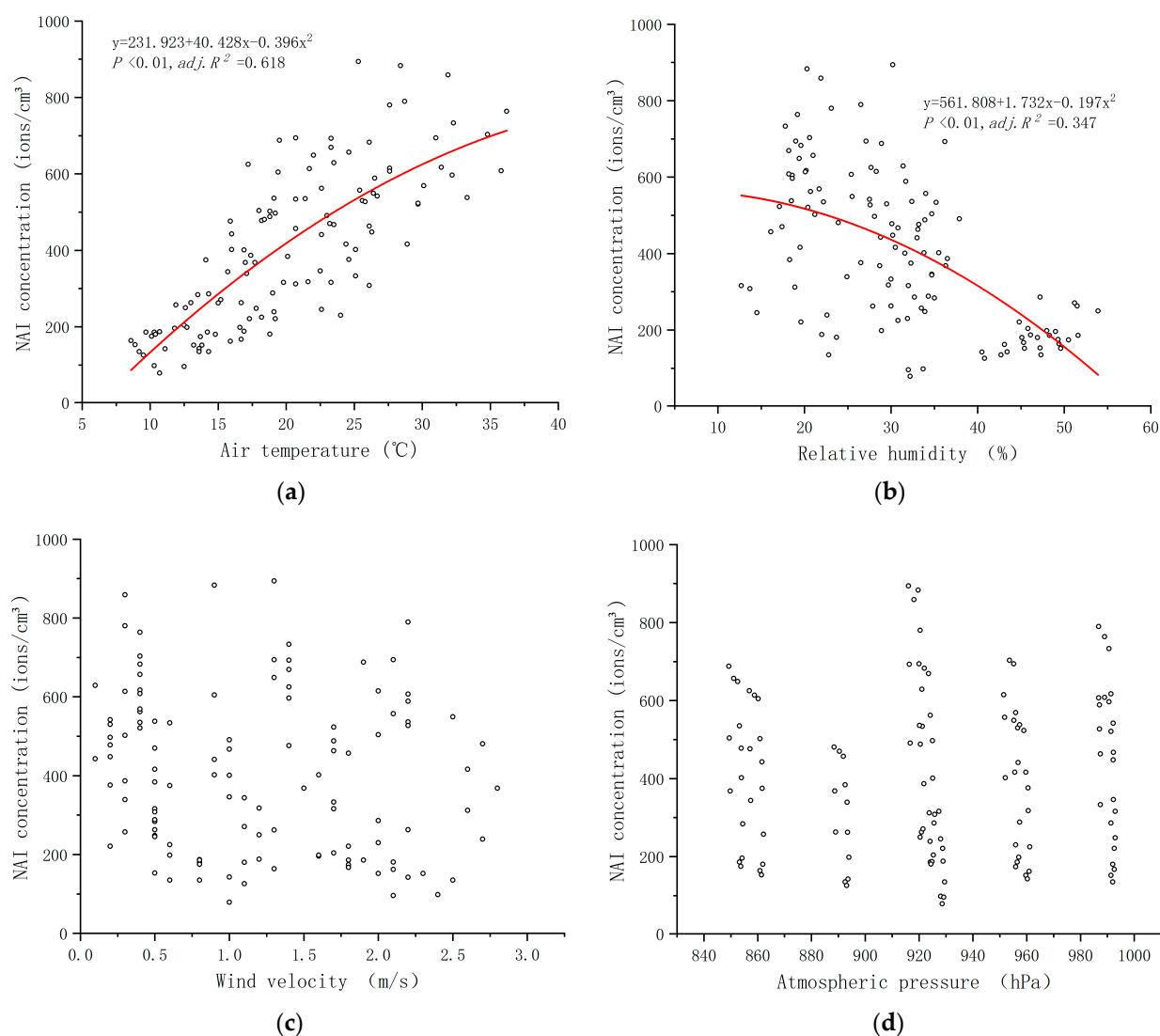


Figure 3. The relationship between temperature (a), humidity (b), wind velocity (c), atmospheric pressure (d), and NAI concentration in a mountainous forest. Temperature and humidity had a significant effect ($p < 0.01$) on the NAI concentration of mountainous forest, but wind velocity and atmospheric pressure did not ($p > 0.05$). Lines that have no significant effect are not drawn in the figure.

