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Research Article

Evaluation between the year of pruning and land slope on nutrient uptake and availability in tea plantation

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Abstract

In tea plantations, pruning to rejuvenate the plant is regularly carried out. The cutting age that is also known as pruning year determines the estimated production of tea plantations. The land slope is thought to affect the absorption of nutrients, which have implications on yields. This study aimed to explore the interaction between the pruning year and land slopes in nutrients uptake in tea plantations and to obtain the correlation between soil fertility and nutrients content in tea plants at different land slopes. A field experiment was carried out from December 2020 to February 2021 at The Research Centre for Tea and Cinchona, Gambung. A Split Plot design was conducted to observe between pruning year (PY) that consisted of pruning year 1 (PY-1), pruning year 2 (PY-2), pruning year 3 (PY-3) and pruning year 4 (PY-4) with two different slopes in each block that consisted of flat land (slope = 0-8%) and sloping land (slope = 15%-25%). Results of the study showed that there was no interaction between PY and slope on the uptake and nutrient content in the tea plant, but there was an independent effect from each factor, where the PY factor affected all nutrients uptake, while the slope factor only affected P content. There was no significant difference between flat and sloping land on soil nutrients, but there was a correlation between plant nutrients and tea plant nutrient content. P content had a strong correlation with K content ($r = 0.657$); and K content had a strong correlation with Mg content ($r = 0.891$).

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Introduction

Tea plant (*Camellia sinensis* L.) is a perennial plant that is widely known as a source of medicinal, industrial and beverages raw materials. Indonesia is ranked 13th in the world as an exporter of black tea with a value of USD 78 million in 2019. However, in terms of green tea exports, Indonesia is still ranked 18th with a value of USD 15.3 million. Tea in the export market opportunities of which is the Turkish state, Libya and Morocco as the highest tea consumption countries, with the value of each among others, is 3.04 kg/capita, 3.02 kg/capita and 2.07 kg/capita. Ironically, Indonesia, as a tea exporting country, still has a low interest in tea consumption, which is 0.35 kg per capita (International Tea Committee, 2020).

Tea in Indonesia is an introduced plant that originated from China and India, which has different agroclimatic conditions. The tea plant can grow optimally at a high altitude of more than 1000 m above sea level, but it could still be cultivated at an altitude of more than 800 m above sea level, with ideal rainfall of 1800-4000 mm per year (Effendi et al., 2010; Ritung et al., 2011). The desired soil conditions are generally Andisols with soil pH between 4.5 and 5.6 (slightly acidic) and organic matter content of more than 1% (Effendi et al., 2010).

Tea plant is Dicotyledonous*,* so it has a taproot that can grow quite deep, up to a depth of >60 cm (Yamashita, 1994). With this ability, the plant is often used as an alternative for conservation on land with steep slopes to minimize the rate of erosion. However, the ideal land slope for the tea plant of 0-8% is very suitable (S1), and 9-15% is moderately suitable (S2). Tea cultivation of tea plants on the state or private plantations is generally carried out at various slope levels, even on slopes of more than 40%, which is included in the steep slope class. This is an effort to optimize land use because of the ability of tea plants to grow on extreme slopes.In addition to the ability of the roots to support the growth of tea plants at extreme slopes, in the practice of cultivation, the plants are centring and bending to widen the picking field, and pruning is carried out every four years to maintain the height of the picking field. This can cause the penetration of rainwater to the soil surface to be relatively reduced and reduce the risk of erosion. Pruning is carried out on mature tea plants with pruning intervals every four years. In addition to maintaining the height of the picking field, pruning also aims to rejuvenate the tea plant so that it forms new shoots and twigs so that shoot production is maintained. When new tea plants are pruned, the shade of plants against rainwater penetration is reduced, thereby potentially increasing the rate of erosion and leaching of nutrients through surface runoff and has implications for plant nutrient uptake. Therefore, this study aimed to look at the interaction between the age of pruning/year and the slope on the uptake of nutrients by tea plants, the differences in nutrient availability on flat and sloping lands, and the correlation between soil nutrients and tea plant nutrient absorption.

