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Role of soil parameters in forest clove (*Syzygium obtusifolium*) habitat and their effects on phenology and production

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Abstract. *Kamsurya MY, Botanri S, Kamaruddin, Hulopi F, Lahabi M, Djumat JL. 2023. Role of soil parameters in forest clove (*Syzygium obtusifolium*) habitat and their effects on phenology and production. Biodiversitas 24: 4910-4918.* Forest cloves (*Syzygium obtusifolium* L) are a type of non-aromatic clove that originally grew wild and are now starting to be cultivated. This study aimed to examine role of soil chemical and physical parameters in clove plant habitat and their influence on flowering phenology and production. The experiment was carried out on the island of Ambon Maluku, for a duration of 17 months from January 2020 - May 2021. A survey was conducted on forest clove plant cultivated by farmers aged between 10-15, and five observation locations were selected using the purposive sampling method. Soil analysis was performed at the Laboratory of Soil Science, Faculty of Agriculture, University of Hasanuddin Makassar, while observational data were analyzed using principal component regression analysis (PCRA). The results showed that soil chemical parameters contributed 14.89% to forest clove plant habitat, with the N and Ca content providing the highest contribution of 3.49% and 3.26% respectively. The contribution of physical parameters amounted to 8.09%, with sand particles exhibiting the highest value of 2.43%. Furthermore, PCRA results found that soil chemical parameters influenced the phenology of forest clove flowering by 21.8%. The relationship between the independent variables (X1 to X5) and flowering phenology (Y) had a correlation (R) of 0.47, while the physical parameters exerted an influence reaching 79.4% with an R-value of 0.89. The average production of fresh and dry clove flowers from forest clove plant was 50.3 and 20.1 kg/plant, respectively.

Keywords: Forest clove, flowering phenology, habitat, soil parameters, production

INTRODUCTION

Forest clove (*Syzygium obtusifolium* L.) is a non-aromatic clove plant widely found in forest across various regions in Maluku, including the islands of Ambon, Seram, Buru, and Lease (Alfian et al. 2019). In the last 15-20 years, several species have been cultivated, such as aromatic clove, although on a limited scale (Kamsurya and Botanri 2022). Commonly known types of aromatic clove include *sanzibar*, *sikotok*, *snailuh*, and Ambon clove. In general, cloves are included in the group of spice plants from the Myrtaceae family, which are native to Indonesia, mainly from the Maluku and North Maluku islands. These plants are also found growing in several areas in mainland Papua (Mahulette et al. 2019a).

One of the key advantages of forest clove plant which makes it desirable for cultivation by farmers is the ability to flower every year. After harvesting, flowering primordia (pregnancy) typically appears within 7-8 months (Kamsurya et al. 2022), and in contrast to aromatic clove, the heavy harvest period ranges from 2-4 years. Ruhnayat et al. (2007) stated that the problems faced by farmers in cultivating and developing aromatic clove are: i) the lengthy flowering period, ranging from 5-7 years after planting, and ii) significant yield fluctuation which follows a 2-4 years cycle. This cycle often comprised a high production in one year, followed by a decrease in the subsequent year after harvesting.

Aside from climate attributes, plant growth, and development are also influenced by soil parameters, both physical and chemical. Gavrilescu (2021) and Sevanto et al. (2021) suggest that growth and production result from complex interactions between plants and environmental factors including soil. The physical properties of soil as habitat affect plant growth and production through the influence of texture, structure, bulk density, and water content (Khalil et al. 2015). Meanwhile, the influence of soil chemical parameters is exhibited through the variables of pH, macro, and micronutrients, such as nitrogen, phosphorus, potassium, calcium, magnesium, iron, copper, zinc, molybdenum, and cobalt. Iskandar et al. (2022) reported that the physical and chemical properties of soil affect the growth and development of vegetation.

The duration from the harvest to the appearance of new flowers, known as the primordia period, represents the initial phase in flowering phenology. According to Tabla and Vargas (2004), this period is one of the important characteristics of a plant life cycle, marking the initial phase of reproduction. Each plant has a different behavior in terms of flowering and fruiting patterns, but in general, this phase begins with the appearance of flower buds and ends with fruit ripening (Fewless 2006). In the context of clove plants, the final phase is characterized by the blooming of flowers, signaling the time for harvest. The yield from clove plants is actually in the form of flowers harvested before fertilization. Several studies related to forest clove plants have been carried out, including investigations on the harvest period and production at different elevations (Kamsurya and Botanri 2022), the correlation between flowering and heat units (Kamsurya et al. 2022), the characteristics of forest clove plants endemic to Maluku (Kamsurya et al. 2023a), morphological traits (Mahulette et al. 2019b), morpho-agronomical diversity (Mahulette et al. 2019c), and effect of microclimate on flowering phenology (Kamsurya et al. 2023b). This study aimed to examine role of soil parameters in habitat of forest clove plant and their influence on flowering phenology and production.

