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CHEMICAL CONTROL OF MOSS AND EPIPHYTIC WEEDS ON PRUNED SEEDLING TEA PLANTS: EFFECTIVENESS, PHYTOTOXICITY, AND ECONOMIC ANALYSIS

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ABSTRACT

Moss and epiphytic weeds colonizing pruned tea (*Camellia sinensis*) stems impede shoot regeneration and increase production costs through labour-intensive manual removal. This study evaluated three chemical treatments, (A) herbicide ammonium glufosinate (5 ml/L) + sticker; (B) soda ash (30 kg/ha) + lime (40 kg/ha); and (C) fungicide (1 kg/ha), against (D) an untreated control, using a randomized complete block design with six replications across 24 plots (25 m² each) at Tea Plantation, West Java, from August to December 2025. Parameters assessed included moss and weed dry biomass, shoot count, shoot height, relative shoot elongation rate (RSER), phytotoxicity, and cost per hectare. All chemical treatments significantly reduced moss and weed biomass at 2–4 weeks after application (WAA), with biomass shrinkage of 66–71%. Efficacy declined by 8 WAA coinciding with increased rainfall (197.5 mm), confirming the transient nature of chemical suppression under humid highland conditions. Treatment B caused visible phytotoxicity, leaf blackening and white surface deposits, making it unsuitable for routine application. The untreated control produced the highest shoot count (236 shoots; significantly greater than treatments A and B), while absolute final shoot height at 112 DAA was numerically greatest in Treatment C (17.25 cm vs. 15.35 cm in the control), although the corresponding shoot height increment did not differ significantly among treatments (13.20–15.31 cm); Treatment B recorded the significantly highest RSER (0.033 day^{-1}) relative to the control (0.024 day^{-1}), though A and C were not significantly distinguishable from either. Economic analysis revealed fungicide as the most cost-efficient option at IDR 213,833/ha, compared to IDR 265,333/ha (A) and IDR 544,333/ha (B).

Key words: Epiphytic weed; Moss suppression; Phytotoxicity; Tea plantation management

INTRODUCTION

Pruning is one of the most critical management practices in tea (*Camellia sinensis* (L.) O. Kuntze) cultivation, aimed at maintaining the plucking table at an accessible height, stimulating the formation of new shoots, and renewing the productive canopy. In Indonesian highland tea estates, pruning cycles typically range from three to five years and are followed by a recuperation period during which the exposed woody framework is particularly susceptible to environmental stress and biological colonisation (Pusat Penelitian Teh dan Kina, 2006). Following pruning, the exposed woody stems and branches become susceptible to colonization by mosses (Bryophyta), liverworts (Marchantiophyta), and epiphytic ferns, most notably kadaka (*Asplenium nidus* L.) and picisan (*Pyrrosia piloselloides* (L.) M.G. Price). These epiphytes thrive under the cool, humid microclimate characteristic of highland tea estates in Indonesia, where relative humidity often exceeds 80% and temperatures range between 15–25°C, conditions that are suboptimal for rapid bark desiccation but highly favourable for bryophyte spore germination and gametophyte establishment *(*Glime, 2017; Proctor, 2009*)*.

The presence of moss and epiphytic growth on tea stems poses several agronomic concerns. Mosses retain moisture against the bark surface, creating conditions conducive to fungal pathogens such as *Exobasidium vexans* Massee, the causal agent of blister blight while simultaneously impeding gaseous exchange and reducing aerobic activity in the cambium. The excessive moisture retention and physical obstruction of buds can delay shoot emergence and suppress the elongation rate of nascent shoots, ultimately reducing crop yield in the plucking cycle following pruning.

Conventional control of moss and epiphytic weeds is performed manually, where workers use bamboo splints, ijuk (sugar palm fibre) brushes, or coconut husks to physically scrub the stems and branches. Although effective, this method demands a high labour input, typically one operator per 0.05–0.07 ha per day, translating into considerable labour costs that strain plantation profitability. In addition to efficiency constraints, manual scrubbing may cause mechanical wounds to the bark surface, potentially creating entry points for opportunistic pathogens and increasing the risk of secondary infection. As labour availability and wages continue to increase in Indonesian plantation agriculture, the economic imperative to identify efficient, mechanisable, or chemical-based alternatives has grown substantially.

