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Does Black Tea Residue Mulch Improve Growth in Household Potted Plants? — A study on Epipremnum Hureum, Mentha Haplocalyx, and Allium Fistulosum

Xueyou Yang

Affiliation: International Department, The Affiliated High School of South China Normal University (HFI)
City: Guangzhou, Guangdong
Postal Code: 510630
Email Address: avena666@163.com

Abstract:

This study investigated whether pretreated black tea residue mulch (2.0±0.1 cm) promotes the height and stem diameter of three common household potted plants: Epipremnum aureum (pothos), Mentha haplocalyx (mint), and Allium fistulosum (green onion). A 6-week controlled experiment was conducted with 90 seedlings (30 per species), split into control (no mulch) and treatment (tea residue mulch) groups under consistent environmental conditions (23±2 °C, 50±10% humidity). Weekly measurements of height, stem diameter, soil pH, and moisture were recorded, with two-way ANOVA and curvilinear regression used for statistical analysis. Results confirmed significant growth promotion ($p<0.05$) from tea residue mulch for all species: mint showed the largest height increase, green onion a late-stage growth amplification, and pothos an early, stable response. Mechanistically, mulch enhanced growth via gradual nutrient release, soil moisture retention, and improved soil microenvironment. This research validates black tea residue as an effective, sustainable organic mulch for home gardening, linking kitchen waste reuse to enhanced potted plant growth, and provides species-specific practical recommendations for gardeners.

Keywords: Black tea residue mulch; potted plant growth; sustainable waste reuse; organic mulch; plant physiology

1. Introduction

The growing concern for sustainable waste management and environmentally friendly gardening has increased interest in reusing organic waste for plant cultivation. In China, annual household food waste exceeds 242 million tons (Huang & Yang, 2022). Tea residue accounts for about 3% of this amount, which equals more than 7.2 million tons each year (2025 Report on Technological Breakthroughs and

Environmental Benefit Calculation of Tea Residue Recycling, 2025). Tea residue is far from being useless waste. The material contains several nutrients important for plant growth, including approximately 4.11% nitrogen and 50.2% carbon. Tea residue also meets heavy metal safety standards. For example, cadmium levels remain below 0.12 mg/kg, which indicates that the material is safe for plant cultivation (Lu et al., 2016). However, most tea residue in China is still disposed of through landfilling. This practice wastes valuable nutrients and also releases methane, a powerful greenhouse gas that contributes to climate change (2025 Report on Technological Breakthroughs and Environmental Benefit Calculation of Tea Residue Recycling, 2025). Among different types of tea, black tea is one of the most commonly consumed in households (Xu et al., 2022). Previous studies suggest that black tea waste may support plant growth because of its nutrient content and physical characteristics (Miao, 2022). However, most existing studies focus on field crops or large-scale agricultural systems (Joes, 2025). For example, some studies examine black tea waste as part of cultivation substrates for crops such as barley (Ghani, 2012). Other studies investigate its role in soil stabilization and soil improvement (Harish & Mahapatra, 2020). Few studies examine the use of black tea residue as mulch for common household potted plants such as Epipremnum aureum (pothos), Mentha haplocalyx (mint), and Allium fistulosum (green onion). The aim of this study is to investigate whether standardized pretreated black tea residue mulch can significantly promote plant height and stem diameter in these three species. First, relevant literature is reviewed to summarize knowledge about the nutrients in black tea residue, the mechanisms through which organic mulch affects plant growth, and the growth characteristics of the selected plants. Next, a controlled experiment compares plant growth between mulched and non-mulched conditions. Two-way ANOVA is then used to test whether significant differences exist in growth indicators among the plant species. The study also discusses the biological mechanisms behind the observed results and provides practical recommendations for home gardeners who want to adopt sustainable plant care practices.

2. Literature Review

2.1 Tea Waste Generation and Nutritional Value

Tea is one of the most widely consumed non-alcoholic beverages globally, and its production and consumption continue to rise steadily (Xu et al., 2022). A large amount of tea residue is generated during processing (such as tea beverage production) and daily brewing. It is estimated that approximately 90% of tea leaves become residue after these processes (2025 Report on Technological Breakthroughs and Environmental Benefit Calculation of Tea Residue Recycling, 2025). For example, Chinese companies that produce only tea beverages generate 180,000 to 200,000 tons of tea residue each year. When not properly reused, these residues become waste that puts pressure on the environment. However, tea residue still retains much of the nutritional value of the original tea leaves. Therefore, many researchers consider tea residue a potential resource for plant cultivation (Miao et al., 2022).

2.2 Composition and Reuse Value of Black Tea Residue

Black tea residue is a byproduct of black tea processing and daily brewing. The material mainly comes from household brewing and industrial production, such as the manufacturing of black tea beverages or instant tea products. Because tea drinking is a common behavior in many households, black tea residue is widely available and easy to collect in large quantities. Black tea residue contains a variety of substances that are beneficial for plant growth. Zheng et al. (2019) found that black tea residue retains over 60% of the bioactive components from raw black tea, including 4.2%-10.1% tea polyphenols and 1.1%-1.4% free amino acids. It is also rich in crude protein (26.0%-35.0%) and crude fiber (13.0%-19.0%). From a nutrient perspective, black tea residue contains 4.11% nitrogen and 50.2% carbon (Lu et al., 2016), as well as minerals like potassium, phosphorus, and magnesium (Miao et al., 2022). These components are all closely related to plant growth and soil health, and they have clear relevance to plant growth (Ghani, 2012). Nitrogen is essential for chlorophyll synthesis and vegetative growth, which directly affect plant height and stem thickness (IERE Team, 2025). Carbon supports soil microorganisms and promotes microbial activity (Liang et al., 2017). Tea polyphenols also have antioxidant properties that help plants tolerate environmental stress (Yan, 2020). Amino acids act as building blocks for plant proteins (Kawade, 2023). Crude fiber can improve soil structure by increasing aeration and water retention, which creates a better root environment for potted plants (Live to Plant, 2025). Minerals such as potassium and phosphorus support root development, flowering, and overall plant growth (Bhat et al., 2024). Because of these characteristics, black tea residue has potential as an organic mulch material for potted plant cultivation.