MATERIALS AND METHODS

Area study

This study was conducted on the island of Ambon, Maluku province, Indonesia, at 5 sites, for a duration of 17 months, from January 2020 to May 2021. The map of the study locations presented in Figure 1 indicates the five sites, i.e., point 1 (3º30'37”S; 128º14'15”E), point 2 (3º35'00”S; 128º10'40”E), point 3 (3º35'27”S; 128º10'39”E), point 4 (3º36'37”S; 128º11'16”E) and point 5 (3º37'11”S; 128º10'55”E).

Field surveys

This research used a survey method and the observation locations were determined using a purposive sampling method (Moleong 2018), method that was directed directly to the land of forest clove farmers, resulting in 5 clusters of community clove gardens, namely: i) Halasi (6 m asl), ii) Tibang (11 m asl), iii) Oli (125 m asl), iv) Wanat (175 m asl), and v) Telaga Kodok (214 m asl). The ordinate point distribution of the observation locations is presented in Table 1.

At each location, there were 3 observation points and 3 plants were collected from each point, totaling 9 samples selected randomly with ages ranging from 10-15 years. The variables observed included: (i) physical and chemical parameters of soil, (ii) flowering phenology, (iii) weight of freshly harvested flowers (kg/plant), and (iv) weight of dry flowers (kg/plant). Soil samples were taken from each observation location consisting of 3 points selected diagonally. Analysis of physical and chemical properties was carried out in the Laboratory of Soil Science, Faculty of Agriculture, University of Hasanuddin Makassar. Flowering phenology (phenophase) was categorized into 6 phases based on the local wisdom of the Maluku people (Kamsurya, 2022), namely: (i) flowering primordia, (ii) stalks appear, (iii) the perfect stalk, (iv) the flowers appear, (v) perfect-sized flowers, and (vi) blooming.

Table 1. Observation points for forest clove on Ambon Island, Maluku, Indonesia

Observation location	Elevation (m asl)	Ordinate position (South & East)
Halasi	6	3º30'37”S; 128º14'15”E
Tibang	11	3º35'00”S; 128º10'40”E
Oli	125	3º35'27”S; 128º10'39”E
Wanat	175	3º36'37”S; 128º11'16”E
Telaga Kodok	214	3º37'11”S; 128º10'55”E

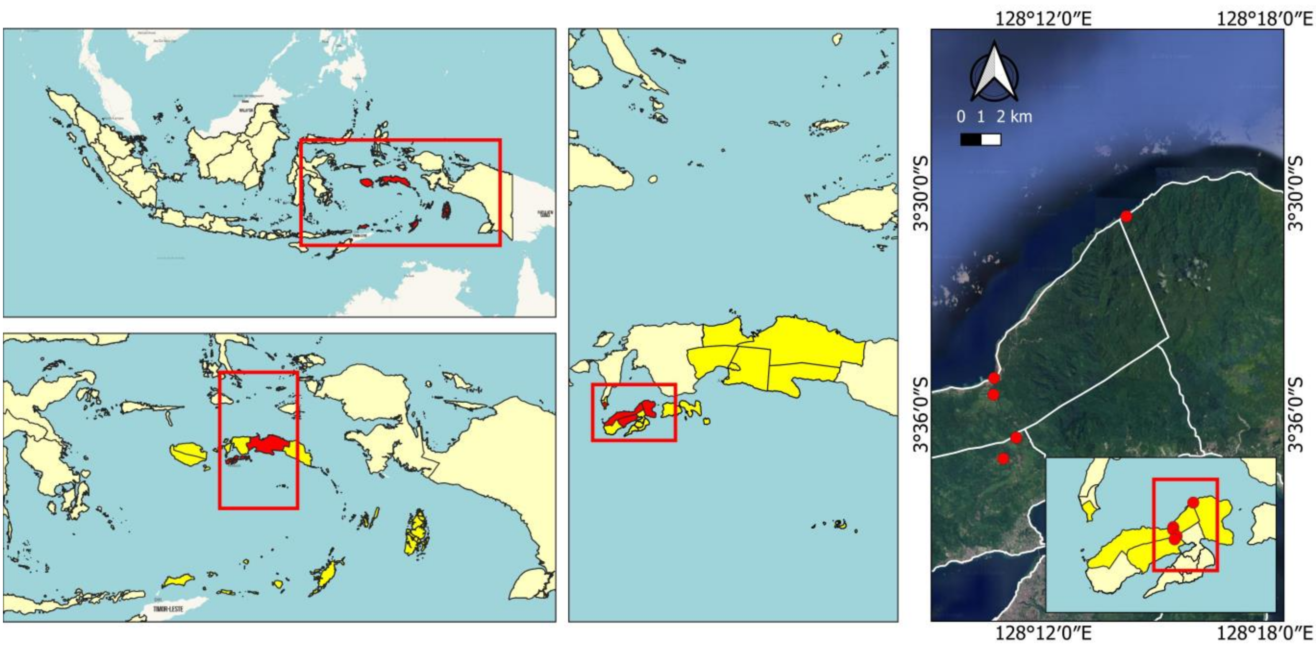


Figure 1. Map of study locations in the Ambon Island, Maluku, Indonesia

Analysis

The data were analyzed statistically using Principle Component Analysis (PCA) to determine role of soil parameters in forest clove habitat. This method was used to reduce data to a smaller number and absorb most of the number of variants (diversity). Data reduction was carried out using the KMO (Kaiser-Meyer-Olkin) and MSA (Measured sampling adequacy) test statistics with statistical criteria >0.5 (Stang 2017). The influence of soil chemical and physical parameters on flowering phenology and production was analyzed using Principal Component Regression Analysis (PCRA) (Gaspersz 1995). The data was analyzed using statistical software, this analysis was used to explain effect of independent on dependent variables, with the models:

