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PRECISION-BASED OPTIMIZATION OF PLUCKING HEIGHT FOR TEA SHOOT YIELD, QUALITY, AND SUSTAINABLE SHOOT GROWTH ACROSS DIFFERENT PRUNING YEARS

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ABSTRACT

Plucking management is a critical factor in maintaining tea production, shoot quality, and next generation of shoot growth. Improper plucking practices, particularly excessive low plucking, can negatively affect plant health by slowing down the shoot growth cycle, reducing the availability of maintenance leaves, and ultimately leading to decreasing shoot yield. Therefore, the need for precision-based plucking height to sustain optimal vegetative growth and yield in each plucking year is needed to be understood. One potential solution is the implementation of precise plucking height which is expected to improve shoot regeneration, maintain plant health and plucking table, and also enhance sustainable productivity in tea plantations. This study was conducted from October to November 2024 at a Tea Plantation in Bandung Regency using a split-plot randomized complete block design consisting of two factors (4×4) with 3 replications. Pruning year as the main plot consisted of 1st year (T1), 2nd year (T2), 3rd year (T3), and 4th year (T4) after pruning. The subplot was plucking height with 0 cm (K0), 1 cm (K1), 2 cm (K2), and 3 cm (K3) pad. Parameters comprised shoot yield per plot (kg), plucking points/m², pekoe shoot percentage, remaining P+1 shoot percentage, remaining P+2 shoot percentage, remaining banjhi shoot percentage and fresh shoot quality were measured. Data were analyzed using Analysis of Variance (ANOVA) (p≤0.05) and followed by Duncan's Multiple Range Test (p≤0.05) if there were significant differences. The highest fresh shoot yield per plot was obtained from the T4K0 combination (70.77 kg plot^{-1}). The highest percentage of remaining shoots P+1 was recorded in the T4K1 treatment (29%). The minimum percentage of remaining banjhi shoot was resulted from T1K2 combination (14%). Meanwhile, fresh shoot quality was highest in the T2K1 combination (78%), followed by T2K2 (75%).

Key words: Plant health, Plucking technology, Pruning year, Shoot growth, Tea plucking.

INTRODUCTION

Tea (*Camellia sinensis* (L.) O. Kuntze) is one of Indonesia's strategic plantation commodities that contributes significantly to the national economy. In recent years, Indonesia's national tea production has shown a fluctuating trend, particularly from 2021 to 2024. National production decreased from 137,837 tons in 2021 to 124,661 tons in 2022, declined to 116,506 tons in 2023, and slightly recovered to 118,895 tons in 2024 (Directorate of Food Crops, Horticulture, and Estate Crips Statistics, 2025). Overall, tea production declined by 13.7% between 2021 and 2024, highlighting the need for improved management practices to sustain productivity. Tea productivity can be determined by various factor such as genetic, cultivation techniques, environmental, and management factors. Haq and Karyudi (2013) reported that cultivation techniques contribute the largest proportion to productivity improvement (35%), followed by genetic factors through clone selection (25%), management practices (25%), and environmental factors such as climate conditions (15%). The tea clones predominantly cultivated in Indonesia are *Camellia sinensis* (L.) O. Kuntze var. *assamica*, owing to their adaptability to Indonesia's climatic conditions and relatively higher productivity (Hanafi *et al.,* 2025). Climate factors, especially temperature and relative humidity, significantly affect tea productivity (Rezamela *et al.,* 2025).

Among the cultivation techniques, plucking management is considered one of the most critical practices because harvested shoots constitute the economic yield of tea plantations. Proper plucking not only determines the quantity and quality of harvested shoots (Salimah *et al.* 2023) but also influences the growth and regeneration of subsequent shoots (Amiri & Asil, 2007). In contrast, improper plucking practices, particularly coarse plucking, can extend plucking cycles (Owuor *et al.,* 1987), reduce the availability of maintenance leaves (Abas, 2013), and decrease the photosynthetic capacity of the tea bush which is important in assimilate mobilitation (Anjarsari *et al.,* 2020). These conditions ultimately reduce tea productivity. Furthermore, excessive removal of foliage can weaken source-sink relationships within the canopy, reduce maintenance foliage, and impair shoot recovery (Pathiranage *et al.*, 2019). Consequently, maintaining an optimal plucking table remains a critical challenge in tea production systems, regardless of the harvesting method employed.