2.3 Mechanisms of Organic Mulch in Plant Cultivation

Organic mulch influences plant growth mainly by regu-

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lating soil conditions and the surrounding microenvironment. Four main mechanisms explain these effects. Firstly, organic mulch covers the soil surface to reduce water evaporation from the soil. This is especially important for potted plants because they have limited soil volume and are easy to dry out. By retaining moisture, mulch ensures that plants have a stable water supply, avoid drought stress, and promote consistent growth (Joes, 2025). Secondly, organic materials like tea residue have good thermal insulation properties (Crespo-López, 2024; Horma et al., 2022). In hot weather, mulch blocks direct sunlight to lower the soil temperature and prevent root heat damage. In cold conditions, it acts as an insulator, reducing heat loss from the soil and protecting roots from low-temperature stress. This temperature stability creates an optimal root environment for plant growth (Gamage, 2025). Thirdly, as organic mulch decomposes, it releases nutrients into the soil and increases soil organic matter content. Organic matter improves soil structure by loosening compacted soil, enhancing aeration and water infiltration, which are extremely helpful to potted plants grown in limited soil spaces. Decomposition also promotes the growth of beneficial soil microorganisms, which help break down nutrients into forms that plants can easily absorb (Zheng et al., 2019). Lastly, organic mulch forms a physical barrier on the soil surface and blocks sunlight from reaching weed seeds. Without sunlight, most weed seeds cannot germinate or grow, so competition for nutrients and water between weeds and target plants becomes less and less. This is especially useful for potted plants, as weeds in small pots can quickly outcompete the main plant for limited resources.

2.4 Research Progress and Limitations of Existing Studies

Most research on tea waste focuses on field crops or large-scale agricultural systems. For example, Ghani et al. (2012) examined the effects of black tea waste on potted barley and found that the material improved soil properties such as bulk density and porosity. Tarashkar et al. (2023) studied tea waste compost as a substrate component for radish cultivation and reported positive effects on taproot growth. Another study by Morikawa and Saigusa (2008) investigated the use of tea waste to adjust the pH of alkaline soils in agricultural fields. These studies show that tea waste can benefit plant growth. However, most studies focus on field crops rather than household potted plants. In addition, many studies use tea waste as a soil additive instead of a mulch material. A small number of studies explore organic mulch for potted plants, but very few involve black tea residue. Joes (2025) mentioned that tea leaves can be used as a natural fertilizer for potted plants, but their research focused on direct soil mixing rather than mulching. Other studies tested traditional mulch materials like wood chips or straw for potted plants and showed that mulch improves moisture retention and growth. For example, a study on potted herbs found that straw mulch reduced watering frequency and promoted plant height (Liang et al., 2025). However, these studies did not investigate black tea residue, which is often more accessible for household use.

2.5 Summary and Research Gap

Existing research confirms that tea residue contains rich nutrients beneficial for plant growth and soil health. Organic mulch also supports plant cultivation through several well-known mechanisms, including moisture retention, temperature regulation, soil improvement, and weed suppression. However, a clear research gap remains. Few studies have examined black tea residue as a mulch for common household potted plants. Most research focuses on field crops or uses tea waste as a substrate component, while mulch research for potted plants relies on non-household materials. This research aims to contribute to filling this gap by testing standardized pretreated black tea residue mulch on three popular household potted plants. The findings aim to provide practical and evidence-based guidance for home gardeners who want to reuse kitchen waste while improving the growth of potted plants.

3. Methodology

This study uses both secondary research and primary experimental research to address the research question. Secondary research provides theoretical support by summarizing existing studies on the use of tea residue and the effects of organic mulch. The primary research uses a controlled experiment to collect data on how black tea residue mulch influences the growth of potted plants.

3.1 Secondary Research

Secondary research builds the theoretical foundation of this study. The research collects information from reliable academic databases, national standards, and trusted gardening guides. The selected sources include peer-reviewed journal articles and recent studies related to tea residue and organic mulch in plant cultivation. Recent publications are prioritized because they reflect current knowledge about sustainable gardening and waste reuse. The study excludes non-peer-reviewed materials, unrelated topics, and studies with unclear methods. The collected literature supports the experimental design and explains how tea residue may provide nutrients for plant growth. The literature also helps place the results of this study within the context of existing research.

3.2 Primary Research

3.2.1 Aim and Research Question

The primary aim of this experiment is to examine how a 2 cm layer of standardized pretreated black tea residue mulch affects plant growth. The experiment focuses on three common household potted plants: Epipremnum aureum (pothos), Mentha haplocalyx (mint), and Allium fistulosum (green onion). The research question is: Does a 2 cm layer of standardized pretreated black tea residue mulch significantly promote plant height and stem diameter of these three potted plants?

3.2.2 Variables

The independent variable is the application of black tea residue mulch. Two experimental groups are established: the treatment group receives a 2cm layer of standardized tea residue mulch, while the control group does not receive mulch. The dependent variables are plant height and stem diameter. These indicators represent overall plant growth, and the experiment measures these indicators regularly over a six-week period. Supporting measurements include soil pH and soil moisture. The experiment also records mulch conditions such as mold coverage, odor, and thickness change. These additional observations prove the consistent environmental and soil condition control, and help explain the possible environmental changes during the experiment.

3.2.3 Materials and Equipment

Standardized nutrient soil (Qingdao Woan Ecological Agriculture Co., Ltd., 2020) was bought online and used. Plant materials included 90 seedlings, with 30 individuals for each species, and 15 additional reserve seedlings (five for each species) were obtained from a local agricultural supplier. A total of 105 plastic pots were prepared for the experiment. Each pot contained nutrient soil, clay pebbles, and meshes for drainage. A 5% sodium hypochlorite solution was used for pot disinfection. The black tea residue used as mulch was collected from household tea brewing. The experiment used several measuring instruments to record plant growth and soil conditions. These instruments included calipers (an ordinary one and a digital one, both with a precision of ±0.01 mm), a ruler, a soil pH meter (±0.1), and a soil moisture meter (±1%). Additional equipment included a 6 mm stainless steel sieve and an electronic hygrothermograph. Microsoft Excel was used to record and organize all experimental data.

