International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 24, No. 3, p. 202-211, 2024

RESEARCH PAPER OPEN ACCESS

Biophysical factors influencing the Height and Diameter structures of Falcata (*Falcataria falcata* (L.) Greuter & R. Rankin) in Agusan del Norte, Philippines

Cornelio S. Casilac Jr.*[1], Adrian M. Tulod[2]

[1]*College of Forestry and Environmental Science, Caraga State University, Butuan City, Philippines*

[2]*Department of Forest Biological Science, College of Forestry and Environmental Science, Central Mindanao University, Musuan, Bukidnon, Philippines*

Key words: Tree growth, Falcata, Elevation, Biophysical factors

http://dx.doi.org/10.12692/ijb/24.3.202-211 Article published on March 18, 2024

Abstract

This study aims to support private tree farmers in making knowledgeable management decisions in their falcata plantation. The effect of biophysical factors on the height and diameter structures of 6-year-old Falcata (*Falcataria falcata*) at various elevations (0-200 m asl, 201-400 m asl, and 401-600 m asl) in Agusan was investigated in this study. Fifteen (15) 20 m x 20 m plots were created at each sampling site a total of 45 plots were established. In this study, the height and diameter structures of 6-year-old falcata were measured and analyzed. Results indicate that elevation, temperature, relative humidity, and soil potassium are key factors influencing the height and diameter structures of 6-year-old falcata trees. The mean height and diameter were highest in the middle elevation, or within 201-400 m asl, and lowest in the higher elevation, or 401-600 m asl. The temperature has a negative and significant relationship with the height and diameter structures of 6-year-old falcata, and tree spacing had a negative relationship with height.

* **Corresponding Author:** Cornelio S. Casilac ✉ corneliocasilac@gmail.com

Introduction

Falcataria falcata (L.) Greuter & R. Rankin) is a huge tree with a first branch reaching a height of up to 20 meters. Falcata trees can reach 100 cm in diameter, have a spreading flat crown, and form a wide umbrella-shaped canopy when growing in the open, with the buttress being tiny or absent (Krisnawati *et al.*, 2011). Tree growth patterns in forest stands vary between locations and individual trees due to both internal and external variables. Environmental variables vary concerning elevation within a species geographical range, resulting in regional diversity in site conditions that may limit growth (Barry, 1992). A higher growth rate boosts a species competitive ability and survival in favorable conditions (Vitasse, 2009).

The elevational gradient plays an important role in a tree or stands growth since trees have different ecological and physiological requirements for survival. Understanding how tree growth responds to environmental gradients is crucial for comprehending the ecology of species distribution and forest ecosystems, as well as for predicting future ecosystem services, as stated by Rapp *et al.* (2012). The growth and mortality rates of trees can be influenced by the elevation, as each species has an optimal altitude level for planting suitability. Some authors suggest that tree growth may decline with elevation (Coomes and Allen, 2007; Leigh, 1975; Bruijnzeel and Veneklaas, 1998; Girardin *et al.*, 2010)

Pathogens (Mallett and Volney, 1999), insects (Rhoades and Stipes, 1999), competition with other trees (Nowak and McBride, 1991; Rhoades and Stipes, 1999), and competition with other vegetation are all biotic variables linked to lower tree growth rates in ecosystems (Close *et al.*, 1996). Gall rust appears to be more common in falcata species at higher elevations. Anino (1991) emphasizes that minor infections occur at lower elevations of 250 meters above sea level, while major infections occur at elevations of 275 to 500 meters above sea level. Severe instances were discovered at elevations ranging from 400 to 600 meters above sea level (Lacandula *et al.*, 2017).

There is a need to investigate the influence of biophysical factors on the height and diameter structures of the falcata at different elevation because the knowledge of how this plant responds are of paramount significance in understanding its ability to respond to climate change. In the Philippines, falcata is one of the most important species for industrial tree plantations (ITPs). Despite the importance of the species, there is no empirical data about its height and diameter structures concerning different elevations.

The study hypothesized that the height and diameter structures of 6-year-old falcata will decline with elevation. More specifically, the hypothesis suggests that the height and diameter structures of the species will reduce at higher elevations due to their vulnerability under such conditions.