$$Y = w_o + w_1K_1 + w_2K_2.....+ w_mK_m + v \text{ .... (1)}$$

Where :

Y : independent variable

K_j : the main component independent variable which is a linear combination of all the standard variables Z (j : 1, 2, …, m)

w_o : constant

w_j :regression model parameters (coefisien regression), (j : 1, 2, …, m)

v : error/galat

In the analysis process, all independent variables were transformed into the standard variable Z. This data transformation was necessary because there were differences in units between the independent variables. Data transformation was achieved using the formula:

$$Z_i = (\frac{x_i - \bar{x}}{s_i}) \text{ .... (2)}$$

Where:

i-th : independent variable in standard form

x_i : the i-th independent variable in its original form

$\bar{x}$ *:* the average value of the independent variables x_i

s_i : standard deviation from x_i

After the algebraic computational process, a regression equation was formed in the form of the original variable 'X', as follows:

$$Y = b_o + b_1x_1 + b_2x_2... + b_px_p \text{ .... (3)}$$

Where:

Y : dependent variable

x_i : the i-th independent variable specified from the start, i = 1, 2,... ,p

b_o : constant (intercept)

b_i : regression coefficient of the i-variable, i = 1, 2, …, p.

RESULTS AND DISCUSSION

Role of soil parameters in forest clove habitat

The results in Table 2 showed that 9 chemical and 4 physical properties were analyzed in this study. Table 3 and Figure 2 show correlation matrix of soil chemical parameters.

Based on the results, in PC1, five variables constituted the main characteristics of soil parameters, namely C-organic (C-org), nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) content. For PC2, there were three variables, including pH, phosphorus (P_2O_5), and Cation Exchange Capacity (CEC), while PC3 comprised one variable of C/N ratio (Table 4).

The relative contribution (weight) of each soil chemical property variable to forest clove habitat was determined based on the main component score (PC) and the eigenvector value. The calculation results showed that the total contribution was 14.89% as indicated in Table 5. Soil chemical variables with the highest contribution were N and Ca content, with values of approximately 3.49% and 3.26% respectively. Meanwhile, chemical parameters with a moderate role included C-org, K, and Mg.

Table 3. Eigenvalues correlation matrix of soil chemical parameters

Component	Eigenvalue	Proportion	Cumulative
PC1	3.71	41.26	41.26
PC2	1.86	20.71	61.97
PC3	1.27	14.15	76.12

Table 2. Soil parameters in the study location

Observation location	pH H_2O	C-Org %	N	C/N ratio	P_2O_5 ppm	K (cmol(+)kg^{-1})	Ca	Mg	CEC	Sand	Dust %	Clay	BD Gr/cm^3
Halasi	6.40	2.63	0.18	15.0	11.4	0.45	5.70	2.1	17.9	32.00	31.0	36.5	1.22
Tibang	6.52	2.10	0.13	16.0	14.0	0.20	5.00	1.8	23.4	30.50	35.5	34.5	1.22
Oli	6.58	2.19	0.22	10.0	11.8	0.25	7.05	1.1	16.0	29.50	39.5	31.0	1.23
Wanath	5.94	1.58	0.13	12.5	11.7	0.20	4.95	2.2	24.9	31.50	33.0	36.0	1.25
Tl-Kodok	6.21	2.32	0.24	11.0	15.1	0.60	7.85	1.4	22.6	30.00	34.0	36.0	1.24
Average	6.33	2.16	0.18	12.9	12.8	0.34	6.11	1.7	21.0	30.70	34.6	34.8	1.23

Note: N: nitrogen; C: carbon; O: oxygen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; CEC: Cation Exchange Capacity; BD: bulk density.