3.2.4 Experimental Procedures (Full version is in the Appendix.)

The experiment lasted for six weeks. The preparation stage began with the collection of black tea residue from household use. The residue was rinsed, dried, and then sieved to obtain a uniform particle size (≤6 mm). This step also helped standardize the moisture content of the mulch material. Plastic pots were disinfected before use. All pots followed the same internal structure. A drainage mesh was first placed at the bottom of the pot, followed by a layer of small clay pebbles. Another mesh layer separated the drainage layer from the soil. Each pot was then filled with 500 g of standardized nutrient soil. Pots randomly assigned to the treatment group received an additional 2 cm layer of pretreated black tea residue on the soil surface. Before the experiment began, all seedlings were acclimated for one week. Only healthy seedlings with similar size and growth conditions were selected and transplanted into the prepared pots. The seedlings were randomly divided into two groups. The treatment group received a 2.0 ± 0.1 cm layer of pretreated tea residue mulch, while the control group received no mulch. All plants grew under the same environmental conditions. The temperature was maintained at 23 ± 2 °C, and relative humidity remained at 50 ± 10%. Regular watering kept soil moisture within an appropriate range. Plant height, stem diameter, soil pH, and soil moisture were measured weekly using calipers, a pH meter, and a moisture meter. Mulch conditions, including odor and thickness, were also recorded once per week through observation and smelling during the six-week study period.

3.2.5 Data Analysis

The main indicators included plant height and stem diameter; minor measurements are soil pH, soil moisture, and mulch characteristics (odor and thickness). Net growth and growth rate were calculated from initial and final measurements. Two-way ANOVA in SPSSAU, an online data processing and analysis tool, was used to determine significant differences in endpoint indicators and growth rates among different plant species under mulched and non-mulched conditions; relevant patterns were presented using line graphs and bar charts.

4. Results

Two-way ANOVA was used to analyze the effects of tea residue mulch (Cover: 0 = without tea residue mulch, 1 = with tea residue mulch) and cultivation duration (0–6 weeks) on the height and stem diameter of three plant species (green onion, mint, pothos). The significance level was set at $p < 0.05$.

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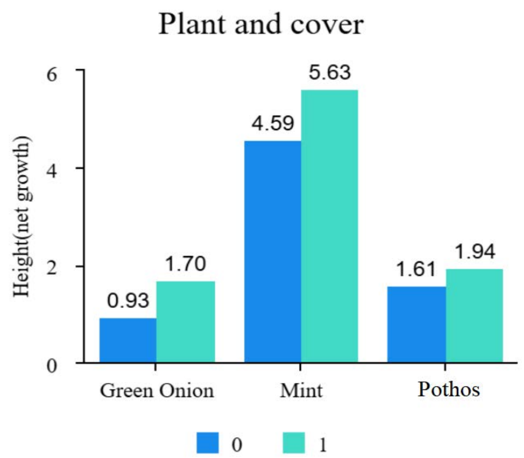
4.1 Overall Effect of Tea Residue Mulch on Net Growth

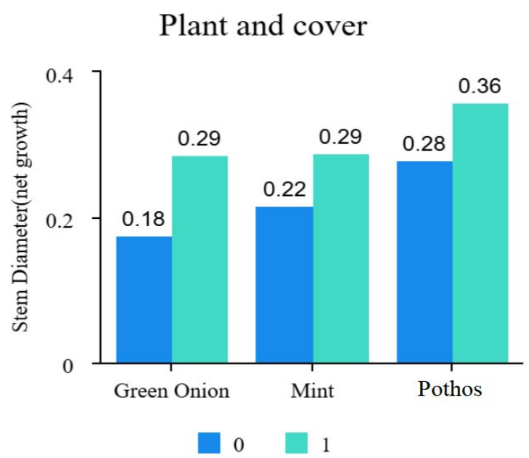
Mean comparisons (mean ± SD) showed that tea residue mulch significantly increased net growth for all three species in both indicators. Two-way ANOVA results for overall net growth are presented in Table 1.

Table 1. Two-way ANOVA endpoint analysis of plant height and stem diameter.

	Two-way ANOVA					
	Source	Sum of Squares	df	Mean Square	F	p Value
Height	duration	258.066	2	129.033	142.589	0.000
	Cover	11.449	1	11.449	12.652	0.001
Stem Diameter	duration	0.124	2	0.062	20.603	0.000
	Cover	0.175	1	0.175	58.015	0.000



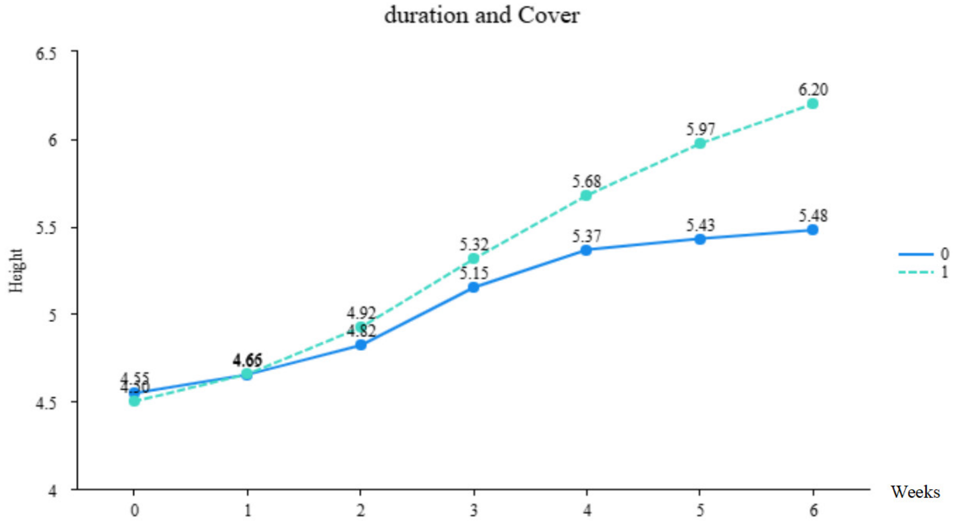
Graph 1. Comparison of mean net height growth with and without tea residue mulch on three plant species.



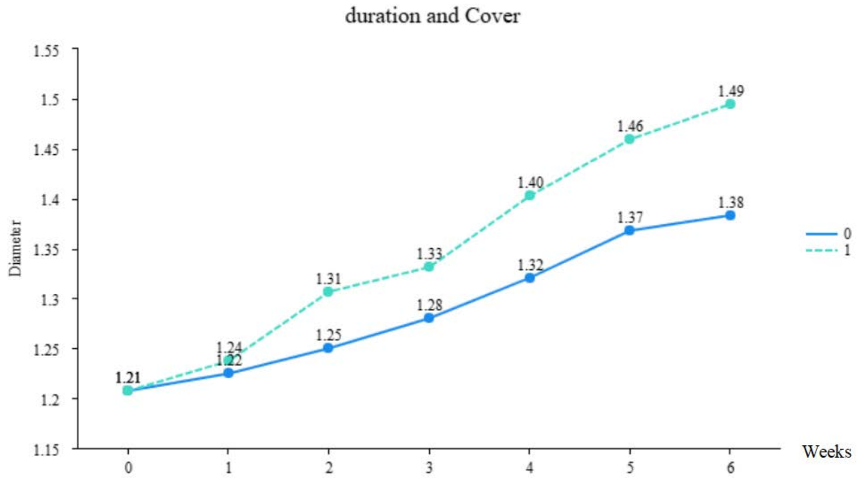
Graph 2. Comparison of mean net stem diameter growth with and without tea residue mulch on three plant species.

