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MODIFICATION OF CANOPY ARCHITECTURE IN TEA TO SUIT FOR MECHANICAL HARVESTING

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ABSTRACT

The shortage of workforce is a significant issue reported in South Indian tea plantations. Inadequate labour availability has hindered the ability to perform harvesting operations within the recommended intervals, leading not only to crop loss but also to deterioration in the quality of black tea due to delayed harvesting. To address this workforce shortage, mechanical harvesters have been introduced. However, the use of mechanical harvesting has revealed that tea plants, particularly those with weak branching systems affected by branch canker and shot hole borer, struggle to withstand the adverse impacts of mechanized harvesting. To mitigate these challenges, a modified pruning and tipping strategy has been explored. Specifically, low pruning at 45 cm from the ground, followed by a two-stage tipping method at 55 cm and 65 cm, was implemented to promote the growth of new, healthy branches and to create a more compact canopy suitable for mechanical harvesting. The results demonstrated that the two-stage tipping approach significantly increased the number of branches and the overall canopy area, thus enhancing the plant's ability to withstand mechanical harvesting pressures. Moreover, the combination of manual and shear plucking methods resulted in the highest tea yields. Additionally, the study found that tea yield tended to decrease as the age of the tea bushes increased. These findings offer valuable insights for the South Indian tea industry, suggesting that optimized pruning, tipping, and harvesting practices can improve both productivity and efficiency in the face of labour shortages and mechanical harvesting challenges.

Keywords: Mechanization, Pruning, Tea, Tipping

India's total tea production for the year 2023 was reported as 1,368 million kilograms, sourced from a cultivated area of 6,19,773 hectares across the tea-growing regions of Assam and West Bengal in the north, and Tamil Nadu, Kerala, and Karnataka in the south (Anonymous, 2024). The Indian tea industry directly employs over one million people, with more than 70-80% of these workers being women. Among the various cultivation practices, harvesting is the most significant, accounting for approximately 70% of the total production costs. Over the past two decades, labour shortages have been a persistent issue in all three southern states of India (Ilango *et al.*, 2013). In addition to the shortage of available workers, rising wages have become a major concern for tea growers, further exacerbating the challenges of controlling production costs (Ilango *et al.*, 2013). In response to these issues, mechanization has emerged as the most viable solution for the Indian tea industry. Southern Indian tea growers, in line with recommendations from the UPASI Tea Research Institute, have progressively adopted mechanized solutions for various cultivation practices, including pitting, pruning, lane cutting, and harvesting (Sharma *et al.*, 1981a; Ilango, 2007). Significant advancements have been made in the use of diverse harvesting equipment, ranging from simple hand-held shears to battery-powered shears, as well as petrol-powered, single-man operated harvesters and two-man operated harvesting machines (Ilango *et al.*, 2013).

The successful implementation of various mechanized equipment and machinery in tea cultivation depends significantly on the modification of existing tea fields to accommodate mechanization. Without such modifications, the expected productivity from both machines and workers cannot be fully realized. Therefore, to effectively mechanize all aspects of tea cultivation, it is essential to modify the tea fields, particularly the canopy architecture. Furthermore, future replanting efforts must adhere to new planting designs that are optimized for mechanization across all cultivation practices (Ilango *et al.*, 2023). In general, manual harvesting remains ideal for small-scale tea plantations or for the production of high-quality, specialty teas. In contrast, mechanical harvesting is more suitable for large-scale tea plantations, where maximizing efficiency and minimizing production costs are paramount (Ilango *et al.*, 2013).

In South India, approximately 80-85% of the existing tea fields are over 80-120 years old,

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necessitating modifications to the canopy architecture to accommodate mechanical harvesting. Among these fields, 15-20% are planted with various tea clones developed by the UPASI Tea Research Institute, while the remaining 80-85% consist of old Assam and China-type seedlings planted up to 120 years ago (Chandra Mouli and Sharma, 1993).