Previous research by Ronoprawiro (1981) explored the potential of glyphosate for moss control in tea estates, demonstrating measurable suppression; however, phytotoxicity risks and evolving regulatory landscapes prompted the search for alternative active substances. In related plantation crops, herbicide-based approaches have been explored with varying degrees of success. In practice, alkaline lime treatments are already an established method for suppressing epiphytic growth on tea bushes, where 10% lime solution is sprayed onto pruned plants specifically to kill moss and lichen and promote even bud break, a use consistent with patented soda ash-lime formulations in which the alkaline mixture raises substrate pH and produces visible desiccation of moss and liverwort tissue within 48 hours of application (Glynson, *et al*., 2008).Glufosinate ammonium, a broad-spectrum contact herbicide acting through inhibition of glutamine synthetase and subsequent accumulation of phytotoxic ammonia, has been evaluated for use in plantation settings and demonstrated efficacy against non-vascular plants, including mosses, at sub-lethal doses relative to many vascular crops (Coetzer *et al*., 2002; Dayan *et al*., 2015).

Despite these individual lines of evidence, no published study has systematically compared the relative efficacy of glufosinate ammonium, alkaline salt mixtures, and fungicidal formulations specifically for the suppression of moss and epiphytic weed biomass on post-pruning tea stems. Furthermore, the phytotoxic potential of such treatments on *Camellia sinensis* shoot emergence and elongation during the post-pruning regeneration window, a period of heightened physiological vulnerability has not been rigorously characterised under Indonesian highland conditions. Prior work on moss suppression in tea (Ronoprawiro, 1981) was conducted with glyphosate, a compound now subject to increasingly stringent regulatory restrictions in Indonesian plantation agriculture, and did not include concurrent phytotoxicity assessment of shoot developmental parameters. The present study therefore addresses a critical applied research gap at the interface of weed science, crop physiology, and plantation management by providing, for the first time, a side-by-side evaluation of three chemically distinct treatment approaches under conditions representative of rancabolang highland tea estates, combining efficacy and safety assessment within a single experimental framework.

This study aimed to (1) determine the effectiveness of controlling moss and weeds on tea seedlings using herbicides, fungicides, and a mixture of soda ash and lime; (2) to analyze the effect of applying these chemicals on the growth of new shoots on tea plants after pruning; (3) to identify a solution for controlling moss and weeds that can replace manual methods (scrubbing moss) with the use of safe and productive chemicals in tea plantations.

MATERIALS AND METHODS

Study site

The experiment was conducted at Block 2.B RAB-2, Rancabolang Tea Plantation, Sugihmukti, Pasirjambu, Bandung Regency, West Java, Indonesia (-7.189964°S, 107.425416°E, altitude ≈ 1,886 m asl). The tea plants were of the seedling type (non-clonal), planted in 1945, and had been pruned one month prior to the application of treatments (July 2025). The site is surrounded by forest vegetation, creating a humid microclimate (RH > 80%) that is highly conducive to moss colonization.

Experimental design and treatments

A randomized complete block design (RCBD) with one factor (monofactorial) was employed, comprising four treatments replicated six times, for a total of 24 experimental plots. Each plot measured 5 × 5 m = 25 m², with a 2-m buffer strip between plots, yielding a total experimental area of approximately 600 m². Treatments were as follows:

Table 1. Experimental treatment design for chemical moss and weed control in pruned seedling tea plants, Rancabolang Tea Plantation, 2025.

Code	Treatment	Active Substance / Formulation	Dose
A	Herbicide + Sticker	Ammonium glufosinate + adjuvant sticker	5 ml L^{-1} herbicide + 2 ml L^{-1} sticker
B	Soda Ash + Lime	Na_2CO_3 (soda ash) + $CaCO_3$ (agricultural lime)	30 kg ha^{-1} + 40 kg ha^{-1}
C	Fungicide	Na_2O, MgO, S, Mn, Cu, Zn, Pb, Cd, As (micronutrient-based)	1 kg ha^{-1}
D	Control	Untreated	Untreated

Application protocol

All treatments were applied on 21 August 2025, one month after pruning, using a 15-litre manual knapsack sprayer calibrated to deliver a uniform spray volume. Chemical solutions were prepared according to recommended concentrations and applied directly onto the pruned tea bushes at field capacity. Soda ash and lime (Treatment B) were dissolved in water prior to application. A single application was made for all treatments throughout the study duration.