To improve harvesting efficiency and address labor shortages, mechanical harvesting has been increasingly adopted in tea plantations. However, with proper operational control and strict plucking standards, machine harvesting can be optimized to maintain productivity and help mitigate labor constraints. Abbas (2013) reported that the use of a double-blade harvesting machine (type 120) with medium plucking standards above the fish leaf (K+0) did not reduce yield, shoot quality, or plant health. In recent years, harvesting practices have increasingly shifted from double-blade machines to single operated electric (SOE) plucking machines using batteries. Prolonged one-handed operation may increase operator fatigue, which could result in deeper plucking and reduced consistency in harvesting height over time. Despite their increasing adoption, studies evaluating the performance and agronomic impacts of SOE harvesting systems are still scarce which requires further investigation.

The response of tea bushes to plucking practices is also influenced by pruning year. Differences in canopy structure, shoot population, vigor, and maintenance foliage among pruning years may affect the optimal plucking strategy required to sustain productivity. Yilmaz *et al.* (2004) reported that in Turkish tea, increasing pruning age raised plucking table height, reduced shoot length, and increased the proportion of banjhi shoots. Shoot number increased up to the third pruning year before declining, while fresh shoot yield peaked at the fourth year and subsequently decreased, accompanied by a sharp reduction in polyphenol content. Each pruning years have different nutrient content due to aged tea plants has specific characteristics and priorities in nutrient utilization (Athallah *et al.,* 2021). Information regarding the appropriate plucking height for different pruning years remains limited. In particular, the use of plucking cushions or pads as a guide for maintaining consistent plucking height has never recorded in scientific research despite its potential role in preserving plucking table. Therefore, understanding the effects of plucking height across different pruning years is essential to develop precision-based using the latest innovation on plucking management strategies maintaining tea shoot yield, quality, and sustainable shoot growth.

MATERIALS AND METHODS

This study was conducted from October to November 2024 at a Tea Plantation in Bandung Regency, using a split-plot randomized complete block design (RCBD) with three replications. Pruning year (T) the main plot factor, consisting of four levels: first year after pruning (T1), second year after pruning (T2), third year after pruning (T3), and fourth year after pruning (T4). Plucking height (K) as the subplot factor, consisting of four plucking heights: 0 cm (K0), 1 cm (K1), 2 cm (K2), and 3 cm (K3). Each experimental plot measured 20 m × 10 m (200 m²). With of a total of 48 plots. The materials and equipment used in this study included a Sanyang Single Operated Electric (SOE) tea harvester model SY/3002, plucking height pad "Bantalan Pemetikan", screws, nails, bamboo quadrat 1x1 m, a weighing scale, office stationery, woven polypropylene sacks (waring), plastic samples, hand counters and tarpaulin.

The parameters observed included shoot yield per plot (kg), number of plucking points per m², percentage of pekoe shoots (%), percentage of remaining banjhi shoots (%), percentage of remaining P+1 shoots (%), percentage of remaining P+2 shoots (%), percentage of remaining banjhi shoots (%) and fresh shoot quality (%). Data on plucking spoints were collected using a 1 m × 1 m quadrat placed within each treatment plot harvested with a Single-Operated Electric (SOE) plucking machine. Shoot yield was recorded on a plot basis without the use of quadrat. The percentages of remaining P+1, P+2 and banjhi shoots were determined from total counts of remaining shoots consisted of (newly emerged shoots, P+1, P+2 and banjhi shoots) within the quadrat immediately after plucking equals the total count of shoots. Fresh shoot quality was observed by the percentage of 200 grams collected fresh leaf per plot and then measure the tender leaves and equals by the total 200 grams.

The data were subjected to analysis of variance (ANOVA) at the 5% significance level. When significant treatment effects were detected, mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Figure 1. *Bantalan pemetikan* plucking height pad

RESULTS AND DISCUSSION

Based on the results of observations of Anova, recap of all the parameters is as served in Table 1.