In newly planted areas, the opportunity exists to modify the planting design, thereby adjusting the canopy architecture to facilitate mechanical harvesting. However, in existing tea fields, whether planted with clonal varieties or the older Assam/China seedlings, modifications are more challenging. The width of the harvesting surface can be adjusted through proper lane cutting (Ilango *et al.*, 2023), but the overall canopy architecture and compactness cannot be significantly altered. This limitation is due to the weak branching systems that are often infested with branch canker and shot hole borer, resulting in loose, underdeveloped branches and an uncompact canopy (Ranganathan and Chandra Mouli, 1984; Muraleedharan and Selvasundaram, 1996).

To modify the canopy architecture of both old Assam/China seedling tea fields and newly planted clonal tea fields, manipulating pruning height followed by a two-stage tipping approach presents a viable strategy. However, both the existing old Assam/China seedling tea fields and the clonal tea fields lack a sufficient number of secondary and tertiary branches necessary for forming a dense, compact canopy. As a result, the branches are few in number and weak due to the presence of stem diseases.

In the conventional pruning method, the UPASI Tea Research Institute recommends pruning to a height of 60-65 cm, followed by tipping, with three tiers of leaves left above the pruned frames (Sharma, 1981b). Tea fields trained using these conventional pruning and tipping methods are generally suitable only for manual harvesting. When mechanical harvesting equipment is employed, the blades tend to damage the top harvesting surface (Ilango *et al.*, 2013). Therefore, by low a pruning at 45 cm followed by two-stage tipping at 55 cm and 65 cm the secondary and tertiary branches can be increased in number to modify the canopy architecture with compactness of the harvesting surface.

MATERIALS AND METHODS

The field study was conducted in both a clonal tea field (UPASI-9) and an old Assam seedling tea field. The experimental plots were located in Valparai, Coimbatore District, Tamil Nadu, situated at latitude 10°5.960'N and longitude 76°58.033'E, at an altitude of 1050 meters above mean sea level. The soil in the area is sandy loam with a pH of 5.0 and an organic matter content of 3%.

In the first experiment, the clonal tea (UPASI-9) was planted in 1994, following a double hedge spacing of 135 cm × 75 cm × 75 cm × 75 cm (walking distance × row-to-row distance × plant-to-plant distance), resulting in a plant population of 13,000 plants per hectare. In the second experiment, the old Assam seedling tea was planted in 1964, following a single hedge spacing of 120 cm × 120 cm (walking distance × plant-to-plant distance), with a plant population of 6600 plants per hectare. The tipping methods applied in the study were the two-stage tipping and conventional three-tier tipping. Both tipping methods were imposed in 2020 during the pruning season in both the clonal tea (UPASI-9) and the old Assam seedling tea.

In the two-stage tipping treatment, the tea was pruned in July 2020 at a height of 45 cm from the ground. Four months after pruning, the growing axillary buds were allowed to develop up to 55 cm, with six leaves and an apical bud. The first tipping was then carried out by nipping off the four leaves and the apical bud at 55 cm. The new shoots were allowed to grow for another 45 days before the second tipping, where the growing shoots were nipped off at 65 cm (Fig. 1). Between 45 cm and 65 cm, four tiers of leaves were added, and the harvesting surface was established at 65 cm from the ground.

In the conventional three-tier tipping treatment, the tea was pruned in July 2020 at 65 cm from the ground. Four months after pruning, axillary buds emerging from