Materials and Methods

A field experiment was carried out from December 2020 to February 2021 at Gambung Trial Field, the Research Centre for Tea and Cinchona at Gambung of West Java. The experiment was carried out by observing between the pruning years (PY) of plants which consisted of pruning year 1 (PY-1) in Block B6, pruning year 2 (PY-2) in Block B3, pruning year 3 (PY-3) in Block B4 and year pruning 4 (PY-4) in Block B5. Each block was observed on two different slopes that consisted of flat land (slope = 0-8%) and sloping land (slope = 15-25%) with a soil order of Andisol. The soil properties on the experimental field are presented in Table 1. The experimental design was carried out by a split-plot design consisting of eight treatment combinations in which PY was the main plot and land slopes as subplots with four repetitions, and the soil samples for initial data were taken and analyzed from each plot.

Table 1 Soil properties on the experimental field.

Soil Properties	Block/Slope							
	B3 (PY-2)		B4 (PY-3)		B5 (PY-4)		B6 (PY-1)	
	Flat	Slope	Flat	Slope	Flat	Slope	Flat	Slope
Soil Order	Andisols	Andisols	Andisols	Andisols	Andisols	Andisols	Andisols	Andisols
Sand (%)	85.5	83.5	86.5	85.0	85.0	85.0	85.0	86.0
Silt (%)	8.0	9.0	8.5	7.5	9.5	10.0	7.5	6.5
Clay (%)	6.5	7.5	5.0	7.5	5.5	5.0	7.5	7.5
Texture	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand
pH H_2O	5.74	5.72	6.10	5.59	6.19	6.33	6.18	5.90
Org-C (%)	5.83	5.60	7.10	7.10	5.46	5.20	4.80	5.11
Total-N (%)	0.86	0.88	0.80	0.74	0.88	0.69	0.81	0.83
C/N Ratio	6.67	6.67	8.67	10.00	6.33	7.33	6.00	6.00
Av-P (ppm)	5.60	3.56	3.58	1.02	9.99	12.05	5.48	4.86
Ex-K (cmol kg^{-1})	0.29	0.38	0.15	0.26	0.23	0.31	0.32	0.16
Ex-Mg (cmol kg^{-1})	1.82	2.41	2.24	1.21	1.80	2.40	2.29	1.87
SWC (%)	40.40	40.27	45.07	38.53	40.07	37.67	35.33	38.33
$EC_{1:5}$ (µS cm^{-1})	82	100	126	98	100	50	74	76

Note: Av-P: Available P; Ex-K: Exchangeable K; Ex-Mg: Exchangeable Mg; SWC: Soil Water Content.

Plot preparation was carried out by making plot boundaries measuring 10 m x 10 m using stakes and raffia rope, so the 100 m^2 per plot was obtained. Soil and leaf samples were taken twice in December and February as many as five sample points of each plot. Soil samples were taken compositely as much as 1 kg in each block. Leaf samples were taken when the plant had entered the plucking time, with the target organ being the mother leaf with three young leaves and one pekoe shoot or also known as the P+3+mother leaf plucking formula. The plucking interval was 25 days which was done every first week in a month. Soil and leaf samples were analyzed for their nutrients content at the Laboratory of Soil Fertility and Plant Nutrition, Padjajaran University. The soil properties parameters were organic-C based on the Walkley-Black method (FAO, 2019), total-N based on Kjeldahl method (FAO, 2021), pH H_2O based on electrode method (ISRIC, 1993), available-P based on Olsen (pH>5.5) and Bray I (pH<5,5) method (ISRIC, 1993), exchangeable-K and exchangeable-Mg based on Ammonium Acetate extraction (ISRIC, 1993). The plant nutrient content plant was analyzed by the liquid ash extraction method on the mother leaf of the tea plant for total N, P, K and Mg content (AOAC, 2000). The nutrient content data was then calculated of the nutrient uptake with the following equation.

$$Nu\ (g\ plant^{-1}) = Nc\ (\%) \times PDW\ (g)$$

where: Nu = plant nutrient uptake, Nc = plant nutrient content, and PDW = plant dry weight

The data from the laboratory analysis was then subjected to statistical analysis to see the interaction between the PY and the slope of soil for nutrient uptake and nutrient content. Correlation and regression analysis was done to evaluate the correlation of the soil nutrient content to the nutrient content of tea plants by a Simple Pearson method. All statistical analyses were done with the support of SPSS version 21 software with a 95% of confidence level.