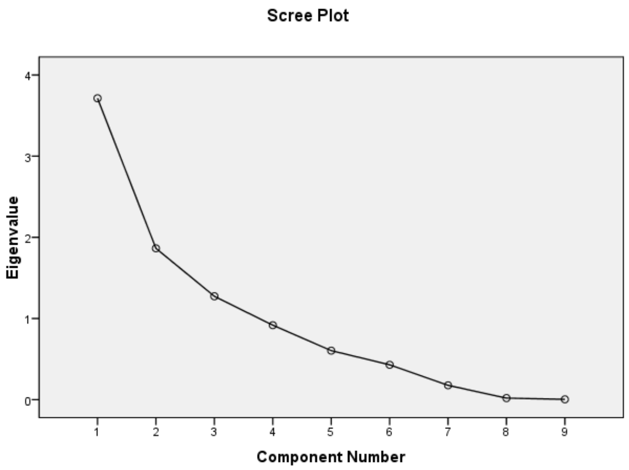


Figure 2. Eigenvalues diagram of soil chemical parameters

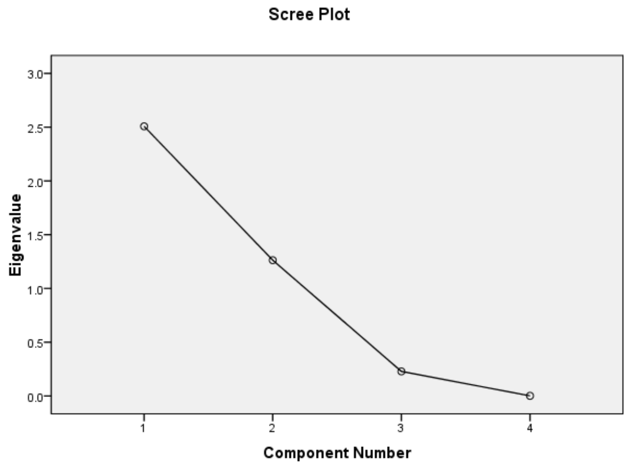


Figure 3. Eigenvalues diagram of soil physical parameters

Table 4. Eigenvalues correlation matrix of soil chemical parameters

Variable	PC1	PC2	PC3
pH	.396	-.692	.175
C-Org	.651	-.438	.482
N	.940	.195	-.075
C/N ratio	-.551	-.458	.666
P_2O_5	.403	.626	.243
K	.711	.316	.466
Ca	.880	.108	-.003
Mg	-.559	.367	.349
CEC	-.439	.555	.404

Table 5. Contribution of soil chemical parameters to forest clove habitat

Variable	Scor PC	Eigenvector	Contribution (%)
pH	1.86	-0.69	-1.28
C-Org	3.71	0.65	2.41
N	3.71	0.94	3.49
C/N ratio	1.27	0.67	0.85
P2O5	1.86	0.63	1.17
K	3.71	0.71	2.63
Ca	3.71	0.88	3.26
Mg	3.71	-0.56	-2.08
CEC	1.86	0.56	1.04
Amount			14.89

Based on the calculation results in Table 4, forest clove habitat index model related to role of soil parameters was constructed as follows:

$HFC_{(ChSoil)}$ = (3.49N) + (3.26Ca) + (2.63K) + (2.41C-Org) – (2.08Mg) – (1.28pH) + (1.17P2O5) + (1.04CEC) + (0.85C/N Ratio) ……… (4)

where:
$HFC_{(ChSoil)}$: forest clove habitat related to soil chemical parameters
pH : soil acidity
C-Org : carbon organic
C/N-ratio : ratio karbon and nitrogen
N : nitrogen
P_2O_5 : phosphorus
K : potassium
Ca : calcium
Mg : magnesium
CEC : Cation Exchange Capacity

In forest clove habitat index model presented in equation 4 above, the chemical parameters of soil were largely determined by the variables of C-organic, nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg), where their contributions reached 93.15%. This means that forest clove plants require habitat with sufficient organic C, N, and K, as well as Ca, and Mg bases.

Based on PCA results of soil physical parameters, two main components explained the total diversity of soil property data by 94.28% (Table 6 and Figure 3).

In PC1 above, three variables constituted the main characteristics of soil parameters, including sand, silt, and bulk density (BD), while PC2 was composed of one variable, namely clay particles (Table 7).

The relative contribution (weight) of each soil physical characteristic variable to forest clove habitat was determined based on the main component score (PC) and the eigenvector value. The analysis results showed that the total contribution was 8.09% (Table 8), with sand particles having the highest value of -2.43%. The other three variables namely dust, clay, and BD contributed 2.18%, 1.25%, and 2.23% respectively.

Table 6. Eigenvalues of soil physical parameters correlation matrix

Component	Eigenvalue	Proportion	Cumulative
PC1	2.51	62.70	62.70
PC2	1.26	31.71	94.28

Table 7. Eigenvalues of the main components of soil physical parameters

Variable	PC1	PC2
Sand	-.970	-.050
Dust	.873	-.474
Clay	.061	.989
BD	.892	.251

Table 8. Contribution of soil physical parameters to forest clove habitat

Variables	PC Score	Eigenvector	Contribution (%)
Sand	2.51	-0.97	-2.43
Dust	2.51	0.87	2.18
Clay	1.26	0.99	1.25
BD	2.51	0.89	2.23
Amount			8.09

In clove forest habitat index model presented in equation 5, the physical parameters of soil were largely determined by the sand, dust, and BD variables, with their contribution reaching 84.55%. This means that forest clove plants require habitat with a sandy loam or dusty loam texture and a low clay content. Soil with a clay texture generally has a relatively low bulk density.