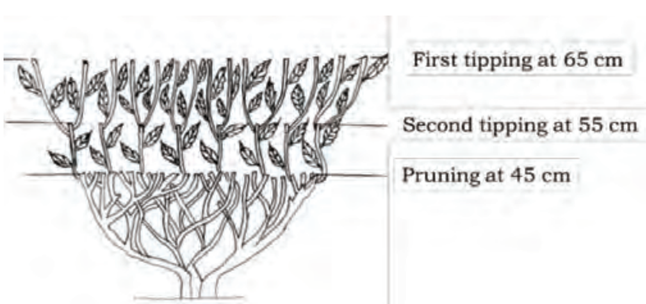

Fig. 1. Two stage tipping

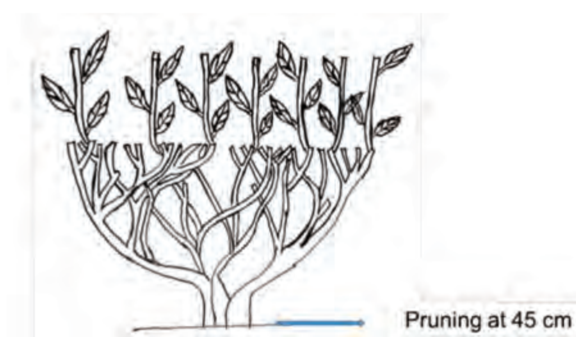

Fig. 2. Conventional three tier tipping

the pruned frames were allowed to grow into shoots with seven leaves and an apical bud. Three leaves (three tiers) were retained on the pruned frame, while the four leaves and the apical bud were nipped off. Between 45 cm and 65 cm, three tiers of leaves were added, and the harvesting surface was established at 65 cm from the ground (Fig. 2). Observations on the length and width of the tea canopy, as well as the number of branches at different heights from the ground, were monitored in 15 bushes in the experimental plots.

Four different harvesting methods were tested in both experiments. The first treatment involved six months of manual hand plucking (December to March and July to August) (Fig. 3) and six months of shear plucking (April to June and September to November). The second treatment consisted of three months of manual hand plucking (January to March) and nine months of shear plucking (April to December) (Fig. 4). The third treatment involved twelve months of shear plucking (January to December). The fourth treatment utilized twelve months of machine harvesting with the Ochiai two-man operated harvesters (January to December) (Fig. 5).

Manual harvesting allows for the selective plucking of young tea leaves and buds, resulting in higher-quality tea. It causes minimal damage to the tea plants and surrounding foliage, but it is labour-intensive and requires a large workforce, especially during peak seasons. This results in higher labour costs, as skilled labourers are necessary, and the method has limited capacity, making it challenging to meet high demand during peak periods. In contrast, mechanical harvesting is faster and more efficient, enabling larger areas to be covered in a shorter time. It is especially suited for large-scale tea plantations due to its higher capacity compared to manual harvesting. Additionally, mechanical harvesting reduces labour costs since fewer workers are required to operate the machines. However, improper maintenance or operation of the machinery can cause damage to the tea plants and surrounding foliage. Furthermore, mechanical harvesting is less selective than manual harvesting, which can lead to a reduction in tea quality.

Branching in a tea plant is characterized by woody stems that meet specific criteria: a minimum length of 10-25 cm (4-10 inches), a minimum thickness of 3-5 mm (1/8-1/4 inch) in diameter, and these branches arise from the main stem or trunk of the tea plant. The total number of primary, secondary, and tertiary branches per plant was counted. Additionally, the canopy area of each plant, measured in cm², was recorded by determining the length and width using a measuring


Fig. 3. Hand plucking


Fig. 4. Shear harvesting


Fig. 5. Two men operated harvesting machine

scale. To ensure consistency in branch counting, inter-observer reliability was assessed through repeated measurements by multiple trained observers. The canopy area was measured non-destructively by using a measuring tape to record the length and width of the canopy, and the area was calculated using the formula: Canopy area (cm²) = Length (cm) × Width (cm). This method provided a reliable estimate of the canopy area, allowing for comparisons between treatments. Canopy area measurements also accounted for gaps and irregularities within the canopy, which were assessed by tracing the outline of the canopy on grid paper and calculating the area of the traced outline (Murthy and Sharma, 1986).

Observations on the weight of green leaf harvested from each plot during each harvest were recorded over a period of four years (2019-2023), covering one pruning cycle. The yield of green leaves was converted into made tea (black tea) using a conversion factor of 23%, meaning that 100g of green leaves produced 23g of made tea. To account for variations in canopy shape and density, canopy area measurements were taken from multiple angles, including the four cardinal directions (north, south, east, and west) and two diagonal directions (northeast-southwest and northwest-southeast).

Four kilograms of harvested leaves from each treatment collected from the experimental plots were processed to produce one kilogram of dried black tea or made tea, following standard manufacturing practices (Roberts and Smith, 1963; Thanaraj and Seshadri, 1990; Ravichandran and Parthipan, 1998).