Materials and methods

Study site

The study was conducted in three different areas in Agusan del Norte, Philippines. Agusan del Norte is situated in Mindanao in the western section of the Caraga region. The area has no definite dry season. Rainfall is pronounced throughout the year with maximum rainfall occurring from November to January. The Falcata plantations sampled in this study are owned by private tree farmers and people's organizations under the National Greening Program. Three (3) municipalities and a city in the Province of Agusan del Norte were covered in this study (Fig. 1).

Sampling design and measurements

Randomized complete block design (RCBD) was used in the study, with three sites or municipalities as blocks and three elevational ranges per site as treatments. The elevation ranges include (a) 0-200 m asl; (b) 201-400 m asl; and (c) 401-600 m asl. In every area, fifteen plots were established. Five 20 m x 20 m sampling plots were established per elevational ranges. A total of forty-five sampling plots were made in the study. The three elevation ranges were selected because based on the data given by the Department of Environment and Natural Resources (DENR) only these elevations have existing Falcata plantations that are common in age during the sampling period of this study.

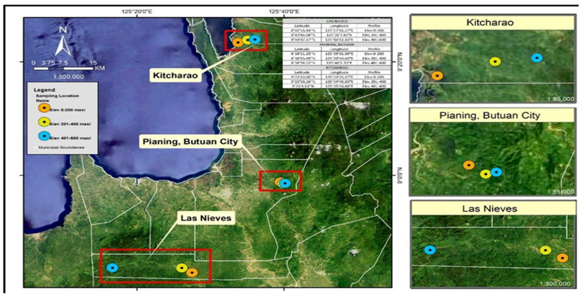

Fig. 1. Map showing the locations of Falcata plantations sampled in this study

Fig. 2. Measuring the Falcata tree height in the study sites using electronic hypsometer

Fig. 3. Measuring the Falcata tree diameters in the study sites using diameter tape

Height and diameter measurements

The total height (m) and diameter at breast height or DBH (cm) of all trees inside the sampling plots were measured and recorded accordingly. The height of the trees was measured using an electronic hypsometer taken from ground level to the highest shoot in a due North direction (Fig. 2). The DBH of a tree was also measured using a diameter tape (Fig. 3).

The incidence of gall rust in each plot was also quantified and calculated using the following equation modified by Rahayu *et al.*, (2018). The incidence status was determined by using the rating scale used by Palma *et al.* (2020) (Table 1).

DI= $(n \div N) \times 100$

Table 1. Rating scale for gall rust incidence per plot

present incidence	Status
<10	Rare
10-<25	Occasional
25-<50	Common
50-<75	Very common
>75	Widespread

Data collection

The site variables at each sampling plot such as air temperature, relative humidity, slope-aspect, and light intensity were determined. Air temperature and relative humidity were determined by using a handheld digital psychrometer and the measurements were done thrice a day specifically at 8:00 in the morning, 12:00 noon, and 3:00 in the afternoon. The light intensity in every plantation was also measured using a digital photometer following the same protocols for determining air temperature and relative humidity.

Statistical analysis

Differences in site variables among elevations were analyzed using analysis of variance (ANOVA). The variations in height and diameter structures due to elevation and site-specific variables were analyzed using linear mixed-effect models (LMM) with the elevation and site variables as fixed effects, and the site replicates as random effects. The significant variables were analyzed using Duncan's Multiple Range tests (DMRT).

Results and discussion

Height structures of Falcata at different elevations

The height growth of 6-year-old Falcata varies across elevations (Fig. 4 and Table 2). The result of the study shows that the highest mean height was observed in the middle elevation or within 201-400 m asl followed by lower elevation or within 0-200 m asl, while the lowest mean height was obtained within 401-600 m asl zone. The results suggest that the height growth of Falcata declined significantly at higher elevations. This result supports an earlier report elsewhere by Coomes and Allen (2007) that tree growth declines with altitude and declines steeply at higher altitudes. Among the three areas, the result of the study shows that the highest mean height was observed in Kitcharao, Agusan del Norte within 200-400 m asl while the lowest mean height was observed in Pianing within 200-400 m asl. In addition, for all three areas across different elevations, the mean height of 6-year-old Falcata in Agusan del Norte was 18.53 m.