Table 1. ANOVA Result From all Parameters

Parameter	Pruning Year (T)	Plucking Height (K)	Interaction (TxK)
Shoot Yield (kg plot^{-1})	*	*	*
Plucking Point (total m^{-2})	*	ns	ns
Pekoe Shoot (%)	*	ns	ns
Remaining P+1 (%)	*	*	*
Remaining P+2 (%)	*	*	*
Remaining Banjhi (%)	*	*	*
Shoot Quality (%)	*	ns	*

Notes: * : Significant at $P <$ 0,05
ns : Not Significant

Pruning year significantly affected all observed parameters. This indicates that tea physiological conditions varied among pruning years, influencing shoot production, shoot composition, and shoot quality. Plucking height significantly affected shoot yield, remaining P+1 shoots, and remaining P+2 shoots, but had no significant effect on plucking points, pekoe shoot percentage, or shoot quality. The significant response of yield indicates that plucking height directly influences the amount of harvested biomass. Lower or coarse plucking heights likely removed a greater proportion of harvestable shoots, resulting in higher immediate yield, whereas higher plucking heights retained more foliage and developing shoots. The significant effects on remaining P+1, P+2 and banjhi shoots suggest that plucking height influences canopy structure after plucking. Higher plucking heights may leave shoots on the plucking table, while lower plucking heights remove a larger portion of developing shoots.

However, the absence of significant effects on plucking point, pekoe percentage and shoot quality indicates that differences in plucking height did not substantially alter the composition of harvested shoots within the range tested (0–3 cm). The interaction between pruning year and plucking height significantly affected shoot yield, remaining P+1 shoots, remaining P+2 shoots, remaining banjhi shoots and shoot quality.

Shoot yield per plot (kg plot^{-1})

Table 1. Shoot yield per plot after Pruning Year and Plucking Height Treatment (kg.plot^{-1})

Pruning year (T)	Plucking Height (K)				Mean
	K0 (0 cm)	K1 (1 cm)	K2 (2 cm)	K3 (3 cm)	
	---------- (kg) ----------				
T1 (PY 1)	22,67^{bcd}	21,33^{abcd}	17,00^{abc}	13,67^{ab}	18,67
T2 (PY 2)	38,23^{e}	20,90^{abcd}	18,87^{abcd}	20,20^{abcd}	24,55
T3 (PY 3)	32,20^{de}	28,10^{cde}	22,00^{abcd}	9,67^{a}	22,99

T4 (PY 4)	70,77[f]	20,42[abcd]	18,87[abcd]	12,97[ab]	34,77
Mean	40,97	22,69	19,18	14,13	

- Means with different superscript letters within the interaction matrix are significantly different at $p < 0.05$.

The interaction between pruning year and plucking height had a significant effect on shoot yield, indicating that the response of yield to plucking height varied depending on pruning age. The highest shoot yield was observed in PY 4 at K0 (70.77 $kg.plot^{-1}$), while the lowest yield occurred in PY 3 at K3 (9.67 $kg.plot^{-1}$). In general, yield tended to decrease as plucking height increased across all pruning years, although the magnitude of the response differed among pruning stages. Pruning year 4 (T4) showed a sharp decline in yield with increasing plucking height, whereas PY1 and PY2 exhibited relatively moderate reductions. The high yield in PY4 at K0 suggests that older pruning cycles with a lower plucking height allow more harvestable shoots to be collected. This is inline with Yilmaz *et al.* (2004) research that pruning age significantly increased fresh shoot yields from age 1 to age 4 and then decreased at the age 5.

In contrast, higher plucking heights retained more immature shoots, resulting in lower harvested yield. These results indicate that the optimum plucking height is dependent on pruning year, and thus harvesting management should be adjusted according to the physiological condition of the tea canopy. Although low plucking height can result in high yield when done repeatedly, it may affect to stagnant plucking table and lead to a thinner maintenance leaf layer. A thin layer of maintenance leaf can reduce the energy available from photosynthesis, resulting in slower shoot growth and the potential grow of “cakar ayam” (Abas, 2013). This called “maintenance leaf” has the role as both sink and source, but mainly act as a source of photoshyntathes that supports development and metabolism. The optimal maintenance leaf height would support numerous shoot growth which is approximately between 4 – 5 layer of physiological mature leaf or not less than 20 – 25 cm (Haq & Karyudi, 2013).

Plucking point (total m-^{2}) and pekoe shoot percentage (%)

Table 2. Plucking point per m^2 and Pekoe Shoot (%) after Pruning Year Treatment

Pruning year (T)	Plucking Point (total m^{-2})	Pekoe Shoot (%)
T1 (PY 1)	87.75[a]	77[c]
T2 (PY 2)	199.50[c]	69[c]
T3 (PY 3)	114.50[ab]	28[a]
T4 (PY 4)	71.92[a]	56[b]

- Means with different superscript letters within the same row are significantly different at $P < 0.05$.