The experiment was conducted using a Randomized Block Design (RBD) to minimize the impact of external factors on the results. The tipping methods involved two treatments, each with 15 replications, while the harvesting methods involved four treatments, each with 5 replications. The data were analyzed using SPSS software (version 23), and the results were expressed as critical difference (CD), standard error (SEm±), and percentage of coefficient variation (CV %). Statistical analyses included one-way ANOVA, two-way ANOVA, two-sample t-test, analysis of covariance (ANCOVA), and linear regression analysis. Duncan's Multiple Range Test (DMRT) was used to compare groups for continuous variables, with a significance level of $P \leq 0.05$ considered statistically significant.

RESULTS AND DISCUSSION

Effect of tipping methods on canopy development

In the UPASI-9 clone, two-stage tipping performed at heights of 55 cm and 65 cm above ground resulted in a 1.5-fold increase in the total number of branches compared to the conventional three-tier tipping method. Consequently, the enhanced branch development following two-stage tipping led to a 1.6-fold increase in the canopy area of the tea bushes relative to the traditional three-tier tipping approach (Table 1).

Similarly, in the old Assam seedling tea bushes, the total number of branches increased by 1.4-fold following two-stage tipping at 55 cm and 65 cm, compared to conventional three-tier tipping (Table 2). This increase in branch number, facilitated by the two-stage tipping method, also resulted in a 1.3-fold increase in canopy area when compared to the conventional three-tier tipping (Table 2).

When comparing the response between clonal tea and old Assam seedling tea populations, the clonal tea plants showed a higher response to the two-stage tipping method in terms of new branch development (Tables 1 and 2). In contrast, the old Assam seedling tea plants, which have weaker branches and are susceptible to bole and branch canker (Chandra Mouli and Sharma, 1993), were less able to develop a greater number of new branches following two-stage tipping, as compared to the younger, more vigorous clonal tea plants.

Table 1. Canopy architecture after two-stage and conventional tipping at different heights in the clonal population

Method of tipping	Canopy area (cm^2)	Number of branches at different heights		
		55 cm	65 cm	Total
Two- stage tipping	11764.07^b (+61.9%)	101.4^b (+79.3%)	79.5^b (+51.7%)	180.9^b (+66.3%)
Conventional three- tier tipping	7279.73^a	80.4^a	41.1^a	121.5^a
SEm±	414.59	2.20	1.14	2.86
CD (*p=0.05*)	889.3	4.73	3.02	6.14
CV (%)	11.92	4.73	6.39	5.18

Figures in parentheses indicate (+) percentage increase in canopy area and number of branches in two-stage tipping compared to conventional three-tier tipping.
Within a column means followed by the same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

Table 2. Canopy architecture after two-stage tipping at 55 cm & 65 cm and after three-tier tipping (old Assam seedling)

Method of tipping	Canopy area (cm^2)	Number of branches at different heights		
		55 cm	65 cm	Total
Two-stage tipping	10495.3[b] (+82.6%)	104.7[b] (+85.8%)	78.5[b] (+56.8%)	183.2[b] (+73.3%)
Conventional three-tier tipping	8673.3[a]	89.9[a]	44.5[a]	134.4[a]
SEm±	140.9	3.2	1.4	3.70
CD (*p = 0.05*)	302.3	6.8	3.1	7.94
CV (%)	4.03	8.79	6.38	6.39

Figures in parentheses indicate (+) percentage increase in canopy area and number of branches in two-stage tipping compared to conventional three-tier tipping.
Within a column means followed by the same letter do not differ significantly at p=0.05 by Duncan's multiple range test.

Response of tea plants to different tipping methods

In the clonal tea population, productivity was significantly enhanced by the two-stage tipping method compared to the conventional three-tier tipping. The annual mean yield increase was 368 kg of made tea per hectare, demonstrating the superior effectiveness of the two-stage tipping technique (Table 3).

Similarly, in the old Assam seedling tea population, tea productivity was also significantly improved by the two-stage tipping method compared to the conventional three-tier tipping. The annual mean yield increase was 233 kg of made tea per hectare, highlighting the effectiveness of the two-stage tipping technique in enhancing productivity (Table 4).