Post hoc test revealed significant differences between the mean height of the 6-year-old Falcata across elevations (Table 2).

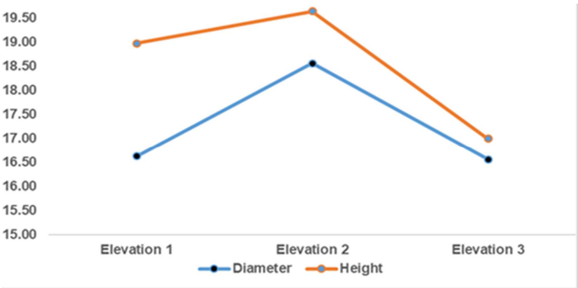

Fig. 4. Mean height and diameter structures of Falcata

Table 2. Differences in the mean height (m) of Falcata across area and elevations

Elevation (m asl)	Pianing	Las Nieves	Kitcharao	Mean	P- value Due to elevation
0-200	16.88	18.67	21.37	18.97 [b]	*0.03
201-400	16.02	18.42	24.46	19.63 [b]	
401-600	18.53	16.23	16.22	16.99 [a]	
Mean	17.14	17.77	20.10	18.53	

The means of different letters are significantly different from each other *significant at (0.05)

Table 3. Differences in the mean diameter (cm) of Falcata

Elevation (m asl)	Pianing	Las Nieves	Kitcharao	Mean	p- value due to elevation
0-200	14.60	18.54	16.72	16.62	0.13 ns
201-400	16.90	17.99	20.8	18.56	
401-600	17.62	16.43	15.62	16.56	
Mean	16.37	17.65	17.71	17.25	

Diameter structures of Falcata at different elevations

Table 3 shows that the lowest mean diameter was observed between 401-600 m asl zone across different elevations followed by those in the lower elevation range of 0-200 m asl. The highest mean diameter was observed between the middle elevation range of 201-400 m asl. The findings suggest that the diameter structures of Falcata are not significantly influenced by elevation. Among the specific locations studied, the smallest diameter was observed in Pianing, Butuan City, which falls within the 0-200 m asl elevation range. Meanwhile, the largest diameter was observed in Kitcharao, Agusan del Norte, which is situated in the 201-400 m asl elevation range. Across all three areas and different elevations, the average diameter of 6-year-old Falcata trees in Agusan del Norte was 17.25 cm, as shown in Table 3. Additionally, the mean diameter of Falcata trees in the 401-600 m asl elevation range was the smallest at 16.56 cm, while those in the 0-200 meter and 201-400 m asl elevation ranges were 16.62 cm and 18.56 cm, respectively.

Growth rates may decrease with altitude because of shorter growing seasons, reduced air and soil temperatures, reduced supply of nutrients, and increased exposure to wind (Coomes and Allen, 2007). The result of the study suggests that the growth of Falcata in Agusan del Norte specifically the height will decrease when it reaches higher elevations 401-600 m asl due to the significant effect of elevation including its biophysical factors. Although the species can be found up to 1600 meters above sea level in its natural habitat the biophysical factors also vary.

A study conducted by the Agricultural Polytechnics College in Kupang (East Nusa Tenggara) found that the species could survive at lower elevations on rocky, reef, or coral-derived soils, but that its growth was inhibited (Djogo, 1997). The species can be found in Papua at Manokwari's lowest point between 55 m asl (Charomaini and Suhaendi, 1997).

Influence of gall rust incidence on the growth of Falcata at different elevations

Gall rust incidence varied significantly among elevations with a ($p < 0.001$) (Fig. 5). Although gall rust incidence differed among elevations, the disease did not significantly affect the height and diameter structures of 6-year-old Falcata in Agusan del Norte suggesting that there are other factors at play. Furthermore, the 6-year-old Falcata appears to be able to withstand the disease, which could be due to its age. However, the detrimental impact of the disease on the height and diameter structures was not observed since the farmers monitored their plantations regularly. Lacandula *et al.* (2017) also found out that the falcata plantation in Gingoog City was seriously affected by gall rust but no mortality in mature trees was observed, mature trees seemed to tolerate the disease. Gall rust disease is a prevalent concern in Falcata plantations, however good disease monitoring and control could help to minimize or eliminate the disease's influence on Falcata growth. The development of gall-rust disease in *F. falcata* can be influenced by cultivating factors, such as plant age, fertilizers, and gall-rust-controlling agents (Lelana *et al.*, 2018).