For net height growth (Graph 1), the mulch group outperformed the control group across all species. For net stem diameter growth (Graph 2), the promoting effect of mulch was similarly consistent. Overall, mint exhibited the largest absolute increase in net height growth with mulch, while pothos had the highest net stem diameter growth in the mulch group among the three species.

4.2 Green Onion's Height and Stem Diameter Responses



Graph 3. Growth pattern of green onion height (cm) with and without tea residue mulch over 6 weeks.



Graph 4. Growth pattern of green onion stem diameter (mm) with and without tea residue mulch over 6 weeks.

Table 2. Two-way ANOVA analysis: effects of duration and tea residue mulch (cover) on green onion height and stem diameter respectively.

	Two-way ANOVA					
	Source	Sum of Squares	df	Mean Square	F	p Value
Height	duration	48.886	6	8.148	237.696	0.000
	Cover	3.477	1	3.477	101.423	0.000
Stem Diameter	duration	1.417	6	0.236	124.679	0.000
	Cover	0.176	1	0.176	92.947	0.000

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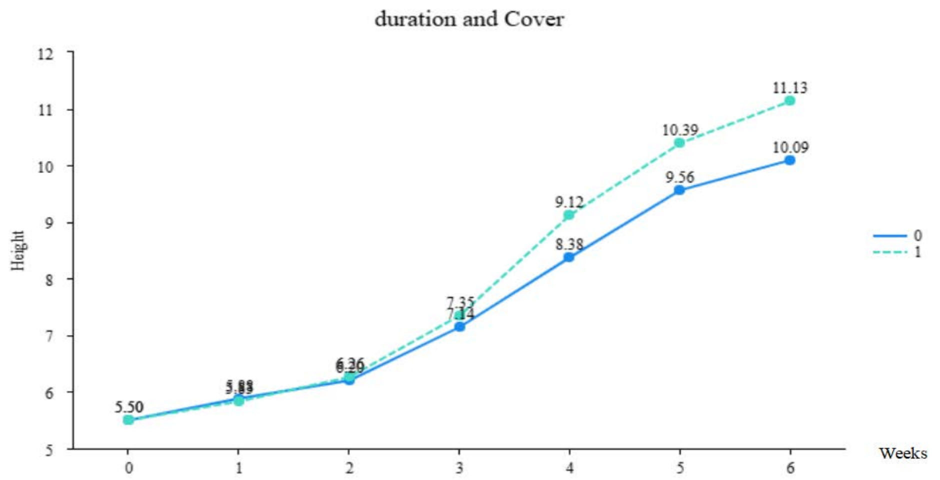
Two-way ANOVA analyzed the effects of duration and cover on 30 sets of green onions' growth (Table 2). For both indicators, duration and mulch had significant effects. The trend plot shows steady growth in both indicators over time (Graph 3, Graph 4). Two groups had almost identical initial values; differences began to appear as the plants continued to grow, which became larger in the later weeks as the mulch group pulled ahead gradually. By week 6, mulch significantly enhanced both indicators compared to the control.

Table 3. Curvilinear Regression: effects of duration and tea residue mulch (cover) on green onion growth pattern in terms of height and stem diameter.

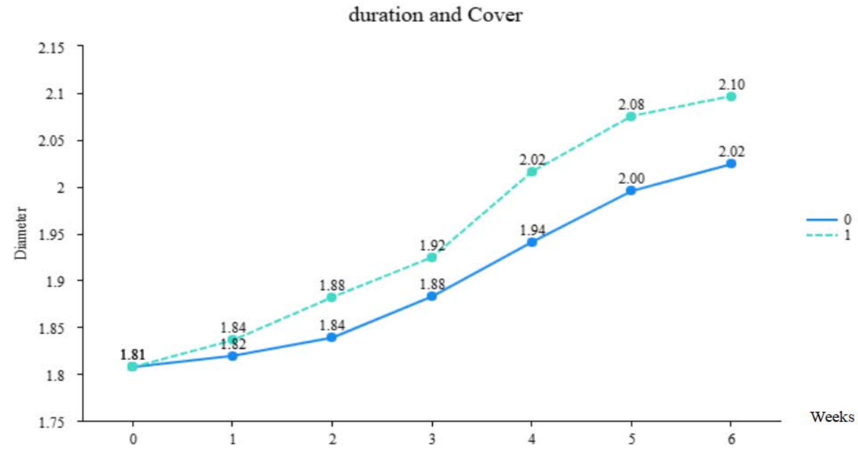
Curvilinear Regression		
Height	Peak Value	5.91
	Duration	6.00
	Model Formula	$\text{Height} = 4.4572380952 + 0.2607738095 \times duration - 0.0036071429 \times duration^2$
Stem Diameter	Peak Value	1.43
	Duration	6.00
	Model Formula	$\text{Stem Diameter} = 1.2022857143 + 0.0344880952 \times duration + 0.0010595238 \times duration^2$

Curvilinear regression models also present the growth pattern (Table 3). Duration had a significant effect on height ($p < 0.001$), while the quadratic term was not significant ($p = 0.438$), so it is a nearly linear growth pattern with slight deceleration in the late stage. For stem diameter, it has a steady linear growth with minimal acceleration. The vertices of the two quadratic curves both lie outside the range, so height and diameter rose steadily and reached the peak at week 6.

4.3 Mint's Height and Stem Diameter Responses



Graph 5. Growth pattern of mint height (cm) with and without tea residue mulch over 6 weeks.



Graph 6. Growth pattern of mint stem diameter (mm) with and without tea residue mulch over 6 weeks.

Table 4. Two-way ANOVA analysis: effects of duration and tea residue mulch (cover) on mint height and stem diameter respectively.