$HFC_{(SP)}$ = (2.23BD) - (2.43Sand) + (2.18Dust) + (1.25Clay) …………… (5)

Where:
$HCh_{(SP)}$: forest clove habitat related to soil physical parameters
BD : bulk density

Effect of soil parameters on flowering phenology

Flowering phenology of forest clove plant which consisted of 6 phases had a total time of about 167.6 days (Kamsurya et al. 2023b). These phases or phenophases include i) flowering primordia, ii) stalk emergence, iii) perfect stalk, iv) bud emergence, v) perfect flower ovary, and vi) blooming. These results were similar to a study by Lestari et al. (2023) on *Anaxagorea* sp. where *A. luzonensis* experienced a more phenology flowering period. Flowering phenology is divided into five stages, namely initiation, flower bud, before blooming, blooming, and flower blooming. Based on the results of principal component analysis (PCA), 5 variables out of 9 soil chemical parameters affected flowering phenology of forest clove plant, namely: i) soil N (X1), ii) C/N ratio (X2), iii) P_2O_5 (X3), iv) K (X4), and v) C (X5). PCRA results showed that the influence of chemical parameters on flowering phenology amounted to 21.8% (R-square 0.218). The relationship between the independent variables (X1 to X5) and flowering phenology as the dependent variable (Y) was included in the strong category with a correlation coefficient (R) of 0.47. The main component regression equation is as follows:

Y1 = 167,40 + 2,708X1 – 0,041X2 – 0,047X3 + 0,728X4 + 0,100X5 …...... (6)
R = 0,47 R-square = 21,8 %

Where:
Y1 : flowering phenology (days)
X1 : N soil (%)
X2 : C/N ratio
X3 : P_2O_5 (ppm)
X4 : potassium (cmol (+)/kg)
X5 : calcium (cmol (+)/kg)

The analysis results showed that soil chemical parameters influenced flowering phenology of forest clove. Based on the above equation, when X = 0, (indicating no influence of soil chemical parameters), flowering phenology lasted for 167.40 days. However, when nitrogen, potassium, and calcium were added, the duration was affected, either extending or reducing depending on the nature of the regression coefficient. When the regression coefficient was negative, phenology duration was reduced, while a positive coefficient resulted in a longer duration. A 1.0% addition of soil N, increased flowering phenology duration by 2.7 days, bringing the total length of time to 168.1 days. On the other hand, a 1.0% addition of the C/N ratio reduced the duration by 0.4 days, resulting in a total length of 167.0 days. Similar effect was observed with other soil chemical properties, such as phosphorus, potassium, and calcium.

PCRA results showed effect of soil physical parameters on flowering phenology of forest clove plants reached 79.4% (R-square 0.794). Collectively, the relationship between the independent variables (X1 to X4) and flowering phenology as the dependent variable (Y) was included in the very strong category with a correlation coefficient (R) of 0.89. The main component regression equation is as follows:

Y2 = 167.6 - 0.136X1 + 0.106X2 + 0.018X3 + 19.436X4 ………… (7)

R = 0,89 R-square = 79,4 %

Where:
Y2 : flowering phenology (days)
X1 : sand (%)
X2 : dust (%)
X3 : clay (%)
X4 : bulk density (g/cm^3)

The analysis results showed that soil physical parameters affected flowering phenology of forest clove. Based on the above equation, when X = 0, (indicating no influence of soil physical parameters), flowering phenology lasted for 167.6 days.

Effect of soil parameters on production

PCRA conducted to determine the influence of soil chemical parameters on forest clove production showed that five soil variables affected the weight of fresh and dry flowers. These variables included nitrogen, C/N ratio, P_2O_5, potassium, and calcium. The influence on fresh and dry flower weight reached 10.5% and 0.6% respectively as shown in equations 8 and 9. Therefore, it was concluded that the chemical parameters of soil collectively had more influence on fresh flower production. The main component regression equation is as follows:

$$Y3 = 53.24 + 4.89X1 - 0.73X2 + 0.08X3 - 1.31X4 + 0.18X5 \quad \ldots\ldots\ldots (8)$$

R = 0.32 R-square = 10.5 %

$$Y4 = 20.30 + 1.11X1 - 0.17X2 + 0.02X3 - 0.30X4 + 0.04X5 \quad \ldots\ldots\ldots (9)$$

R = 0.08 R-square = 0.60 %

Where:
Y2 : fresh flower weight (kg)
Y3 : dry fresh flower weight (kg)
X1 : N soil (%)
X2 : C/N Ratio
X3 : P_2O_5 (ppm)
X4 : potassium (cmol (+)/kg)
X5 : calcium (cmol (+)/kg).