Response of tea plants to different harvesting methods

In both the clonal tea and old Assam seedling tea populations, among the four different harvesting methods, regardless of the tipping methods, six months of manual hand plucking combined with six months of shear plucking (T_1) resulted in the highest yield. This was followed by three months of manual hand plucking and nine months of shear plucking (T_2), and twelve months of shear plucking (T_3). The lowest yield was observed with twelve months of machine harvesting (T_4). As the duration of shear harvesting increased from six months to nine months and then to twelve months, a decline in productivity was observed. In the clonal tea population, six months of manual hand plucking and six months of shear plucking (T_1) produced a yield that was 1.3 times higher compared to twelve months of shear plucking (Tables 3 and 4).

Similarly, in the old Assam seedling tea population, six months of manual hand plucking and six months of shear plucking also resulted in the highest yield, showing a 1.3-fold increase compared to twelve months of shear

Table 3. Response of clonal tea plants to different tipping methods

Harvesting methods	Tipping methods		
	Productivity (kg/made tea/ha)		
	Two-stage tipping	Conventional three-tier tipping	Mean
Treatment 1	4698.6[d] (+10.8%)	4193.0[d]	4445.8[d]
Treatment 2	3931.1[c] (+10.0%)	3537.1[c]	3734.1[c]
Treatment 3	3559.3[b] (+10.1%)	3200.2[b]	3379.8[b]
Treatment 4	3051.1[a] (+7.0%)	2837.2[a]	2944.1[a]
Mean	3810.0 (+ 9.5%)	3441.9	3625.9
SEm±	43.94	33.53	28.48
CD (*p = 0.05*)	95.74	73.06	62.05
CV (%)	2.29	1.54	1.24

Figures in parentheses indicate (+) percentage increase in canopy area and number of branches in two-stage tipping compared to conventional three-tier tipping.
Within a column means followed by the same letter do not differ significantly at *p=0.05* by Duncan's multiple range test.
Treatment 1: Six months of manual hand plucking and six months of shear plucking
Treatment 2: Three months of manual hand plucking and nine months of shear plucking
Treatment 3: Twelve months of shear plucking
Treatment 4: Twelve months of machine harvesting with two men operated harvesters

Table 4. Response of old Assam seedling tea plants to different tipping methods

Harvesting methods	Tipping methods		
	Productivity (kg/made tea/ha)		
	Two-stage tipping	Conventional three-tier tipping	Mean
Treatment 1	4046.5[d] (+ 9.2%)	3675.4[d]	3861.0[d]
Treatment 2	3510.9[c] (+ 7.7%)	3240.6[c]	3375.8[c]
Treatment 3	3020.5[b] (+5.9%)	2841.7[b]	2931.1[b]
Treatment 4	2418.3[a] (+ 4.7 %)	2304.3[a]	2361.3[a]
Mean	3249.0 (+ 6.9%)	3015.5	3132.3
SEm±	67.20	43.41	52.86
CD ($p = 0.05$)	146.42	94.58	115.18
CV (%)	3.27	2.28	2.67

Figures in parentheses indicate (+) percentage increase in canopy area and number of branches in two-stage tipping compared to conventional three-tier tipping.
Within a column means followed by the same letter do not differ significantly at $p=0.05$ by Duncan's multiple range test.
Treatment 1: Six months of manual hand plucking and six months of shear plucking
Treatment 2: Three months of manual hand plucking and nine months of shear plucking
Treatment 3: Twelve months of shear plucking
Treatment 4: Twelve months of machine harvesting with two men operated harvesters

plucking. Prolonging the duration of shear harvesting or using machine harvesting negatively impacted productivity, likely due to damage to the leaves in the tea canopy. As reported by previous studies, the blades used in shears and harvesting machines cause leaf damage, reducing leaf area and leading to significant crop loss (Sharma *et al.*, 1981a; Sharma *et al.*, 1981b; Satyanarayana and Sharma, 1985; Ilango *et al.*, 2013) (Tables 3 and 4).