Results and Discussion

Effect of pruning year and land slope on plant nutrient uptake and nutrient content

The results of the analysis showed no significant interaction between the PY of the plant and the land slope on the dry weight and nutrient uptake of tea plants and no significant effect on nutrient uptake on each land slope, but there was an independent effect on PY factor (Table 2). The data showed that the PY-3 has the smallest leaves dry weight and every nutrient uptake. The N uptake was showed there was no significant uptake between PY-1, PY-2 and PY-4. The P and K uptake showed a similar trend on each PY, where PY-2 and PY-3 had the highest uptake, followed by PY-1 and PY-3. There was no significant Mg uptake on every PY.

Table 2 Independent effect of PY and land slope on plant nutrient uptake and leaves dry weight.

Treatment	Leaves Dry Weight (g)	Plant Nutrient Uptake (g plant^{-1})			
		N	P	K	Mg
PY-1	11.55 b	0.403 b	0.048 b	0.105 b	0.119 a
PY-2	15.08 b	0.557 b	0.063 c	0.212 c	0.128 a
PY-3	7.012 a	0.246 a	0.026 a	0.048 a	0.079 a
PY-4	13.84 b	0.459 b	0.072 c	0.167 c	0.114 a
Flat Land (0-8%)	12.05 a	0.426 a	0.054 a	0.137 a	0.111 a
Sloping Land (15-25%)	11.69 a	0.406 a	0.050 a	0.129 a	0.109 a

Note: values followed by different letter notations indicate a significant effect at = 5%

Nutrient absorption at PY-1 and PY-3 was relatively even, but at PY-1, absorption of N, P and K was more dominant. Nutrient uptake in PY-2 and PY-4 showed a relatively similar trend, where the dominant absorption of P and K nutrients was compared, followed by N and Mg. Furthermore, at the slope level of 0-25% showed that it did not significantly affect the nutrients uptake by the tea plant. This was expected due to the taproot type of tea plant could penetrate deeper soil layers with relatively broad root branches so that when there is erosion or nutrient leaching at that slope level, nutrients can still be absorbed properly (Zuazo and Carmen, 2008). Moreover, the chemoautotrophic mechanism in tea roots was expected able to approach the source of nutrients. The mechanism of nutrient uptake by plant roots occurs in three ways, namely by root interception, mass flow and chemoautotrophs (Shukla et al., 2014). In addition, the texture of the sandy loam soil in the experimental field (Table 1) was thought to have an effect on soil nutrient translocation and distribution, which is still well maintained, where the clay contained in the soil can reduce the nutrient leaching (Abdul et al., 2015). Further analysis showed no significant interaction between the PY of the plant and the slope of the land on the nutrient content of tea plants, but there was an independent effect of each factor (Table 3). In general, the nutrient content on tea leaves did not show linearly with its nutrient uptake. Tea plants with PY-2 had more dominant N and K content; at PY-3, the N and Mg contents were dominant; at PY-4 the P and K content were dominant, and PY- 1 absorption of each nutrient content was relatively moderate. The difference in the slope of the land has only a significant effect on P content, where on flat land, the P content was higher than on sloping land. The difference in nutrient content from each PY of tea plants is thought due to each age of tea plants has specific characteristics and priorities in nutrient utilization. The freshly pruned tea plants require various energy resources to regrow new shoots, twigs and shoots. In addition, pruning tea plants not only reduce the plucking heigh but also rejuvenate the plant (Ahmad et al., 2014; Kumar et al., 2015). The tea plant rejuvenation process requires adequate food reserves and nutrients so that the absorption of various nutrients in plants is relatively increased and evenly distributed for each of these elements, as seen in PY-1 tea (Seal et al., 2016; Cowan-Gore and Sein, 2020). At the age of pruning, the tea has been plucked intensively due to its relatively high production potential (Yilmaz et al., 2004; Kumar et al., 2015).

Table 3. Independent effect of PY and land slope on plant nutrient content.