PCRA conducted to determine the influence of soil physical parameters on forest clove production showed a relatively low effect on the fresh and dry weight (equations 10 and 11). The variable with the greatest influence was bulk density. The main component regression equation is as follows:

$$Y5 = 53.24 - 0.074X1 - 0.194X2 + 0.844X3 - 39.168X4 \quad \ldots\ldots\ldots (10)$$

R = 0.22 R-square = 0.046 %

$$Y6 = 20.30 + 0.269X1 - 0.480X2 + 0.857X3 - 7.905X4 \quad \ldots\ldots\ldots (11)$$

R = 0.31 R-square = 0.045 %

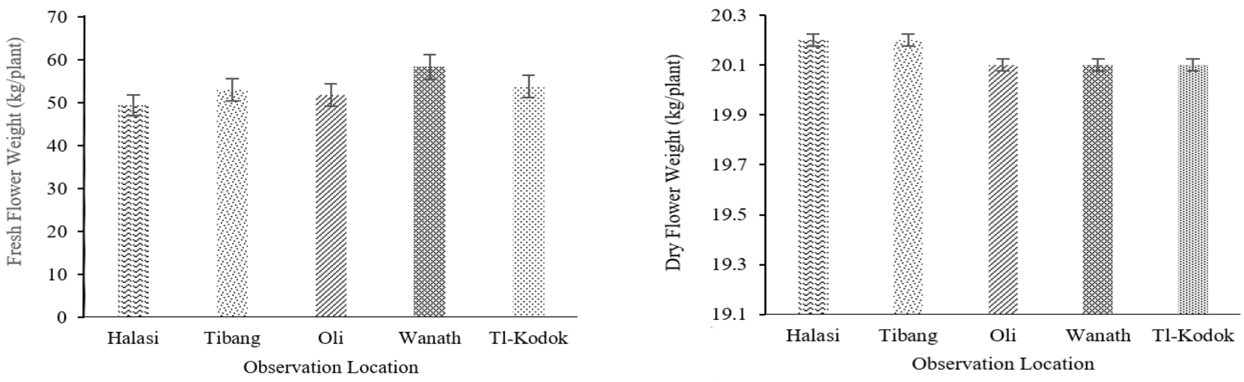
Where:
Y5 : fresh flower weight (kg)
Y6 : dry flower weight (kg)
X1 : sand (%)
X2 : dust (%)
X3 : clay (%)
X4 : bulk density (g/cm^3)

When: X = 0 (indicating no influence of soil physical parameters), production of fresh and dry flowers reached 53.24 kg/tree and 20.30 kg/tree respectively (Figure 4). The influence of soil physical properties on the weight of fresh and dry flowers was relatively small, less than 1%. Therefore, it was concluded that the physical parameters of soil did not affect production of forest clove plants.

Figure 4 shows that the average production of fresh clove flowers at the five observation sites was 53.3 kg/plant. The lowest and highest values were found at the Halasi and Telaga Kodok observation sites, reaching 49.4 kg/plant and 53.8 kg/plant respectively. The highest production of dried flowers was obtained at Halasi and Tibang, each with a value of 20.1 kg/plant, while the lowest was observed at Oli, Wanath, and Telaga Kodok, reaching 20.1 kg/plant.

Discussion

The contribution of soil chemical and physical properties to forest clove habitat was approximately 11.49% as shown in Tables 5 and 8. This was attributed to five parameters, namely nitrogen, C/N ratio, phosphorus (P_2O_5), potassium, and calcium base cations. The magnitude of this contribution was significantly lower than effect of the microclimate on flowering phenology of forest clove, which reached 93.5% (Kamsurya 2023b). Although the contribution of soil parameters in forest clove habitat is relatively small, it is significantly needed. This is because nitrogen, phosphorus, potassium, and calcium are essential macronutrients for plants, needed in large quantities, and cannot be replaced by other nutrients. As described by Brown et al. (2022), these mineral nutrients are essential or beneficial for growth and development as well as for the quality attributes of the plant or harvested product. A nutrient is considered essential when the life cycle of a plant species cannot be completed in its absence. The physical and chemical characteristics of soil regulate the number of nutrients available to plants. Consequently, their relevance in nutrient supply to crops must be regularly checked for long-term development and increased crop production (Suleiman et al. 2017).



A B

Figure 4. A. Fresh flower weight. B. Dry flower weight forest clove

The availability of nutrients determines the adequacy of soil in aiding plant growth. Given the complexity and incomplete understanding of nutrient availability, plant response remains the only reliable basis for diagnosing deficiencies. To maintain the sustainability of production, management practices that can improve soil fertility and quality must be implemented (Wakgari et al. 2020). According to Kumari et al. (2022), plant nutrition is one of the most effective ways to reduce abiotic stress on crops.

In forest clove habitat index model as presented in Equation 4, soil parameters had both positive and negative influence on flowering phenology. Variables with a positive influence included nitrogen, potassium, and calcium, while those with a negative effect were the C/N ratio and P_2O_5 content. A positive influence suggests that an increase in these variables would lead to a longer duration of flowering phenology. Conversely, a negative influence implies that increasing these variables would result in earlier or shorter flowering phenology time, below 167.4 days. Soil property variable with the greatest influence was the nitrogen content. An addition of 0.1% nitrogen increased the length of flowering phenology by 0.27 days. Similar effect was observed with the addition of potassium and calcium to soil. The reverse condition occurred when the C/N ratio and P_2O_5 content increased.