Shoot parameters such as shoot count and shoot height (cm) were recorded on ten representative shoots per plot at each observation. The relative shoot elongation rate (RSER) was calculated as: RSER = $(\ln H_2 - \ln H_1) / \Delta t$, where H_2 and H_1 are final and initial shoot height respectively, and Δt is the time interval in days. Moss and weed dry biomass was measured at 2, 4, and 8 WAA by collecting approximately 200 g of fresh biomass per plot, oven-drying at 80°C for 48 hours until constant weight, and recording dry weight (g/m^2). Percentage biomass shrinkage was calculated relative to the initial fresh weight basis.

Economic analysis

Cost analysis was based on actual field labour data (IDR 46,000/person-day; 14 person-days/cycle; 0.42 ha/person/day realised capacity) and current market prices for chemical inputs. Total cost per hectare (IDR/ha) was computed as the sum of chemical material costs and labour costs for each treatment group.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and mean separation was performed using Duncan's Multiple Range Test (DMRT) at $\alpha = 0.05$, using statistical software.

RESULTS AND DISCUSSION

Phytotoxicity observations (3 DAA)

Visual assessment conducted three days after application revealed distinct differential responses among treatments. Treatment B (soda ash + lime) caused the most severe phytotoxic symptoms, characterised by leaf blackening resembling scorch injury, deposition of a white powdery layer on leaf surfaces, and rapid yellowing and desiccation of moss and weed tissues, with some species exhibiting necrotic blackening (Figure 1). These symptoms are consistent with strong alkalinity-induced cellular damage from the elevated pH generated by the calcium-sodium carbonate-lime mixture applied at high concentrations.

Figure 1. Phytotoxicity of Soda Ash + Lime (Treatment B)

Figure 2. Phytotoxicity Observations 3 Days After Application

Treatment A (herbicide + sticker) induced wilting and yellowing in moss and weed tissues within the same timeframe, consistent with the mechanism of ammonium glufosinate—inhibition of glutamine synthetase, leading to ammonia accumulation and chloroplast disruption. Treatment C (fungicide) showed comparatively delayed visible response; kadaka and other mosses did not exhibit wilting or yellowing at 3 DAA, suggesting a slower mode of action via the micronutrient-mediated disruption of fungal and bryophyte metabolism. The untreated control (D) maintained vigorous moss and weed growth with no phytotoxic manifestations.

Observation of shoot parameters

Table 3. Summary of shoot parameters across treatments, 84-day observation period (28–112 DAA).

Parameter	Treatment				Verdict
	A	B	C	D	
Total shoot addition	78^{b}	88^{b}	101^{ab}	137^{a}	D significantly > A, B; C not distinguishable from either group
Dead shoots at end	18.00^{a}	18.61^{a}	21.67^{a}	34.11^{a}	No significant difference anywhere
Shoot height increment (cm)	13.48^{a}	14.66^{a}	15.31^{a}	13.20^{a}	No significant difference anywhere
RSER (day^{-1})	0.030^{ab}	0.033^{a}	0.027^{ab}	0.024^{b}	Only B sig. > D; A and C not distinguishable from either

Values followed by the same letter within a parameter are not significantly different (DMRT, α = 0.05).