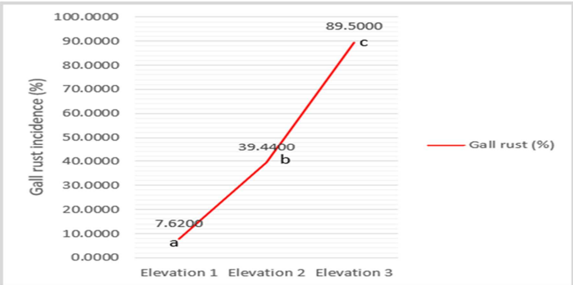

Fig. 5. Mean gall rust incidence (%) of 6-year-old Falcata trees across different elevation

The occurrence of gall rust in the three Agusan del Norte locations studied ranged from 'rare' to 'widespread,' indicating that it occurs between 40-600 meters above sea level. Figure 5 shows that rare gall rust incidence occurs between 0-200 m asl (7.62 %), common (39.44 %) disease incidence for elevations between 201 - 400 m asl, and widespread disease incidence (89.51 %) for elevations between 401 - 600 m asl. On the other hand, widespread gall rust disease was recorded between higher elevations, and this could be partly because of elevation (Palma *et al.,* 2020). Rahayu *et al.* (2018) stressed that the successful infection and spread of gall rust disease are dependent upon the favorable conditions for the growth and development of the causal agent (*U. falcatarium*).

The most severe gall rust disease at SFI in Sabah occurred at elevations > 900 m asl (Anonymous, 1993); while in East Timor, the disease appeared in the mountains south-west of Dili at elevations between 700 and 900 m asl (Morris, 1987). Depending on the complex relationships between the disease, the tree, the environment, and the human management techniques at the site or in the region, the occurrence of gall rust disease may be consistent throughout wide territories or may vary from site to site (Rahayu *et al.*, 2018). Braza *et al.*, (1997) stated that areas with high elevations are not considered for the planting of *F. falcata* in the Philippines where the environmental conditions appear conducive to rust development.

Influence of site variables on the growth of Falcata at different elevations in Agusan del Norte

The results of the analysis of variance (ANOVA) revealed that, out of eleven (11) site variables, only four (4) exhibited significant differences among elevations, as demonstrated in Table 4. These variables were slope-aspect (p-value=0.0005), temperature (p-value=0.03), relative humidity (p-value=0.02), and soil potassium (K) (p-value=0.008). Table 9 provided further details on the data pertaining to slope-aspect.

Further, along with the significant effect of elevation towards height growth of 6-year-old *F. falcata*, Table 5 shows that of all the site variables considered, only temperature (p-value=0.002) and spacing (p-value=0.023) have a significant influence on the height growth of Falcata. Both variables have negative coefficients of (-0.898) for temperature and (-0.338) for the spacing, which implies for negative correlation against height.

Influence of temperature on the height and diameter structures

The results of the study show that temperature has a negative effect on the growth of 6-year-old Falcata across area and elevations, as temperature rises the height and diameter decreases as shown in Fig. 6 and 7.

Table 4. Analysis of variance (ANOVA) of site variables among elevations

Site variables	df	SS	MS	F-value	*p*-value
Slope-aspect	2	87949	43974	14.41	0.0005**
Temperature	2	15.394	7.70	3.98	0.03*
Relative humidity	2	117.335	58.67	4.52	0.02*
Gall rust incidence	2	51644.78	25822.39	54.08	0.00**
Tree spacing	2	14.548	7.274	1.165	0.322 ns
Light intensity	2	6.28E+08	3.14E+08	1.325	0.28 ns
Nitrogen	2	0.0072	0.004	2.72	0.08 ns
Phosphorous	2	223.690	111.8453	2.377	0.101 ns
Soil potassium	2	160778.3	80389.16	5.561	0.008**
Soil Ph	2	0.2053	0.1027	0.3022	0.741 ns
Organic matter	2	2.87	1.434	2.718	0.08 ns