Soil factors influenced flowering phenology and production of forest clove plants as shown by their joint effect through the interaction of nitrogen, C/N ratio, P_2O_5, potassium, and calcium content. This collective influence is due to the mechanism of nutrient absorption by plants, which generally occurs in conditions where there is a balance in the availability of various elements in soil. In the context of this study, the results demonstrate a balance between the nutrients N, P, K, and Ca. When one of these nutrients becomes limited in quantity, it can act as a growth-limiting factor in flowering phenology. This is emphasized in a previous study by Warsi and Dykhuizen (2017), indicating that the evolutionary response of plant populations is determined by the most growth-limiting nutrient. According to Hao et al. (2023) nitrogen, phosphorus, and potassium are the three macronutrients needed for plant growth and development. Junfei Gu et al. (2018) also reported nitrogen as an important factor influencing plant growth. As stated by Leghari et al. (2016), all plants use nitrogen in the form of NO_3^- and NH_4^+ which significantly increases crop yield and quality through their important role in biochemical and physiological functions. Gashamurthy et al. (2019) stated that plants usually take most of the nutrients in ionic form. Nitrogen is absorbed in the form of nitrate (NO_3^-) and ammonium (NH_4^+), P as primary ($H_2PO_4^-$) or secondary (HPO_4^{2-}) orthophosphate, and K in its elemental ion (K^+). Furthermore, Gautier et al. (2021) reported phosphorus as an essential nutrient. Plants have developed the ability to adapt their habitat conditions to maximize the uptake and use of phosphate (Pi) when the element is present in limited amounts.

Nitrogen transformation in the soil takes place through the role of microbes. Nevins et al. (2023) stated that the transformation of nitrogen between organic to inorganic forms is controlled by a combination of abiotic and biotic processes. The enzyme-driven biological mineralization process adds N to the soil when organic N is converted to NH_4^+. After mineralization, the available NH_4^+ can be converted from NH_4^+ to NO_3^- through the nitrification process. Nitrogen can be lost from soil to the atmosphere through denitrification, a process controlled by anaerobic microbes. Soil NH4+ can be converted into NO_3^- through the nitrification process by soil microbes, including bacteria and archaea. For decades it was thought that nitrification was carried out by only two groups of soil bacteria: *Nitrosomonas* and *Nitrobacter*. *Nitrosomonas* converts NH_4^+ to NO_2^-, and *Nitrobacter* converts NO_2^- to NO_3^-. However, recent discoveries have found that several other groups of soil microbes can convert NH_4^+ to NO_2^- by ammonia-oxidizing microbes and NO_2^- to NO_3^- by nitrite-oxidizing microbes. Nitrifying bacteria and archaea obtain energy by oxidizing inorganic N compounds NH_4^+ and NO_2^-. In addition, *Nitrospira* can complete both steps of the nitrification process (NH_4^+ to NO_2^- and NO_2^- to NO_3^-). Denitrification is the conversion of NO_3^- into the gaseous form N_2 and nitrous oxide (N_2O) in low oxygen conditions. Denitrification is a process facilitated by *Pseudomonas* microbes commonly known as soil denitrifying bacteria. Imamuddin (2010) states that the complete breakdown of nitrogen in the form of ammonia in the soil takes place in two stages, namely, ammonia becomes nitrate (nitrification) and nitrate becomes N_2 gas (denitrification). In biological systems, nitrification is often ineffective because the growth of nitrifying bacteria is very slow and sensitive to environmental factors such as temperature, pH, ammonia concentration, nitrate and C/N ratio.

Five soil property variables, in this case, nitrogen, C/N ratio, P_2O_5, potassium, and calcium were found to influence flowering phenology and production of forest clove plant (equation 5-7). Nitrogen plays role in plant vegetative growth, as a constituent of chlorophyll, protein, and enzymes. According to Fathi (2022), this element contributes significantly to plant growth and development, with its deficiency ultimately leading to a reduction in yields. It is found in the inorganic form or organic compounds, together with C, H, and O, as well as sulfur (S), forming various kinds of amino acids, enzymes, nucleic acid, chlorophyll, alkaloids, and purine bases. Nitrogen also correlates significantly with the development of meristem tissue, contributing to growth, and consequently, flowering phenology.

The influence of phosphorus nutrients shown in the form of P_2O_5 in this study was predominantly negative. This means that sufficient phosphorus is needed for flowering and plant production. An increase in the amount will shorten the time for flowering phenology and improve production. This is because the nutrient plays a crucial role in promoting the formation of plant flowers, and when phosphorus is lacking, flowering and production are hampered. According to Bechtaoui et al. (2021), a decrease in the plant phosphorus content resulted in reduced rates of photosynthesis and stomatal conductance. The total chlorophyll content increases in P-deficient plants, due to the lack of phosphorus molecules to maintain photosynthetic functions, specifically those of Rubisco and fructose-1,6-bisphosphatase.