3.5. Validation of the Improved Combination

$T_2A_3C_1$ was the best combination of factors screened by the orthogonal design experiment, with an average concentration of NAI (578 ions/cm³) significantly higher than those of the other combinations. However, due to the orthogonal experiment, there are still some schemes not listed in the previous orthogonal combination. Therefore, in the following experiment, the improved regimen $T_1A_3C_1$ was compared with the optimal combination regimen $T_2A_3C_1$, designed by the orthogonal array to verify the improvement effect on NAI concentration.

The results of the validating experiment (Table 5) showed that although no significant differences were obtained between the improved combination $T_1A_3C_1$ and the optimal combination $T_2A_3C_1$ in terms of mean NAI concentration, the combination $T_1A_3C_1$ had significantly higher NAI concentrations during the morning period than $T_2A_3C_1$.

Table 5. The results of the validating experiment.

Combinations	NAI Concentration (Ions/cm ³)			
	Morning Period	Noon Period	Afternoon Period	Daytime Period
T ₁ A ₃ C ₁	347 ± 21 a	734 ± 55 a	778 ± 48 a	619 ± 42 a
T ₂ A ₃ C ₁	293 ± 16 b	707 ± 49 a	734 ± 54 a	578 ± 44 a

Note: combination T₁A₃C₁ is the improved protocol and combination T₂A₃C₁ is the optimal combination based on the results obtained from the orthogonal array experiment. Different letters indicate a significant difference between the means at $p \leq 0.05$.

The results of the verification experiment are shown in Table 5. Although the average NAI concentration (daytime period) of the improved combination T₁A₃C₁ was not significantly different from that of the optimal combination, T₂A₃C₁, the NAI concentration of the T₁A₃C₁ combination was significantly higher than that of the T₂A₃C₁ combination in the morning period. According to our monitoring results, the NAI concentration of combinations T₁A₃C₁ and T₂A₃C₁ did not differ significantly during the daytime period, which may be due to the absence of significant differences in meteorological factors between the two combinations. Similarly, due to significant differences in meteorological factors between the two combinations, NAI concentrations and values of the two combinations were significantly different in the morning. The differences of meteorological factors are shown in Table 6.

Table 6. The difference comparison results of meteorological factors of the validating experiment.

	T ₁ A ₃ C ₁ vs. T ₂ A ₃ C ₁			
	Morning Period	Noon Period	Afternoon Period	Daytime Period
<i>p</i> value	<0.001	0.182	0.094	0.104

Note: combination T₁A₃C₁ is the improved protocol and combination T₂A₃C₁ is the optimal combination based on the results obtained from the orthogonal array experiment.

4. Discussion

Forest environments have important healthcare value. NAI are important active ingredients in forest environments, playing an important role in promoting physical rehabilitation [14,41]. NAI have been described as vitamins found in air [14]. Studies show that NAI can reduce the concentration of environmental particulate matter [22], purify air [49], kill bacteria [50], reduce inflammation [3], fight depression [51,52], and promote physical recovery [53] and antioxidant activity [54]. Therefore, the concentration of NAI is the basis of evaluating the health quality of forest environments. Given that China's aging population is increasing the medical expenditure burden [55], the need for health promotion through the healing function provided by forest environments is increasing [56]. However, due to the expansion of cities and the development of farmland, the natural forests in the plains are gradually being destroyed and are disappearing [44,45]. Therefore, mountain forests will be key sites for attaining health benefits, to use the beautiful natural environment of mountain forests and take advantage of the health factors in forest environments for physical and psychological healing in many countries and regions [56]. The concentration of NAI is one of the key environmental factors creating the healing effect of mountain forest environments [26]. It is important to study the effect of site conditions on the concentration of NAI and to quickly identify locations with high NAI concentrations in mountain forests according to site conditions.