Response of different ages of tea bushes to different tipping methods

Both in clonal tea (UPASI 9) and old Assam seedling tea, a higher yield was achieved in the first year following the implementation of the two different tipping methods (Tables 5, 6). However, as the age of the tea field progressed from the first to the fourth year, a declining trend in yield was observed in both clonal tea and old Assam seedling tea, regardless of the tipping methods (Tables 5,6). This decline in productivity can be attributed to repeated shear and machine harvesting over the four-year period, which negatively impacted the overall yield (Ilango *et al.*, 2013; Sharma *et al.*, 1981b; Sharma *et al.*, 1982; Satyanarayana *et al.*, 1991; Satyanarayana *et al.*, 1994).

Adopting low pruning at 45 cm, as opposed to the current practice of pruning at 65 cm, along with two-stage tipping at 55 cm and 65 cm instead of conventional three-tier tipping, promoted the growth of a greater number of new branches. This approach also resulted in a modified canopy architecture, characterized by increased compactness, which is better suited for mechanical harvesting in tea.

Statistical analysis of decline in productivity

To assess whether the decline in productivity over time is statistically significant, a linear regression analysis was performed using SPSS software (version 23). The results revealed a significant negative correlation between yield and the age of the tea field ($p < 0.05$). The R-squared value indicated that 75% of the variation in yield could be explained by the age of the tea field.

Comparison with conventional methods

The decline in productivity over time is a well-documented phenomenon in tea cultivation. However, the rate of decline observed in this study is slightly higher than what is typically reported for conventional methods. This may be attributed to the increased frequency of harvesting and the use of mechanical harvesting techniques, which can induce stress on the tea plants. The repetitive nature of these harvesting methods, particularly when combined with less optimal management practices, likely contributes to reduced plant vigour and, consequently, lower yields over time.

Interaction between tipping method and age

To analyze the interaction between tipping method and age, a two-way ANOVA was conducted. The results revealed a significant interaction between tipping method and age ($p < 0.01$). The interaction plot indicated that the decline in productivity over time was more pronounced under the two-stage tipping method compared to the conventional three-tier tipping method. These additional analyses offer a deeper insight into the relationship between the decline in productivity, tipping

Table 5. Response of different age of clonal tea plants to different tipping methods

Year from pruning	Tipping methods		
	Productivity (kg/made tea/ha)		
	Two-stage tipping	Conventional three-tier tipping	Mean
1st year	4784.1d (+ 14.6%)	4193.0c	4488.6d
2nd year	4008.9c (+ 9.3%)	3537.1b	3773.6c
3rd year	3333.8b (+ 7.1%)	3200.2b	3227.0b
4th year	3113.3a (+ 6.8%)	2837.2a	2975.3a
Mean	3810.0 (+9.5%)	3441.9	3625.9
SEm±	36.13	20.11	21.92
CD (*p=0.05*)	78.73	43.81	47.76
CV (%)	1.50	0.92	0.96

Figures in parentheses indicate (+) percentage increase in canopy area and number of branches in two-stage tipping compared to conventional three-tier tipping.
Within a column means followed by the same letter do not differ significantly at $p=0.05$ by Duncan's multiple range test.

Table 6. Effects on different age of old Assam seedling tea plants to different tipping methods

Year from pruning	Tipping methods		
	Productivity (kg/made tea/ha)		
	Two-stage tipping	Conventional three-tier tipping	Mean
1st year	4046.5d (+ 12.8%)	3675.4d	3861d
2nd year	3510.9c (+ 5.7%)	3240.6c	3375.8c
3rd year	3020.5b (+5.2%)	2841.7b	2931.1b
4th year	2418.3a (+ 4.4%)	2304.0a	2361.3a
Mean	3249.0 (+ 7.6%)	3015.5	3132.3
SEm±	46.98	49.58	33.12
CD (*p = 0.05*)	102.37	107.96	72.17
CV (%)	2.3	2.6	1.7

Figures in parentheses indicate (+) percentage increase in canopy area and number of branches in two-stage tipping compared to conventional three-tier tipping.
Within a column means followed by the same letter do not differ significantly at $p=0.05$ by Duncan's multiple range test.

method, and the age of the tea field, highlighting the compounded effects of both factors on yield over time.