	Two-way ANOVA					
	Source	Sum of Squares	df	Mean Square	F	p Value
Height	duration	760.895	6	126.816	133.997	0.000
	Cover	8.565	1	8.565	9.050	0.003
Stem Diameter	duration	1.839	6	0.306	112.856	0.000
	Cover	0.117	1	0.117	42.970	0.000

Both duration and cover significantly influenced mint growth with $p<0.003$ (Table 4). The growth pattern differs from that of green onions. Mint height increased slowly during the first two weeks; however, the growth rate accelerated after Week 3 (Graph 5). During this stage, the advantage of the mulch treatment became more apparent. Stem diameter increased at a more stable rate throughout the experiment (Graph 6). The mulch group maintained a consistent advantage over the control group, although the difference was less in plant height.

Table 5. Curvilinear Regression: effects of duration and tea residue mulch (cover) on mint growth pattern in terms of height and stem diameter.

Curvilinear Regression		
Height	Peak Value	10.09
	Duration	6.00
	Model Formula	$\text{Height} = 5.3386428571 + 0.4577500000 \times \mathit{duration} - 0.0790595238 \times \mathit{duration}^2$
Stem Diameter	Peak Value	2.02
	Duration	6.00
	Model Formula	$\text{Stem Diameter} = 1.7986111111 + 0.0313214286 \times \mathit{duration} + 0.0024722222 \times \mathit{duration}^2$

Curvilinear regression parameters for mint are presented in Table 5. The regression models show that, for height, the quadratic model was highly significant. Both duration ($p<0.001$) and the quadratic term ($p<0.001$) were significant too, indicating an accelerating growth pattern, as well as the stem diameter. Mint height's quadratic curve opened upward with the minimum at -2.89 weeks (outside the range) and led to a continuous increase and a maximum value at week 6. The quadratic curve for mint diameter opened upward with its minimum at -6.33 weeks

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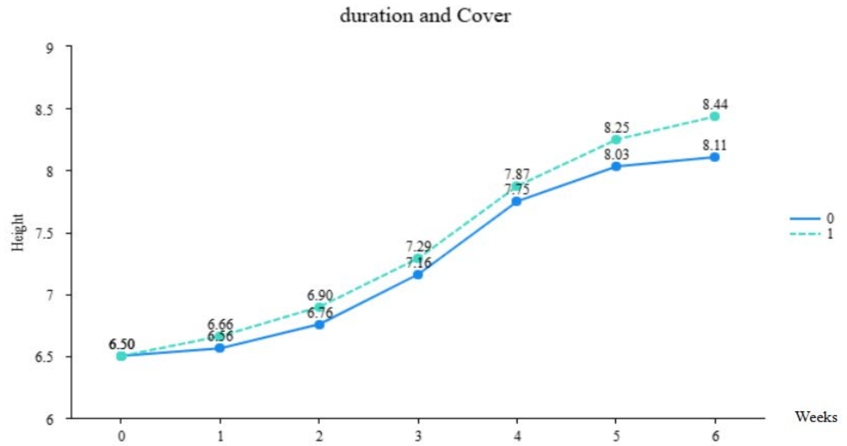
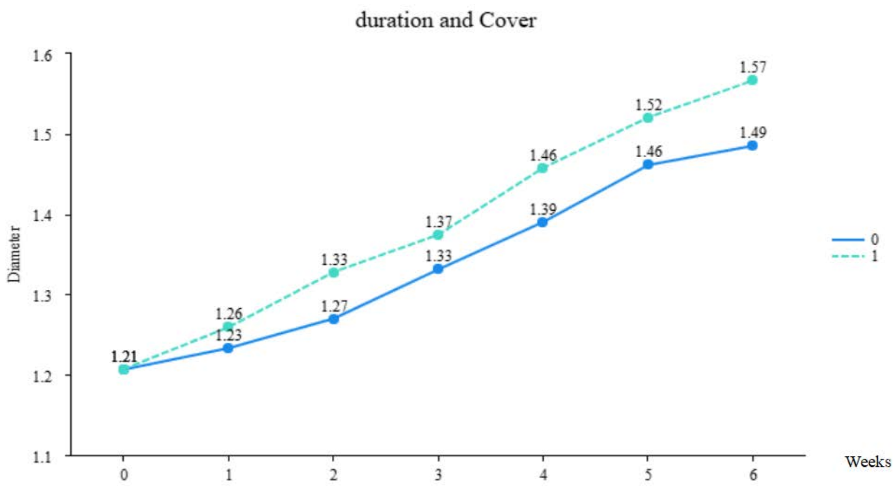
(outside the range), so it had a steady increase and reached the maximum at week 6.

4.4 Pothos' Height and Stem Diameter Responses



Graph 7. Growth pattern of pothos height (cm) with and without tea residue mulch over 6 weeks.



Graph 8. Growth pattern of pothos stem diameter (mm) with and without tea residue mulch over 6 weeks.

Table 6. Two-way ANOVA analysis: effects of duration and tea residue mulch (cover) on pothos height and stem diameter respectively.

	Two-way ANOVA					
	Source	Sum of Squares	df	Mean Square	F	p Value
Height	duration	97.283	6	16.214	985.182	0.000
	Cover	1.151	1	1.151	69.963	0.000
Stem Diameter	duration	2.666	6	0.444	208.028	0.000
	Cover	0.121	1	0.121	56.640	0.000

For pothos' two indicators, duration and mulch were also highly significant ($p<0.001$) (Table 6). The trend plot showed stable, consistent growth for both indicators (Graph 7, Graph 8). Unlike the other two species, pothos responded to mulch as early as week 2, with a persistent growth gap between the mulch and control groups through week 6.

Table 7. Curvilinear Regression: effects of duration and tea residue mulch (cover) on pothos growth pattern in terms of height and stem diameter.

Curvilinear Regression		
Height	Peak Value	8.48
	Duration	6.00
	Model Formula	Height = $6.4001746032 + 0.2602500000 \times duration - 0.0123134921 \times duration^2$
Stem Diameter	Peak Value	1.50
	Duration	6.00
	Model Formula	Stem Diameter = $1.2003571429 + 0.0502023810 \times duration + 0.0009880952 \times duration^2$

The curvilinear regression model for pothos is provided in Table 7. For pothos' height, both duration ($p<0.001$) and the quadratic term ($p=0.001$) were significant. For stem diameter, only duration was significant ($p < 0.001$), while the quadratic term was not significant ($p = 0.345$). Both quadratic curves have minimum points outside the range, so they kept growing until reaching a relative maximum at Week 6.