** Significant at (0.01); * significant at (0.05); ns- not significant

Table 5. Influence of site variables on the height structures of 6-year-old Falcata plantations

Site variables	Estimate	Std. error	df	t-value	*p*-value
Slope-aspect	-0.0080	0.0071	31	-1.138	0.264 ns
Temperature	-0.8983	0.2542	31	-2.3173	0.002*
Humidity	-0.0381	0.0771	31	-0.495	0.624 ns
Spacing	-0.3380	0.1412	31	-2.395	0.023*
Gall rust incidence	-0.0182	0.0211	31	-0.860	0.397 ns
K	0.0042	0.0037	31	1.148	0.260 ns

* Significant at (0.05), ns- not significant

Table 6. Differences in the mean temperature (°C) across area and elevation

Elevation	Pianing	Las Nieves	Kitcharao	Mean
0-200	29.37	30.35	28.63	29.45 [a]
201-400	30.57	28.69	23.98	27.75 [b]
401-600	29.56	29.65	28.94	29.38 [a]
Mean	29.83	29.56	27.18	28.86

The means of the different letters are significantly different from each other

Table 7. Differences in the mean spacing (m^2) across the area and elevation

Elevation (m asl)	Pianing	Las Nieves	Kitcharao	Mean
0-200	11.9	8.40	6.60	8.97
201-400	11.60	9.60	6.00	9.06
401-600	8.00	11.60	900	9.53
Mean	10.5	9.87	7.2	9.19

It was observed in the study by Way *et al.* (2010) found that increasing temperature generally decreases tree growth for tropical trees because tropical trees operate below their optimum temperature. According to Soerianegara *et al.*, 1993 that the optimal temperature range is between 22 °C and 29 °C with a maximum of 30–34 °C and a minimum of 20–24 °C. Based on the result of the study that the optimum temperature for Falcata in Agusan del Norte was 27.5 °C at 201-400 m asl as shown in Table 6.

The highest temperature was recorded along lower elevation or within 0-200 m asl with (29.45 °C) and followed by higher elevation or within 401-600 m asl (29.38 °C) and the cooler temperature was recorded along middle elevation or within 201-400 m asl. However, it might be expected that temperature was low at higher elevations but it is quite the opposite.

In addition, there are multiple interacting factors that determine tree growth and temperature has a strong influence on tree growth (Clark *et al.*, 2010). There are different researchers have found either greater or lesser tree growth with rising temperatures (Briffa *et al.*, 1998; Boisvenue and Running, 2006; Adams *et al.*, 2009; Linares & Tíscar, 2011), which alone would benefit some populations or tree species. Post hoc test revealed significant differences between the mean temperature in Agusan del Norte across elevations as shown in Table 6.

Influence of tree spacing on the height structures

The results show that tree spacing has a significant effect on the height structures of 6-year-old Falcata in Agusan del Norte as shown in Fig. 8. It was supported by the study of Oliver and Larson (1996) state that a decrease in height growth happens more possibly at very wide spacing on trees with weak epinastic control. This may be due to the fact that trees with weak epinastic control have a more difficult time adjusting to changing light conditions and maintaining proper balance and structure as the surrounding trees compete for resources. However, the competition for nutrients and other site variables between Falcata and intercropping was not assessed and is subject to future studies. The wider tree spacing among the three elevations was obtained by higher elevation (401-600 m asl) with a mean of 9.02 m² shown in Table 7 and it shows a significant effect against height structures of 6-year-old Falcata. Therefore, the specific effects of tree spacing on growth can vary depending on the species and site conditions.

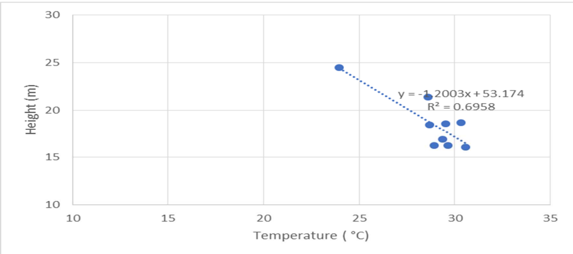

Fig. 6. Influence of temperature on the height structures of 6-year-old Falcata at the study sites