The results showed that pruning year significantly affected the number of plucking points and the percentage of pekoe shoots. The highest plucking point value observed was in the second year after pruning (TP2) (199.5 total m^{-2}). Although PY4 showed the highest production weight, the number of plucking points or shoots within the quadrat was higher in PY2. This may be attributed to differences in biomass weight or shoot weight across different pruning ages. Safitri and Junaedi (2018) reported that tea productivity reaches its peak during the second and third years after pruning before declining in the fourth year. Tea is pruned every 4 to 5 years in order to maintain its productivity and reachable plucking table. Pruning tea is important to keep plant at the vegetative stage and focusing the energy to enhance branching and greater number of soft and tender leaves (Maudu *et al.,* 2010). Therefore, PY2 represents the peak pruning age, producing a higher number of plucking points, whereas PY1 serves as a recovery period after pruning injury, during which shoot growth is re-established and development becomes more active in PY2. It has been reported that pruning can increase the number of plucking points through the activation of axillary buds (Hossen *et al.,* 2021).

The first and second pruning years also exhibited the highest percentages of pekoe shoots. According to Sukasman (1988), as pruning age increases, competition among shoots for photosynthates intensifies due to the expansion of the plucking table. This condition contributes to a reduction in the percentage of pekoe shoots and promotes the development of dormant (banjhi) shoots as the availability of photosynthates becomes increasingly limited.

Remaining P+1, P+2 and banjhi shoot percentage (%)

Table 3. Remaining P+1, P+2 and banjhi shoot percentage after Pruning Year and Plucking Height Treatment (%)

Pruning year (T)	Plucking Height (K)				Mean
	K0 (0 cm)	K1 (1 cm)	K2 (2 cm)	K3 (3 cm)	
---- Remaining P+1 Shoot (%) ----					
T1 (PY 1)	13^{c}	23^{de}	12^{c}	25^{e}	18
T2 (PY 2)	17^{cd}	16^{cd}	10^{bc}	11^{c}	14
T3 (PY 3)	8^{ab}	3^{a}	4^{ab}	22^{de}	9
T4 (PY 4)	16^{cd}	29^{e}	8^{ab}	11^{c}	16
Mean	14	18	8	17	
---- Remaining P+2 Shoot (%) ----					
T1 (PY 1)	0^{a}	0^{a}	13^{def}	16^{efg}	7
T2 (PY 2)	6^{bc}	26^{h}	8^{cd}	18^{fg}	14
T3 (PY 3)	0^{ab}	8^{cd}	6^{c}	20^{gh}	9
T4 (PY 4)	5^{abc}	10^{cde}	9^{cd}	15^{defg}	10
Mean	3	11	9	17	
---- Remaining Banjhi Shoot (%) ----					
T1 (PY 1)	24^{abcd}	16^{ab}	14^{a}	24^{abcd}	19
T2 (PY 2)	21^{abc}	19^{abc}	34^{de}	28^{bcde}	26
T3 (PY 3)	63^{g}	79^{abcd}	83^{h}	50^{f}	69
T4 (PY 4)	38^{de}	36^{de}	75^{gh}	70^{gh}	55
Mean	36	38	51	43	

- Means with different superscript letters within the interaction matrix are significantly different at $P < 0.05$.

The remaining shoots were observed to determine the shoots left behind at different plucking heights and their potential for sustainable shoot growth in the next generation. The percentage of remaining P+1 shoots was highest in PY4 at 1 cm height, while the lowest was recorded in PY3 at 1 cm height. The P+1 shoots are likely to develop into P+3 or higher in the following plucking cycle. The growth for 3 leaves above fish leaf is about 14 to 17 days (Haq & Karyudi, 2013). In manual plucking with medium plucking, pluckers usually leave K+0 or fish leaf in the plucking table centre and K+1 or fish leaf with one leaf in the side of the canopy (Abas, 2013). The leaves retained under higher plucking standards, such as K+1 or K+0, function as maintenance leaves that support photosynthesis and shoot growth, whereas P+1 shoots are actively developing sinks expected to become harvestable in the next cycle.