5. Discussion

5.1 Overall Impact of Tea Residue Mulch

Tea residue mulch creates more stable soil conditions and promotes plant growth through several interconnected and universal mechanisms. First, tea residue contains nutrients that support plant development, as black tea residue retains about 4.11% nitrogen and 50.2% carbon, along with smaller amounts of potassium, calcium, and magnesium (Lu et al., 2016). When it decomposes, these are gradually released into the soil and provide a steady supply for plant growth. Second, the mulch layer helps maintain soil moisture. Organic mulch reduces evaporation from the surface and limits air-soil vapor exchange, which keeps soil moisture more stable over time (Joes, 2025). It can also buffer soil temperature fluctuations and reduce stress on plant roots (Gamage et al., 2025). In addition, decomposing tea residue contributes organic matter to the soil. This supports microbial activity and improves soil structure (Zheng et al., 2019). Better soil structure improves aeration and nutrient retention.

5.2 Species-Specific Growth Traits and Mulch Responses

5.2.1 Green onion (Allium fistulosum L.)

Green onion's slow, steady growth and late-stage mulch response are due to its shallow, fibrous root system (Graph 9) and low metabolic rate. Unlike deep-rooted plants, its roots are primarily distributed in the top 0–15 cm of soil (Gansu Provincial Agricultural Technology Extension General Station, 2018). Therefore, the root surface area is small and limits rapid nutrient uptake (Table 8). This trait means green onions rely on sustained and low-concentration nutrient supply rather than short-term ones, which is an adaptation to their natural role as a cool-season crop and their gradual growth accumulation.

Table 8. Root traits and nitrogen metabolism of Allium fistulosum L. under organic fertilization (Liu et al., 2020). Data are mean ± SD (n=3).

Growth Stage of Allium fistulosum	Root Surface Area (cm^2/plant)	Nitrogen Uptake Rate (mg/plant·d)	Nitrate Reductase Activity (μmol NO_2^-/g·h)
Seedling (15 DAP)	0.82 ± 0.09	0.8 ± 0.1	12.3 ± 1.1
Tillering (35 DAP)	1.56 ± 0.12	1.2 ± 0.2	28.7 ± 2.3
Bulb Expansion (60 DAP)	1.34 ± 0.10	1.0 ± 0.1	21.5 ± 1.8
Mature (80 DAP)	1.21 ± 0.08	0.7 ± 0.1	15.2 ± 1.4

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Graph 9. Green onion root system.

Source: https://pixy.org/146059/; Image Link: https://pixy.org/src/14/146059.jpg

Tea residue mulch aligns perfectly with this because its decomposition releases nitrogen at a steady rate that takes care of green onions' uptake ability (Table 8). Additionally, green onions' epigeal germination and compact structure make it less able to compete for resources, so it depends on stable soil conditions. Root penetration in the shallow soil layer is also caused by tea residue's ability to improve soil aeration and reduce bulk density. The peak in nitrate reductase activity at the tillering stage (Table 8) also aligns with the greater nutrient release from tea residue, which provides reasons for the widening growth gap in the late experiment.

5.2.2 Mint (Mentha haplocalyx)

Mint's significant height growth and mid-stage acceleration are due to its herbaceous, fast-growing physiology and specialized resource allocation strategy. Their roots are highly branched, explore a larger soil volume, and make the largest contact with soil nutrients and water. This root structure supports a high metabolic rate and the exceptional photosynthetic capacity that prioritizes vertical shoot growth. In natural, undeveloped habitats, this trait helps mint compete for limited amount of light and make rapid shoot elongation an evolutionary priority. To support and accelerate this growth, mint has a specialized nutrient demand profile, and nitrogen is the most limiting factor. Moderate nitrogen supply can lead to a relative maximum height, chlorophyll content, and shoot dry weight. In contrast, excess nitrogen will disrupt its metabolic balance (Barawkar et al., 2025). Table 9 quantifies mint's nitrogen response through trials on Mentha spicata, a closely related species with nearly identical growth and nutrient requirements (Barawkar et al., 2025).

Table 9. Growth parameters of Mentha spicata L. under different fertilizer levels (60 days after planting).

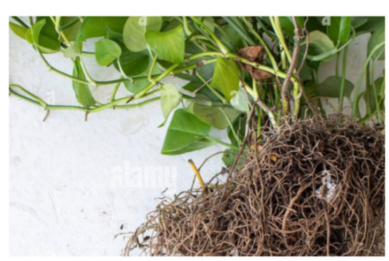
Fertilizer Level	(NPK kg/hactare)	Plant Height (cm)
F2 (Control)	100:50:50	27.81
F3 (Optimal)	80:50:40	34.88
F6 (Overplus)	120:50:50	24.37

Note: The fertilizer ratio "NPK", or "$N\text{-}P_2O_5\text{-}K_2O$", is a standard for labeling nutrient content (UMass Extension, 2011), where the three numbers represent the mass of nitrogen, phosphorus, and potassium applied per hectare (kg/ha), respectively (Barawkar, 2025).

Tea residue mulch also provides an ideal condition. Its natural nitrogen content (4.11%, Lu et al., 2016) mineralized gradually over the 6-week experiment. It released nitrogen at a rate that matches the optimal level in Table 9. After the initial 2 weeks, when the establishment period was focusing on root development, the mint turned to a rapid shoot expansion. During this phase, advanced microbial decomposition of tea residue increases nutrient release that directly fuels the plant's high nitrogen demand for vertical growth. Additionally, its high transpiration rate (a byproduct of its fast photosynthetic rate) further reinforces the mulch's effect. Rapid shoot growth increases water needs, and tea residue's moisture retention property maintains relatively consistent soil hydration. Consequently, it has an efficient nutrient uptake through the dense root system. Stem diameter growth, by contrast, is a lower priority for mint's resource allocation during this phase. The plant gets available nutrients and water through light competition (shoot elongation) rather than radial growth.

5.2.3 Pothos (Epipremnum aureum)

Pothos' early, stable response to mulch is driven by its epiphytic-adapted physiological traits and high sensitivity to soil moisture fluctuations. As a climbing evergreen, pothos evolved to grow in tree canopies that have irregular and periodic water availability. Thus, pothos has a succulent-like root system (Graph 10) with thickened epidermal cells that store water but are vulnerable to waterlogging or drought, and a conservative growth strategy that prioritizes survival over rapid expansion (Gamage et al., 2025). Table 10 quantifies pothos' root growth rate and related measurements.



Graph 10. Roots of the pothos houseplant.