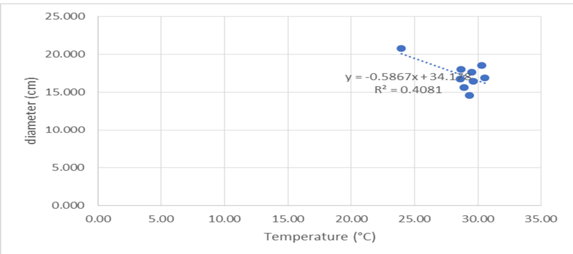

Fig. 7. Influence of temperature on the diameter structures of 6-year-old Falcata at the study sites

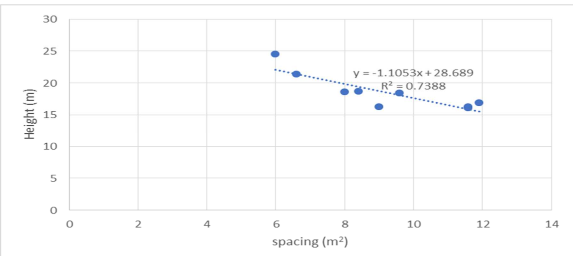

Fig. 8. Influence of spacing on the height structures of 6-year-old Falcata at the study sites

Influence of soil potassium, temperature, and relative humidity to the diameter structures

For diameter as shown in Table 8, the results show that soil potassium with a (*p*-value=0.008), temperature (p-value=0.044), and relative humidity (*p*-value=0.044) show a significant effect on the diameter growth of Falcata. The temperature had a coefficient of (-0.628) which implies a negative correlation against diameter, and relative humidity shows a positive correlation against diameter with a coefficient of (0.0490) as well as soil potassium (0.0019) as shown in Table 9. It was supported by the study of Wright *et al.* (2011) that potassium (K) increases the growth rates and decreases the stand-level fine root biomass. It was contradicted by the study of Baribault *et al.* (2012) that the diameter growth of tropical trees was correlated to soil potassium (K) and phosphorous (P) but not for leguminous plants.

In seedlings, potassium (K) increases growth rate (Santiago *unpublished data*) and when combined with N addition increased growth rates of smaller trees. Table 8 shows that diameter and soil potassium (K) is positively correlated. However, this finding was based on a lower r-squared value of 0.1097. Post hoc test revealed significant differences between the mean potassium in Agusan del Norte across elevations as shown in Table 9.

As shown in Table 9, the middle elevation range of 201-400 m asl had the highest average potassium content of 286.6 ppm, whereas the higher elevation range of 401-600 m asl had a potassium content of 246.93 ppm. Additionally, the highest potassium content in Agusan del Norte was found in Pianing, Butuan City, which falls within the higher elevation range of 401-600 m asl.

Fig. 9 shows the positive correlation of relative humidity against the diameter structures of 6-year-old Falcata with (r^2=0.5066). It was supported by the study of Hegde *et al.*, (1998) and Roth (1981), that the seasonal variation in atmospheric relative humidity might influence tree circumference due to bark and sapwood water storage. Post hoc test revealed significant differences between the mean relative humidity in Agusan del Norte across elevations and shown in Table 10.

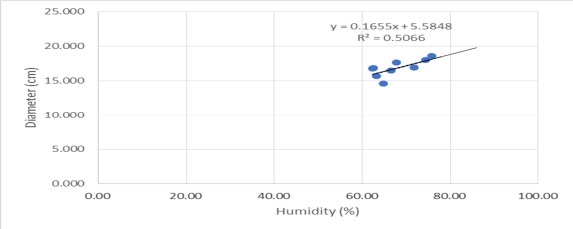

Fig. 9. Influence of Relative Humidity on diameter structures of 6-year-old Falcata at the study sites

Table 8. Influence of site variables on the diameter structures of 6-year-old Falcata plantation

Site variables	Value	Std. error	df	t-value	*p*-value
Slope-aspect	0.0101	0.00815	31	-1.239	0.2247 ns
Temperature	-0.628	0.299	31	-2.094	0.044*
Humidity	0.0490	0.1006	31	0.4871	0.044*
Spacing	-0.093	0.144	31	-0.571	0.5723 ns
light intensity	0.0004	0.0000	31	1.358	0.1843 ns
K	0.0019	0.0042	31	2.818	0.0084**
soil pH	*0.5273*	*0.818*	*31*	*0.645*	*0.524 ns*