We found that NAI concentrations have a distinct diurnal variation profile. Specifically, NAI concentrations were highest at 14:00 p.m.–16:00 p.m. and lowest at 7:00 a.m.–9:00 a.m. This may be due to the distribution of meteorological factors during the day. We conducted correlation analysis and linear regression analysis between NAI and meteorological factors based on hourly data and found significant correlations between NAI and relative air humidity and air temperature. Relative air humidity is an important factor affecting NAI

concentrations. In addition, it can be seen from the formula of oxygen-based NAI that water can produce NAI by Lenard force, and oxygen-based NAI can react with water [9–13].

The forest canopy density had an important effect on NAI concentrations. The results of an earlier study [27] on a forest environment in a plain showed that the higher the canopy density of the forest in the same area, the higher the NAI concentration. In this study, forest with a high canopy density (>0.7) was most favorable for NAI concentration. This is consistent with the results of previous studies [40,41], showing that the NAI concentration of mountain forest was also affected by forest canopy density. Because of the very strong positive correlation between moisture content in the air and the production of NAI [26,42], a high canopy density in a mountain forest has increased air moisture due to plant transpiration; simultaneously, the dense canopy cover blocks the sun's rays, reducing water evaporation in the forest and thereby resulting in higher water content in the air of the mountain forest [27], which is conducive to the generation of NAI. The effect of the forest canopy density on the NAI concentration in mountain forest was different at different times of day. The forest canopy density had the highest effect on the NAI concentration at noon, and the effect in the morning and afternoon was low. This is consistent with the influence of canopy density on the air humidity in the forest. Our results show that a high canopy density promoted the release of NAI, and thus enhanced the health-promoting capacity of the forest environment. This finding is similar to those obtained in earlier studies [24,27,31]. In our study, we also found that the NAI concentration in the mountain forest environment with the same canopy density was significantly different at different altitudes. This indicates that the elevation and canopy density of mountain forest affect the NAI concentration. This link has not been reported in previous studies. We think that the reason for this finding may be that the superposition of two environmental factors, altitude and canopy density, in the mountain forest changed the conditions for the generation of NAI in the forest, which led to the significant difference in the NAI concentration observed in the forest. Such changes may include the following aspects: (1) temperature and humidity changes caused by altitude, (2) changes in vegetation species and leaf tip morphology caused by vertical landscape changes, and (3) changes in oxygen concentrations at different elevations.

Altitude had a significant effect on the NAI concentration. In mountain forests, elevation can not only directly affect the change in meteorological factors [57], but also indirectly affect the distribution and morphology of plant species [58]. All these effects can further affect the NAI concentration in mountain forests [29]. In this study, the average NAI concentration in the sample plot at low altitude (1000 m) was the highest, and that the sample plot at low altitude (1000 m) was the highest in the morning, noon, and afternoon, a trend which is similar to previous reports [26,41]. Our results indicate that the mountain forest at low altitude had the highest NAI concentration and was therefore the most suitable for forest health-related activities. The reasons why altitude affects the NAI concentration were analyzed in detail and found to depend on how NAI are produced in the air. NAI can be grouped according to the different ways in which they are produced and their main compositions as natural NAI, corona NAI (generated by the corona discharge ionization), and Lenard NAI (generated by the shearing force of water) [12,33,59–61]. Natural NAI are the main NAI in the forest [33]. The production of natural NAI is affected by the activity of oxygen molecules [33,61]. The higher the altitude, the lower the temperature and activity of oxygen molecules, and less natural NAI are produced [61]. In addition, with increasing altitude, the oxygen concentration in the environment gradually decreases, and so fewer oxygen molecules are available for conversion to NAI [2,61]. Therefore, given these many reasons, the NAI concentration at high altitude is significantly lower than that at low altitude. Therefore, health activities in mountain forests should be performed in low-altitude areas.