The percentage of remaining P+2 shoots was highest in PY3 at 3 cm height, while the lowest was recorded in PY1 at 0 cm, 1 cm height and PY3 at 0 cm height. The 0 cm plucking table height showed the lowest results, which may be due to the complete removal of the P+2 formation. The remaining P+2 shoots have the potential to develop into overmature shoots, which may subsequently reduce shoot quality in the next plucking cycle. Plucking height 0 cm means plucking above the fish leaf or 0 cm after the last plucking height without using plucking height pad. Research on TRI clones by Jayasinghe *et al.* (2018) showed that it needs 11 days to develop first leaf, 16 days second leaves and 23 days for the third leaves with the addition of 20 – 23 days for harvestable stage. The development shoot of GMB series is needed to be understood. Excessive retention of P+2 shoots may increase competition for photosynthates, slow shoot growth, and delay newly emerged shoot growth turnover due to higher nutrient demand. That is inline with Liu *et al*. (2024) as the plant grows, photosynthates and nutrients are allocated to actively growing sink organs, such as newly developing shoots, as a mechanism for efficient nutrient utilization. However, an excessively high proportion of remaining P+2 shoots may indicate that harvesting was conducted too lightly, resulting in the loss of potential harvestable yield during the current plucking cycle. Therefore, maintaining an appropriate balance between harvested shoots and a post-harvest canopy dominated by newly emerged and P+1 shoots, with minimal P+2 and banjhi remaining shoots, is essential to ensure efficient shoot regeneration, stable or even plucking table, and sustained yield across harvesting cycles.

The percentage of remaining banjhi shoots was highest in PY3 at 2 cm height, while the lowest was recorded in PY 1 at 2 cm. The highest value was observed in PY 3 at a 2 cm plucking table height. Banjhi shoot is called dormant phases in the growth of tea shoot. A natural cyclic pattern of tea shoot growth including alternative active and dormant phases (Jayasinghe *et al.* 2018). As the pruning age increases, the proportion of banjhi shoot becomes higher compared to pekoe shoots (Hossen *et al.,* 2021). The increase in banjhi shoots as the years of pruning pass due to several physiological factors such as hormonal imbalance or the auxin-cytokinin balance shifts (Yilmaz *et al.,* 2004), resource limitation of carbohydrate and starch (Nissanka *et al,*. 2004), decreased photosynthesis as the canopy ages leading to decreasing net phtosynthetic rate and structural senescense as the older branch system gets (Kumar *et al.,* 2015).

Fresh shoot quality (%)

Table 4. Fresh shoot quality after Pruning Year and Plucking Height Treatment (%)

Pruning year (T)	Plucking Height (K)				Mean
	K0 (0 cm)	K1 (1 cm)	K2 (2 cm)	K3 (3 cm)	
	(%)				
T1 (PY 1)	40^{bcd}	32^{b}	50^{de}	46^{cd}	42
T2 (PY 2)	71^{fh}	78^{h}	75^{fh}	71^{fh}	74
T3 (PY 3)	43^{bcd}	37^{bc}	49^{cd}	63^{ef}	48
T4 (PY 4)	39^{bcd}	45^{cd}	36^{bc}	19^{a}	35
Mean	48	48	53	50	

- Means with different superscript letters within the interaction matrix are significantly different at $P < 0.05$.

The highest interaction in shoot quality percentage was observed in PY 2 at 1 cm plucking height followed by P Y2 at a 2 cm plucking height, PY 2 at 3 cm and 0 cm. Higher plucking heights selectively harvested more tender shoots, resulting in improved shoot quality. Similar findings have been reported where finer harvesting standards increased the proportion of tender shoots and improved tea quality. Study demonstrated by Long *et al.* (2022) that harvest standards directly influence the composition of young shoots (shoot + 1 or 2 leaves) generally provides higher-quality raw material than harvesting older shoots with more expanded leaves. Aaqil *et al.* (2023) also mentioned that fine plucking producing a higher proportion of tender shoots and superior quality compared with coarse plucking.

CONCLUSION

1. The highest fresh shoot yield per plot was obtained from the PY4 at 0 cm height combination (70.77 kg plot^{-1}). The highest percentage of remaining shoots P+1 was recorded in the PY4 at 1 cm treatment (29%). The minimum percentage of remaining banjhi shoot was resulted from PY1 at 2 cm combination (14%). Meanwhile, fresh shoot quality was highest in the PY2 1 cm combination (78%), followed by PY 2 at 2 cm height (75%). Overall, plucking at 1–2 cm height appears to provide favorable conditions for maintaining shoot balance and quality. However, further studies involving a larger number of replications and a longer observation period are necessary to comprehensively evaluate the effects of plucking table height on shoot yield, productivity, sustainable shoot growth and shoot quality.
2. Future research should investigate post-plucking shoot growth under each treatment, as differences in plucking table height may affect subsequent shoot development and the interval to the next plucking cycle.

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