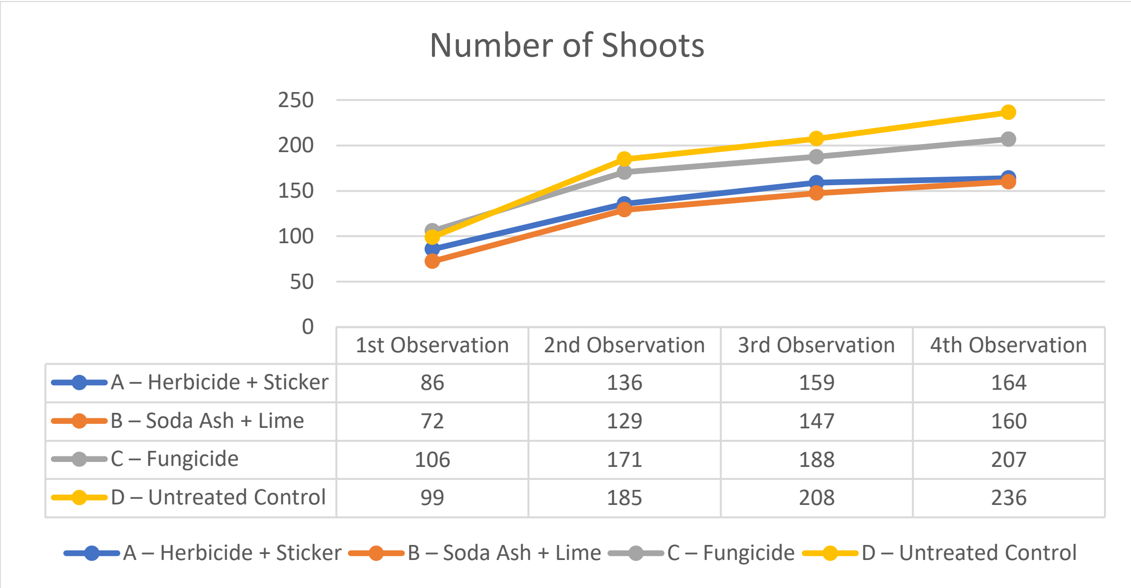

Figure 2. Graph of the Number of Shoots at Each Observation

The untreated control (D) produced the highest cumulative shoot count throughout all four observation periods, reaching 236 shoots at 112 DAA, significantly greater than treatments A and B (DMRT, α = 0.05); Treatment C (207 shoots) was not significantly different from either the control or the other chemical treatments. This result may appear counterintuitive given the expectation that moss removal would favour shoot development. One plausible explanation is a compensatory growth response: plants subjected to persistent mild biotic stress, such as moss colonisation on stems, may initiate a greater number of lateral buds to maintain canopy area and photosynthetic capacity, while the physiological stress of chemical exposure may temporarily suppress meristematic activity and bud initiation in treated plots. This interpretation is consistent with general compensatory-growth responses reported under sub-lethal stress in woody perennials, though it was not directly tested in the present study and warrants confirmation through dedicated meristem-activity or hormonal assays in future work.

The number of dead shoots recorded at the end of the observation period was numerically highest in the untreated control (34.11) compared with the chemically treated plots (18.00–21.67; Table 3), which may suggest a protective effect of moss and weed suppression on shoot survival. However, this difference was not statistically significant (DMRT, α = 0.05; all treatments sharing letter "a"), and should therefore be interpreted as a numerical trend rather than evidence of a true treatment effect. A larger sample size or extended replication may be needed to determine whether this trend reflects a genuine biological effect of epiphyte load on shoot mortality.