Terrain has a strong effect on the NAI concentration. In this study, the average NAI concentration in the sample plot in a valley was the highest, whereas that on the ridge was the lowest. At noon and in the afternoon, the NAI concentration in the valley topography was the highest; in the morning, the NAI concentration in the hillside topography was

the highest; and the NAI concentration on the ridge was the lowest at all time periods. Previous studies have not reported the effect of topographic factors on the NAI concentration. However, we can infer and predict the influence of topographic factors on the NAI concentration by considering the influence of topographic factors on microclimate factors. Topographic factors of mountain forests affect forest microclimate such as air temperature, relative humidity and wind velocity [62]. The change in these factors affects the accumulation and diffusion of anions in mountain forests, which leads to the change in the NAI concentration [41]. The mountain forest in the valley area had the highest concentration of NAI, indicating it is the most suitable for forest human-health-related activities. In addition, the mountain forest in the ridge area had the lowest NAI concentration, indicating it to be the most unsuitable for activities to gain health benefits from the forest. Therefore, health-related activities in mountain forests should preferentially be conducted in the valley area.

In conclusion, our findings show that different site selection conditions and environments have different effects on NAI concentrations. For example, the concentration of NAI was the highest in the S6 combination, but the lowest in the S7 combination. Our findings also suggest that altitude and crown density have significant effects ($p \leq 0.01$) on NAI concentrations (Figure 3). The results of this study provide a theoretical basis for the rapid selection of the best healthcare sites in mountainous forests.

The limitation of this study is that only a short-term monitoring and analysis of NAI concentration in mountain forests was conducted, and no comparative study was conducted on NAI concentration in mountain forests of the northern and southern slopes. Future studies should establish long-term monitoring stations and comparative studies of mountain forests on the northern and southern slopes, which are conducive to a comprehensive analysis of NAI concentration in mountain forests affected by terrain, altitude and community.

5. Conclusions

The advantage of the orthogonal array design is that it can improve the efficiency of multi-factor and multi-level influence experiments [63]. In our study, only nine combinations ($L_9(3^3)$) in the orthogonal array tests were designed to test the three site condition factors with three levels for each factor. Based on the results of the orthogonal experiment, a verification experiment was established. The verification results showed that the NAI concentration of improved combination $T_1A_3C_1$ was higher than that of the optimal combination from orthogonal array design. The combination of mountain forest at low altitude with high canopy density and a valley topography is best for increasing the concentration of NAI. Altitude, canopy density, and topography were significant factors affecting the spatial distribution of NAI concentrations. We suggest that researchers or policy makers take into account altitude, canopy density and topographic factors that affect NAI concentration when studying or establishing sites for health promotion activities in forest parks in the future. This article provided a unique perspective on the study of the spatial distribution of NAI.

Author Contributions: Q.C., R.W., J.L. and D.W. designed the study and experiment; Q.C. and R.W. collected the data; Q.C., R.W. and X.Z. conducted the data analysis; Q.C., R.W., J.L. and D.W. provided the statistical methods; Q.C., R.W., J.L. and D.W. drafted the paper; Q.C., R.W., X.Z., J.L. and D.W. edited the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National 12th Five-Year Scientific and Technological Support Plan (grant no. 2015BAD07B0203 and grant no. 2015BAD07B06), and the Opening Project of Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention (LAP 3).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are contained within the article.

Acknowledgments: We wish to express our thanks for the support received from the administration of Taibai Mountain National Forest Park, China, and for allowing us to collect samples. We also thank the 10 volunteers from Northwest A&F University for their helpful work during the collection of data. The authors sincerely appreciate the helpful and constructive comments provided by the reviewers on the draft manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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