**Significant at (0.01), ns- not significant

Table 9. Differences in the mean potassium (ppm) across area and elevation

Elevation	Pianing	Las Nieves	Kitcharao	Mean
0-200	96.4	38.6	170.400	101.8[b]
201-400	114.8	370	363	282.6[a]
401-600	299	144	297.800	246.93[a]
Mean	170.07	73.33	277.07	163.68

Table 10. Differences in the mean relative humidity (%) across area and elevation

Elevation (m asl)	Pianing	Las Nieves	Kitcharao	Mean
0-200	64.88	75.894	62.49	67.75 [a]
201-400	71.85	74.50	62.61	70.74 [b]
401-600	67.841	66.56	63.25	65.88 [a]
Mean	68.19	72.32	62.81	68.00

Table 11. Results in soil nutrient analysis in the study sites

Elevation	Area	%N	P (ppm)	K (ppm)	Soil pH	OM%	Texture
0-200	1	0.083	3.6	96.4	5.53	1.66	Medium
0-200	2	0.06	2.8	38.6	5.82	1.12	Medium
0-200	3	0.07	10	170.4	5.38	1.32	Medium
Mean		0.071	5.45	101.8	5.58	1.37	
201-400	1	0.06	9.2	114.8	5.95	1.22	Medium
201-400	2	0.12	2.8	37.4	5.36	2.44	Medium
201-400	3	0.12	8	363	5.16	2.33	Medium
Mean		0.1	6.67	171.73	5.49	2	
401-600	1	0.08	16	299	6.20	1.58	Medium
401-600	2	0.04	9.4	144	6.25	0.74	Medium
401-600	3	0.13	6.60	297.8	4.39	2.52	Medium
Mean		0.08	10.67	246.93	5.61	1.61	

Table 10 shows that the highest mean relative humidity was obtained in the middle elevation (70.74%) followed by the lower elevation (67.75%). Among areas, Las Nieves has the highest relative humidity recorded in Agusan del Norte between 0-200 m asl (75.89%).

Table 11 shows the highest mean nitrogen (%) recorded was at the middle elevation (201-400 m asl) with 0.1%, followed by lower elevation (0-200 m asl) with 0.07% and at higher elevations (401-600 m asl) with 0.08% nitrogen. The highest mean phosphorous along elevations was at higher elevation (401-600 m asl) with 10.67 ppm and the lowest recorded was at lower elevation (0-200 m asl) with 5.45 ppm. For its soil pH, the highest was recorded at higher elevation (401-600 m asl) and the lowest was at lower elevation (0-200 m asl). Further, for the organic matter content (%) the highest OM was recorded at middle elevation with 2% and the lowest was recorded at lower elevation with 1.32% organic matter content.

Conclusion

Furthermore, the conclusion that the cessation of planting species higher than 400 m asl was recommended due to the combined effect of elevation as well as site conditions on Falcata growth. Furthermore, based on the result it was strongly recommended not to plant Falcata trees higher than 400 meters above sea level to reduce gall rust incidence because the disease is more prevalent at this elevation and may infect other Falcata trees in the area because gall rust infection is airborne.

It's important to note that the specific effects of temperature on falcata growth can vary depending on the site conditions and management practices. Other environmental factors, such as light, water, and nutrients, can also interact with temperature to affect tree growth. Overall, understanding the influence of temperature on falcata growth can help inform management strategies and improve the productivity and sustainability of falcata plantations.

If infected with gall rust disease, cutting and burning of infected plant parts were recommended, and cessation of planting in areas with an elevation higher than 250 m asl. In addition, the results of this study suggest that Falcata plantations situated within the middle elevation range (201-400 m asl) are still favorable for the species to grow, and can potentially yield a generous harvest for tree farmers if appropriate management practices are applied during the initial stages of the plantation.

Acknowledgment

The authors express their gratitude to the Commission on Higher Education (CHED), Caraga State University (RAF-ITPs), and the Local Government of Pianing, Las Nieves, and Kitcharao, Agusan del Norte for their invaluable contributions to the successful completion of this study.

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