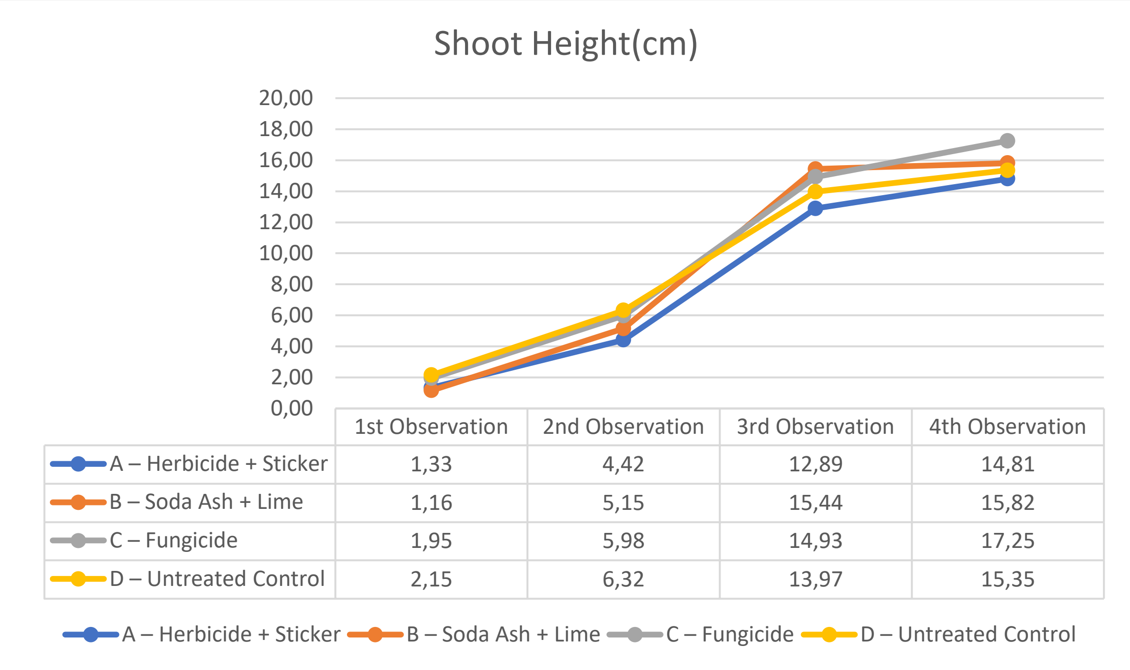

Figure 3. Graph of Shoot Height at Each Observation

Shoot height increment over the 84-day observation period, as summarised in Table 3, did not differ significantly among treatments (DMRT, $\alpha = 0.05$; range 13.20–15.31 cm). It should be noted that this increment metric is distinct from the absolute cumulative shoot height recorded at the final (4th) observation shown in Figure 3, where Treatment C reached 17.25 cm and the untreated control reached 15.35 cm; readers should take care not to conflate the two metrics, and a brief clarifying note distinguishing "increment" (Table 3) from "absolute final height" (Figure 3) is recommended in the Methods or table/figure captions to avoid this ambiguity. Numerically, the chemically treated plots, particularly B (14.66 cm increment) and C (15.31 cm increment), trended higher than the untreated control (13.20 cm increment), consistent with the same ranking visible in the absolute final-height series. If this numerical trend is considered alongside the absolute height data, it would be broadly consistent with findings by Ronoprawiro (1981), who reported that the measurable benefit of moss control on shoot elongation manifests 3–4 months post-treatment, when cambium activity differences become apparent; a plausible mechanism is improved stem microclimate, whereby removal of moss reduces excessive moisture retention, improves aeration, and decreases the risk of pathogenic colonisation at the bark surface, potentially enabling more efficient translocation of photosynthates to elongating shoots. This mechanistic interpretation remains speculative, however, given the absence of a statistically significant treatment effect on the increment parameter as analysed.

The relative shoot elongation rate (RSER) was significantly highest in Treatment B (0.033 day^{-1}) relative to the untreated control (0.024 day^{-1}) (DMRT, $\alpha = 0.05$). Treatments A (0.030

day^{-1}) and C (0.027 day^{-1}) were intermediate and not significantly distinguishable from either Treatment B or the control. Despite producing the highest absolute shoot count, the control's lower RSER may reflect the fact that initial shoot heights were already comparatively larger, reducing the proportional rate of growth. The elevated RSER in Treatment B is consistent with a possible post-stress compensatory elongation response following initial chemical exposure and reduced moss competition, though this interpretation should be treated as tentative given that it co-occurs with the most severe phytotoxic symptoms observed in this trial (see Phytotoxicity section above), and warrants further investigation before being interpreted as a genuinely beneficial effect.

Moss and weed biomass

Table 4. Mean dry biomass (g/m²) and percentage biomass shrinkage of moss and weeds at 2, 4, and 8 weeks after application (WAA), with corresponding rainfall (mm).

Treatment	2 WAA (g/m²)	4 WAA (g/m²)	8 WAA (g/m²)	2 WAA % Shrink	4 WAA % Shrink	8 WAA % Shrink	Rainfall (mm)
A – Herbicide + Sticker	133.83	61.67	97.00	70.73%	30.83%	48.50%	115 / 93 / 197.5
B – Soda Ash + Lime	120.33	65.33	97.50	71.34%	32.67%	48.75%	—
C – Fungicide	118.50	66.17	101.50	66.91%	33.08%	50.75%	—
D – Untreated Control	118.50	73.17	98.33	71.39%	36.58%	49.17%	—

WAA = Weeks After Application.

All chemical treatments reduced moss and weed dry biomass relative to initial values, with the most pronounced suppression observed at 4 WAA across treatments A, B, and C—achieving dry weights of 61.67, 65.33, and 66.17 g/m² respectively, versus 73.17 g/m² for the control. The highest percentage biomass shrinkage at 2 WAA was recorded in the control (71.39%), which is attributable to natural desiccation following pruning rather than chemical action, underscoring the importance of contextualising chemical efficacy against environmental background effects.