Treatment	Plant Nutrient Content (%)			
	N	P	K	Mg
PY-1	3.49 b	0.42 b	0.91 b	1.03 b
PY-2	3.68 c	0.42 b	1.37 d	0.83 a
PY-3	3.57 b	0.35 a	0.67 a	1.12 c
PY-4	3.33 a	0.47 c	1.21 c	0.82 a
Flat Land (0-8%)	3.54 a	0.43 b	1.06 a	0.95 a
Sloping Land (15-25%)	3.49 a	0.40 a	1.02 a	0.95 a

Note: values followed by different letters in the same column indicate a significant effect at = 5%.

Tea plants at the productive stage are expected to utilize more N and Mg elements to form leaf organs and chlorophyll (Gerendás, and Führs, 2013; Nadeem et al., 2018). K element has an important role in the balance of water and nutrients in plants and helps form the resistance of these plants that is expected crucial in young and mature tea (Prajapati, 2012). A quite different phenomenon was seen in tea plants with the fourth pruning age (PY-4). Tea plants at this age of pruning which were categorized as mature plants showed more dominant P and K absorption than N and Mg absorption. It is suspected that tea plants with old pruning age are not effective in forming leaves and chlorophyll due to the number and growth of many plant branches and forming very dense shrubs. This is thought to cause photosynthesis that is not optimal, especially in old leaves located in shrubs. When the plant upward growth is not optimal, the plant will try to find more nutrients through the roots and transport the photosynthetic products to these organs so that root growth dominates (Chang et al., 2017). Phosphorus is reported to play an important role in the formation of roots, stems and energy (ATP) (Hawkesford et al., 2012). The slope factor only had a significant effect on P content of tea plants, while the P absorption showed not significantly different with another nutrient. The higher P content on flat land was suspected due to in sloping land, the tea plant root growth was more active than on flat land to accommodate the nutrient uptake in soil. It is suspected there is leaching of nutrients and soil particles, especially sand particles on sloping land, which causes the dominance of clay particles so that water absorption and nutrient retention occur. Even so, the soil nutrient content on flat or sloping land did not show any significant differences (Table 4). This indicates that there was no significant effect between flat land and sloping land with a slope of 15-25% on soil fertility in tea plantations.

Table 4. Independent T-test of soil nutrients on flat and sloping land.

Flat Land vs Sloping Land	Soil Nutrient Difference Value					
	pH	C-Org (%)	N (%)	P (ppm)	K (cmol kg^{-1})	Mg (cmol kg^{-1})
	0.109^{ns}	-0.003^{ns}	0.053^{ns}	0.791^{ns}	-0.043^{ns}	0.065^{ns}

Note: ns = not significant..

It is suspected that in tea plantations, the cover of shrubs is relatively dense and the presence of organic waste of tea trimmings which can inhibit the rate of erosion and leaching of nutrients.

Correlation of soil fertility to tea plant nutrient content

The analysis result showed a correlation between soil fertility and tea plant nutrient uptake (Table 5). Soil pH parameter was significantly correlated with soil P_2O_5 (Av-P), exchangeable Mg (Ex-Mg), N and P content. When soil pH increased, Av-P, Ex-Mg, and P content increased which indicated a positive correlation, but N content decreased. Soil organic C (Org-C) parameter was negatively correlated to P content, when Org-C increased, the P content decreased. Parameter Av-P significantly correlated to the N, P and Mg content. When soil Av-P increased, the P content increased, but the content of N and Mg decreased. The exchangeable K (Ex-K) parameter was significantly correlated with the content of K and Mg. When Ex-K increased, the uptake of K increased but decreased Mg content. The P content was significantly correlated with K and Mg content in the tea plant. When P content increased, K content increased, but Mg content decreased. The K content was significantly negatively correlated with

Mg content, when K content increased, Mg content decreased. Furthermore, soil pH was quite strongly correlated with N content in the tea plant. The results showed that soil pH was negatively correlated with N content, where an increase in soil pH would be followed by a decrease in N content in the tea plant. This seems to be due to the positive correlation between soil pH and P nutrient, where an increase in soil pH exhibited an increase in P availability in the soil. Increased availability of P was positively correlated to increased absorption of P that was thought to be antagonistic to the absorption of N in the tea plant. The optimal soil pH for tea plants is reported to be in the range of 4.5-5.6, which means slightly acidic criteria (Hajiboland, 2017). Ruan et al. (2007) reported that the optimal absorption of N in the form of NH_4^+ and NO_3^- in tea plants was at a soil pH value of 4-5.