The amount of phosphorus content in the soil is generally abundant, but what is available to plants is very low, namely around 0.1-0.5% (Rahmi 2023). The presence of phosphate in soil is usually in the form of $AlPO_4$ in acidic soils and $Ca_3(PO_4)_2$ in alkaline soils. Plants cannot absorb phosphorus in bound form so it must be converted into a form that can be absorbed by plants (Elfiati 2005), namely in the form of $H_2PO_4^-$ or HPO_4^{2-} depending on the soil pH (Kumar et al. 2018). The availability of phosphorus in the soil can involve the role of soil microorganisms, namely fluorescent pseudomonads from the bacterial group (Susanti and Advinda 2021), types of fungi such as *Aspergillus* sp. and *Penicillium* sp. and actinomycetes in the form of *Streptomyces* (Handayani 2011). The research results of Suliasih and Rahmat (2007) reported that the bacterial isolate *Bacillus pantothenticus* is a microbe that has the ability to dissolve $Ca_3(PO_4)_2$ into high phosphate compounds. Kour et al. (2021) stated that there are three domains of P-solubilizing and mobilizing microorganisms, namely archaea, bacteria and eukarya. Strains belonging to the genera *Arthrobacter*, *Bacillus*, *Burkholderia*, *Natrinema*, *Pseudomonas*, *Rhizobium*, and *Serratia* have been reported as efficient and potential P solubilizers.

Potassium and calcium are basic cations that influence flowering phenology and production of forest clove plants due to their role in creating resistance for the shoots. During flowering phenology, vegetative organs (shoots) undergo modification to become generative organs, initiating flowering process. An increase in the amount of soil potassium nutrients will prolong the duration. According to Wang et al. (2013), this essential nutrient influences most of the biochemical and physiological processes which play role in plant growth and metabolism. Among other nutrients, potassium functions in activating various types of enzymes, promoting carbohydrate metabolism, spurring root development, nitrogen metabolism, and protein synthesis, neutralization of important organic acids, acceleration of tissue growth, and shoot meristem development. Meanwhile, calcium plays role in compiling cell walls, cell formation, elongation, membrane structure and permeability, maintaining cell strength, and formation of protein content in mitochondria. These functions result in the synthesis of carbohydrates, proteins, amino acids, and enzyme activity, which altogether promote the long flowering phenology time and production of forest clove plant. In the soil there are various species of bacteria capable of dissolving potassium, such as *Pseudomonas*, *Burkholderia*, *Acidothiobacillus ferrooxidans*, *Bacillus mucilaginosus*, *Bacillus edaphicus*, *Bacillus circulans* and *Paenibacillus* sp. (Parmar and Sindhu 2013). Based on the research results of Pratama and Anas (2016), it was reported that there were microbial isolates that could dissolve potassium which were identified as the species *Achromobacter xylosoxidans* and *Burkolderia cepacia*.

According to Prajapati and Modi (2012), Potassium (K) can increase crop yields and improve quality, necessary for various plant growth processes. In terms of the complex role in photosynthesis, K plays a part in enzyme activation and production of adenosine triphosphate (ATP). This is crucial in regulating the rate of photosynthesis compared to its role in stomatal activity. When solar energy is used to combine CO_2 and water to form sugar, the initial high-energy product is ATP, which is then used as the energy source for many other chemical reactions. As stated by Prasad and Shivay (2020), Ca is an essential plant nutrient responsible for the integrity of plant cells and structures, but it is generally ignored due to the abundant availability in most cultivated soil. White and Broadley (2003) emphasize the various structural role in cell walls and membranes. Ca is also a counter-cation for inorganic and organic anions in the vacuole, and the cytosolic Ca^{2+} concentration ($[Ca^{2+}]$cyt) is the obligatory intracellular messenger coordinating responses to various plant developments.

The average production of fresh and dry clove flowers was 50.3 kg/plant and 20.1 kg/plant respectively. Based on these results, the water content of forest clove flowers at harvest time reached 60%. This is in line with a study by Kamsurya and Botanri (2022) stating that higher elevation does not guarantee increased fresh crop production. Elevations exceeding 246.13 m asl were not followed by additional crop yields. In other words, this point is the optimal elevation measure to obtain maximum production in the form of fresh flowers reaching 54.86 kg/plant. Meanwhile, maximum dry flower production was achieved at an optimal elevation of 240 m above sea level with a yield of 20.55 kg/plant.

In conclusion, soil parameters, both chemical and physical contributed to habitat of forest clove plant, with respective contributions reaching 14.89% and 8.09%. The chemical variables implicated were nitrogen, C-organic, potassium, calcium, and magnesium, which collectively had an influence of approximately 93.15%. Three physical parameters had significant contributions including sand, dust, and bulk density, reaching 84.55%. The chemical and physical parameters significantly affected flowering phenology, with values of 21.8% and 79.4% respectively. On the other hand, both parameters were found to have a relatively low effect on clove flower production.

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