Statistical comparison between clonal and seedling tea

To compare the productivity between clonal and seedling tea, a two-sample t-test was performed. The results demonstrated that the mean yield of clonal tea (3626 kg/ha) was significantly higher than that of seedling tea (3132 kg/ha) ($p<0.05$).

Accounting for age differences

We acknowledge that the age difference between the clonal tea (planted in 1994) and seedling tea (planted in 1964) populations may have influenced the results. To account for this, an analysis of covariance (ANCOVA) was performed with age as a covariate. The results indicated that the age of the tea plants had a significant effect on yield ($p < 0.01$). However, even after adjusting for age, the clonal tea still exhibited a significantly higher yield compared to the seedling tea ($p < 0.05$).

Discussion of genetic differences

The genetic differences between clonal and seedling tea populations may also influence their response to different treatments. Clonal tea is recognized for its uniformity and higher yield potential, whereas seedling tea tends to be more genetically diverse and may exhibit greater resilience to environmental stresses. The results of this study suggest that clonal tea may be more responsive to two-stage tipping and mechanical harvesting, possibly due to its genetic characteristics. However, further research is required to comprehensively understand the role of genetics in how tea plants respond to various cultivation practices, including their adaptability to different harvesting methods and tipping strategies.

Economic significance of improvements

The results demonstrate consistent improvements in both tea yield and quality with the two-stage tipping method. To assess the economic implications of these improvements, we estimated the potential increase in revenue for tea cultivators.

Assuming an average tea price of Rs. 110/kg, the annual mean yield increase of 368 kg/ha in clonal tea and 233 kg/ha in old Assam seedling tea translates to additional revenues of Rs. 40,480/ha and Rs. 25,630/ha, respectively. These estimates suggest that two-stage tipping can offer significant economic benefits for tea cultivators, enhancing both yield and profitability.

Cost-benefit analysis of additional labour

To assess the cost-effectiveness of two-stage tipping, a cost-benefit analysis was conducted considering the additional labour required. The additional labour for two-stage tipping was estimated at 15 man-days/ha, depending on the tea cultivar and farm size. Assuming an average labour cost of Rs. 450/day, the total additional labour cost for two-stage tipping would amount to Rs. 6,750/ha.

When compared to the estimated additional revenue of Rs. 40,480/ha for clonal tea and Rs. 25,630/ha for old Assam seedling tea, the cost-benefit analysis clearly indicates that two-stage tipping is a profitable investment for tea cultivators. The additional revenue generated significantly outweighs the labour costs, making it an economically beneficial practice.

Long-term sustainability of improvements

To assess the long-term sustainability of the improvements achieved through two-stage tipping, we analyzed data from a four-year study period (2020-2024). The results indicate that the improvements in tea yield were sustained throughout the four years, with no significant decline in yield or quality observed. However, to ensure the continued sustainability of these improvements, it is essential to implement integrated crop management practices, including regular pruning, fertilization, and pest management. By combining two-stage tipping with these best management practices, tea cultivators can maintain yield improvements over the long term while reducing the environmental impact of tea cultivation.

This study investigated the effects of two-stage tipping and different harvesting methods on tea yield and quality in both clonal and seedling tea populations. The results demonstrated that two-stage tipping significantly enhanced tea yield in both populations, with clonal tea showing a more pronounced response. Furthermore, manual hand plucking and shear plucking yielded higher productivity than machine harvesting. However, the study also observed a decline in productivity over time, possibly due to the increased frequency of harvesting and the use of mechanical harvesting methods. While the study highlights the potential of two-stage tipping and optimized harvesting methods to improve tea productivity and quality, further research is needed to fully understand the underlying causes of the observed decline in productivity and to develop strategies to mitigate this trend. Additionally, the genetic differences between clonal and seedling tea populations and their influence on responses to different treatments should be explored further. Overall, the findings of this study provide valuable insights for tea cultivators and researchers, offering strategies to improve both the productivity and sustainability of tea cultivation practices.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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