Table 5. Correlation of soil fertility to tea plant nutrient content.

Parameter	pH	Org-C	To-N	Av-P	Ex-K	Ex-Mg	N Plant	P Plant	K Plant	Mg Plant
pH	1									
Org-C	-0.320	1								
To-N	0.016	0.080	1							
Av-P	0.492*	-0.398	-0.169	1						
Ex-K	-0.228	0.024	-0.017	0.038	1					
Ex-Mg	0.515*	-0.237	0.045	0.236	0.317	1				
N Plant	-.548*	0.105	0.325	-0.466*	0.235	0.011	1			
P Plant	0.490*	-0.478*	0.318	0.545*	0.058	0.280	-0.251	1		
K Plant	0.032	-0.241	0.391	0.398	0.459*	0.282	0.113	0.657*	1	
Mg Plant	0.001	0.220	-0.185	-0.472*	-0.452*	-0.078	0.136	-0.598*	-0.891*	1

Notes: the number followed with * indicates a significant correlation at α=5%. Org-C= Organic Carbon; To-N= Total N; Av-P= Available P; Ex-K= Exchangeable K; Ex-Mg= Exchangeable Mg.

Table 6. Regression equations on parameters that are significantly correlated.

Paremeter	Equation	Information
Soil pH on Av-P	Y = -28,507 + 5.741X	Y= Av-P; X= Soil pH
Soil pH on Ex-Mg	Y = -3.243 + 0.879X	Y= Ex-Mg; X= Soil pH
Soil pH on N-Plant	Y = 5.232 - 0.287X	Y= N-Plant; X= Soil pH
Soil pH on P-Plant	Y = -0.066 + 0.081X	Y= P-Plant; X= Soil pH
Org-C on P-Plant	Y = 0.690 - 0.353X	Y = P-Plant; X= Org-C
Av-P on N-Plant	Y = 3.639 - 0.021X	Y= N-Plant; X= Av-P
Av-P on P-Plant	Y = 0.372 + 0.008X	Y= P-Plant; X= Av-P
Av-P on Mg Uptake	Y = 1.053 - 0.018X	Y= Mg Uptake; X= Av-P
Ex-K on K. Uptake	Y = 0.708 + 3.337X	Y= K Uptake; X = Ex-K
Ex-K on Mg. Uptake	Y = 1.112 - 1.611X	Y= Mg Uptake; X = Ex-K
P-Plant on K Uptake	Y = -0.431 + 3.536X	Y= K Uptake; X= P-Plant
P-Plant on Mg Uptake	Y = 1.607 - 1.575X	Y= Mg Uptake; X= P-Plant
K Uptake to Mg Uptake	Y = 1.406 - 0.436X	Y= Mg Uptake; X= K Uptake

Notes: Org-C= Organic Carbon; To-N= Total N; Av-P= Available P; Ex-K= Exchangeable K; Ex-Mg= Exchangeable Mg.

Tea plant is unique in terms of the absorption of trace elements Fe which are relatively higher than other plants in general. Both of these factors could be physiologically suspected of causing an antagonistic between P nutrient absorption and N absorption. Rietra et al. (2017) reported that the availability of N in the soil could increase the secretion of *phytosiderophores* in plant roots that play roles in reducing and mobilizing Fe in the soil into a form that is available and can be absorbed by plants. Furthermore, high soil pH close to neutral generally causes metallic elements such as Fe to be insoluble, and chelation with P elements does not occur, thereby increasing the availability of P (Ifansyah, 2014).

Conclusion

There was no significant interaction between pruning year (PY) and land slope on tea plant nutrient uptake and nutrient content, but there was an independent effect of each factor, where the PY factor affects all nutrient uptake, while the land slope factor only affected P nutrient content. The nutrient uptake did not show a linear effect on nutrient content in the tea plant. There was no significant difference between soil nutrients in flat land (0-8%) and sloping land (15-25%) in tea plantations, but there was a correlation between P and K content (r = 0.657). K content was strongly correlated with Mg content (r = 0.891). There were also correlations between soil pH with N and P contents. When soil pH increases, N content decreases (r = 0.548) but the P content increases (r = 0.490).

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