Source: https://www.alamy.com/; Image Link: https://c8.alamy.com/comp/2RBNEG2/root-ball-of-the-pothos-houseplant-repotting-houseplant-rootbound-house-plant-root-system-2RBNEG2.jpg

Tea residue mulch's primary impact on pothos is not nutrient supply, though its gradual release supports steady growth, but immediate moisture retention. The mulch layer maintains the optimal moisture range from Week 1. Additionally, pothos' aerial root (Graph 11) formation is greatly improved and strengthened by stable soil moisture (Table 10). In this case, its nutrient and water uptake efficiency becomes higher, too. Unlike mint and green onion, pothos does not have apparent growth phase shift, so the mulch effect remains consistent over time.

Graph 11. Pothos aerial root (Hall,2025)

Image Link:https://positivebloom.com/wp-content/uploads/2022/06/hand-holding-pothos-with-root.jpg.webp

Table 10. Moisture response of Epipremnum aureum root and photosynthetic traits (Gamage et al., 2025).

Soil Moisture Content (%)	Root Growth Rate (mm/d)	Net Photosynthetic Rate (μmol CO_2/ m^2·s)	Root Respiration Rate (μmol O_2/ g·h)
30–35 (Low)	0.21 ± 0.03	6.8 ± 0.5	8.3 ± 0.6
40–50 (Optimal)	0.35 ± 0.04	12.4 ± 0.8	15.7 ± 1.1
55–60 (High/Waterlogged)	0.28 ± 0.03	8.2 ± 0.6	10.1 ± 0.7

5.3 Temporal Dynamics of Growth and Mulch-Species Synergy

Different species followed different response patterns during the six-week period. These patterns were mainly related to the properties of organic mulch. Tea residue mulch releases nutrients slowly during decomposition, while its moisture-retention effect appears immediately after application. These two mechanisms influence how resources become available to plants at different stages of growth. Previous research on organic amendments has reported similar processes (Negi et al., 2021; Zheng et al., 2019). The growth trends described below are based on the weekly measurements collected during the six-week experiment.

5.3.1 Trajectory 1: Slow-Amplification (Green Onion & Mint)

During the first two weeks, the mulch layer had not decomposed sufficiently to release a noticeable amount of nutrients. Soil microorganisms also required time to adapt to the tea residue and gradually overcome the inhibitory effects of polyphenols. As a result, nutrient availability remained similar between the treatment and control groups at the early stage. From Week 3 onward, the situation began to change. Microbial activity increased as decomposition progressed, and nutrient release gradually accelerated, and nitrogen release became more evident during this stage. This timing shows that mint entered a period of rapid shoot expansion, while green onion began its tillering stage. Both stages require higher nutrient input to support new tissue development. Green onion showed a slightly delayed response compared with mint. One possible explanation is about its root characteristics at the seedling stage. Young green onion plants have a relatively small root surface area; as the root system develops, the plants become better able to use nutrients released from the mulch. By Week 6, the continuous nutrient supply from decomposition matched the plants' peak demand. (Liu et al., 2020).

5.3.2 Trajectory 2: Stable-Response (Pothos)

Pothos showed a different pattern. The treatment group began to display a growth advantage as early as Week 2, and this remained relatively stable all the time. Tea residue mulch affects soil moisture immediately after application. The residue forms a protective layer on the soil surface, which reduces direct evaporation and slows vapor exchange between the soil and the air. As a result, soil moisture remains more stable over time. For pothos, this stable microenvironment is especially beneficial. Pothos does not require a sudden increase in nutrient supply. Instead, it benefits from a steady and moderate level of resources, which provides stable nutrient input. Therefore, the mulch maintained a continuous growth advantage rather than producing a delayed or strongly amplified effect.

5.4 Suggestions for Home Gardeners

Several simple care strategies can help gardeners use tea

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residue mulch effectively. For green onions, gardeners should apply pretreated tea residue mulch after transplanting. The mulch layer should remain undisturbed during growth. Regular watering helps keep soil moisture stable. Gardeners can add a thin layer of mulch again in Week 3 or Week 4 to support nutrient supply during the tillering stage. Extra chemical fertilizer is usually not necessary. Mint requires similar mulch use after the seedlings become stable. Gardeners should use pots with good drainage so that the soil remains well aerated. Watering can increase slightly after Week 3 because plant growth becomes faster at this stage. Extra nitrogen fertilizer is not needed because tea residue already provides sufficient nutrients. Light trimming around Week 4 or Week 5 can also encourage branching. For pothos, gardeners should apply the mulch soon after potting. The mulch layer should stay on the soil surface during the whole growth period. Pothos benefits from stable soil moisture, so moderate and regular watering is important. The plant should also receive adequate natural light each day. Good lighting supports photosynthesis and works together with the improved soil conditions created by the mulch.

6. Conclusion and Evaluation

6.1 Conclusion of Research

This study investigated the effects of tea residue mulch on the growth of three common potted plants, green onion, mint, and pothos, over a 6-week period, using two-way ANOVA to analyze the impacts of mulch application and cultivation duration on plant height and stem diameter. The results confirmed that tea residue mulch significantly promoted the growth of all three species, with consistent positive effects on both key growth indicators (all $p<0.001$ for mulch main effect). Specifically, mint showed the strongest increase in plant height because it grows quickly and requires more nitrogen during rapid vertical growth. Tea residue mulch slowly releases nutrients during decomposition, and this process supports the height growth of mint. Green onion showed a later growth advantage, and the difference between treatment and control appeared mainly in the later weeks. It depends on a stable nutrient supply during development, and the gradual nutrient release from mulch matched this requirement. Pothos showed an early and stable response. This species is sensitive to soil moisture stability, and the mulch layer helps reduce evaporation and maintain more stable soil moisture. Mechanistically, the growth-promoting effects of mulch came from three important functions: supplementation of essential nutrients via gradual decomposition, improvement of soil microenvironment, and improvement of the soil fertility through increased organic carbon and microbial activity.

6.2 Limitations

Although these species represent different growth forms, they cannot represent the full diversity of ornamental or edible plants. Different plants have different root structures, nutrient demands, and growth strategies. For this reason, the conclusions may not apply equally to all plant types. Besides, the research focuses on a limited number of growth indicators. Plant height and stem diameter provide clear measurements of visible plant development, but they cannot fully explain the underlying biological processes. The experiment does not measure soil nutrient content, microbial community changes, or plant chlorophyll levels, which could provide additional information about how tea residue mulch influences soil fertility and plant physiology. The experimental duration is another limitation. The study lasts six weeks and mainly captures short- to mid-term plant responses to the mulch treatment. Organic mulch continues to decompose over time and gradually releases nutrients into the soil. A short experimental period, therefore, cannot determine whether the observed growth advantages remain stable during longer cultivation cycles. The results should therefore be interpreted mainly as evidence of short-term effects.