The sharp increase in biomass at 8 WAA across all treatments coincided with a marked rise in rainfall (197.5 mm), consistent with the role of precipitation in: (i) physically leaching active substances from plant surfaces; (ii) restoring soil and surface moisture levels; and (iii) triggering the resumption of spore germination and vegetative growth in mosses and liverworts. These dynamics confirm that chemical control efficacy under tropical highland conditions is inherently transient and heavily mediated by climatic factors, particularly rainfall intensity and frequency. Liu *et al.* (2022) similarly reported that sub-optimal abiotic conditions including elevated humidity can override the physiological suppression induced by chemical treatments, redirecting plant and epiphyte metabolic activity toward growth.

To achieve more optimal outcomes, re-application of the active compounds is recommended provided that no shoot emergence is observed within a 8–12 weeks after application. This interval-based approach is considered sufficiently safe for the tea plant, as it allows adequate physiological recovery between applications while minimizing the accumulation of active ingredient residues in plant tissues and the surrounding environment.

Economic analysis of control options

Table 5. Economic cost analysis per treatment group (IDR/ha)

Treatment Group	Chemical Cost (IDR/ha)	Labour Cost (IDR/ha)	Total Cost (IDR/ha)
A – Herbicide + Sticker	IDR 158,000	IDR 107,333	**IDR 265,333**
B – Soda Ash + Lime	IDR 437,000	IDR 107,333	**IDR 544,333**
C – Fungicide	IDR 106,500	IDR 107,333	**IDR 213,833**

Labour cost based on 14 person-days × IDR 46,000/day ÷ 6 ha/day realised capacity. Exchange rate reference: IDR 15,500/USD (December 2025).

Fungicide Treatment C represents the most cost-competitive option at IDR 213,833/ha (≈ USD 13.8/ha), combining the lowest chemical material cost with acceptable shoot performance and moderate moss suppression. Soda ash + lime (B), despite its strong initial efficacy, carries the highest total cost (IDR 544,333/ha ≈ USD 35.1/ha) and poses unacceptable phytotoxicity risks under standard application conditions, making it unsuitable as a routine management tool without significant dose adjustment and application refinement. Herbicide treatment A (IDR 265,333/ha ≈ USD 17.1/ha) occupies an intermediate position; as a contact herbicide, ammonium glufosinate produced visible wilting and yellowing of plant tissue at 3 DAA, and numerically lower shoot height increment and RSER than Treatment C, suggesting a greater short-term physiological cost to shoot regeneration despite its lower price than Treatment B.

Compared with the manual, scrubbing moss method which requires an estimated 20–25 person-days/ha at the same wage rate, in total IDR 920,000–1,150,000/ha, all three chemical options represent substantial cost savings of 53–81%, constituting a compelling economic argument for the adoption of chemical control strategies, provided phytotoxic risks are properly managed.

CONCLUSION

This study demonstrates that chemical control of moss and epiphytic weeds in post-pruning seedling tea represents an effective and economically viable alternative to the conventional manual scrubbing method. Key findings are summarised as follows:

- All three chemical treatments (herbicide + sticker, soda ash + lime, and fungicide) significantly suppressed moss and weed biomass at 2–4 WAA, with percentage biomass shrinkage of 66–71%.
- Efficacy declined by 8 WAA under high-rainfall conditions (197.5 mm), indicating that treatment durability is strongly dependent on microclimate and requires monitoring and re-application strategies.
- Soda ash + lime caused severe phytotoxicity (leaf blackening, surface deposits) and is not recommended for routine application without dose adjustment and timing modification.
- Fungicide (Treatment C) is the preferred option: lowest total cost (IDR 213,833/ha), acceptable shoot safety, the greatest absolute final shoot height at 112 DAA (17.25 cm; Figure 3), and potential dual-utility as a blister blight management tool, although its shoot height increment was not statistically distinguishable from other treatments (Table 3).
- The untreated control produced the significantly highest shoot count, possibly reflecting a compensatory growth response under mild biotic stress, though this mechanism was not directly tested; shoot height increment did not differ significantly

across treatments, while Treatment B alone showed a significantly higher relative elongation rate than the control.

- An integrated management approach combining selective chemical application, shade regulation, microclimate improvement, and extended monitoring to 3–4 months post-application is recommended for sustainable moss and weed control in highland tea estates.

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