6.3 Implications and Future Research Direction

This study provides useful insight into how black tea residue mulch affects plant growth and soil conditions. The research examines plant growth performance and changes in the growing medium from these two perspectives. Weekly data also makes the analysis consider growth trends over time rather than relying only on final measurements. Besides, the three species are not only popular home-planting choices in the city but also represent different growth habits and physiological characteristics. Because of this diversity, the results are more reliable on how tea residue mulch may function in small-scale potted planting. The study also contributes practical value for household gardening. Many homes produce tea residue as everyday kitchen waste, but this material is often discarded without further use. This research evaluates whether the residue can function as an organic mulch for potted plants under controlled conditions. The results show that the mulch can support plant growth while improving soil moisture stability. For future studies, researchers could expand the study in several meaningful ways. One potential step is to include a wider range of plant species, such as flowering plants and woody shrubs. Testing them would help determine whether tea residue mulch provides general benefits or mainly supports certain plant groups. Studies could also include more comprehensive measurements in order to better understand how the mulch influences plant growth and soil conditions. For example, researchers could measure plant chlorophyll content to evaluate whether the mulch affects photosynthetic efficiency. In addition, longer experimental periods would provide a clearer picture of mulch performance over time. Studies that extend for several months could track the decomposition of tea residue and observe how nutrient release changes during later growth stages. This type of monitoring would help determine whether the growth advantages observed in this study remain stable during longer cultivation periods. Future experiments could also investigate different application strategies. For example, they could compare different mulch thicknesses and particle sizes, since these factors may influence moisture retention and decomposition speed. They could also test mixtures of tea residue with other organic materials, such as compost, in order to explore whether combined organic amendments can create more effective and sustainable growing media for household potted plants.

7. References

Barawkar, R., Mali, P. C., Gajbhiye, R., Parulekar, Y., & Dhopavkar, R. (2025). Effect of planting methods and fertilizer levels on growth of mint (mentha spicata L.). *International Journal of Agriculture and Food Science*, *7*(7), 643–647. https://doi.org/10.33545/2664844x.2025.v7.i7i.578

Bhat, M. A., Mishra, A. K., Shah, S. N., Bhat, M. A., Jan, S., Rahman, S., Baek, K.-H., & Jan, A. T. (2024). Soil and Mineral Nutrients in Plant Health: a Prospective Study of Iron and Phosphorus in the Growth and Development of Plants. *Current Issues in Molecular Biology*, *46*(6), 5194–5222. https://doi.org/10.3390/cimb46060312

Crespo-López, L., Coletti, C., Arizzi, A., & Cultrone, G. (2024). Effects of Using Tea Waste as an Additive in the Production of Solid Bricks in Terms of Their porosity, Thermal conductivity, Strength and Durability. *Sustainable Materials and Technologies*, *39*, e00859–e00859. https://doi.org/10.1016/j.susmat.2024.e00859

Docin. (2025, December 4). *2025 Report on Technological Breakthroughs and Environmental Benefit Calculation of Tea Residue Recycling*. Docin; Docin. https://www.docin.com/p-4922384219.html

Gamage, D. N. V., Peiris, T., Kasthuriarachchi, I., Mohotti, K. M., & Biswas, A. (2025). Enhancing Soil Resilience to Climate Change: Long-Term Effects of Organic Amendments on Soil Thermal and Physical Properties in Tea-Cultivated Ultisols. *Sustainability*, *17*(3), 1184–1184. https://doi.org/10.3390/su17031184

Gansu Provincial Agricultural Technology Extension General Station. (2018). *Ludi shucai zaipei jishu* [Open-field vegetable cultivation technology]. Lanzhou University Press.

Ghani, E. T. A. (2012). Effect of Black Tea Wastes on Some of Soil Properties and Barley (Hordium Vulgar L.) Growth and Yield. *ResearchGate*, *12*(3), 186–189. https://www.researchgate.net/publication/328652671

Hall, L. (2022, June 15). Pothos Aerial Roots: Why They Grow And What To Do. *Positivebloom*. https://positivebloom.com/pothos-aerial-roots/

Harish, P., & Mahapatra, A. (2020). Soil Stabilization Using Tea Waste. *IOP Conference Series: Materials Science and Engineering*, *970*(1), 012035. https://doi.org/10.1088/1757-899x/970/1/012035

Horma, O., Charai, M., & Mezrhab, A. (2022). Improving the Thermal Insulation of Cement-Based Composites Using Tea Waste Aggregates. *Lecture Notes in Networks and Systems*, *386*, 466–476. https://doi.org/10.1007/978-3-030-93817-8_43

Huang, L., & Yang, L. (2022). Present Situation and Prospect of Urban Domestic Waste Treatment in China. *Sustainable Development*, *12*(05), 1347–1354. https://doi.org/10.12677/sd.2022.125152

IERE Team. (2025, June 30). Why Is Nitrogen Important in Soil? - the Institute for Environmental Research and Education. The Institute for Environmental Research and Education; *IERE Team*. https://iere.org/why-is-nitrogen-important-in-soil/

Joes, B. (2025, July 17). Are Tea Leaves Good for Soil? - Nature's Fertilizer Secret - GardenerBible. GardenerBible; *GardenerBible*. https://gardenerbible.com/are-tea-leaves-good-for-soil/

Kensuke Kawade, Hiromitsu Tabeta, Ferjani, A., & Masami Yokota Hirai. (2023). The Roles of Functional Amino Acids in Plant Growth and Development. *Plant and Cell Physiology*, *64*(12), 1482–1493. https://doi.org/10.1093/pcp/pcad071

Liang, C., Schimel, J. P., & Jastrow, J. D. (2017). The Importance of Anabolism in Microbial Control over Soil Carbon Storage. *Nature Microbiology*, *2*(8). https://doi.org/10.1038/nmicrobiol.2017.105

Liang, M., Chen, L., Chen, G., Zhao, Y., Liu, G., Sun, E., Yong, C., Huang, H., Li, F., & Qu, P. (2025). Protective Effects of Straw Mulching on Soil Health and function: a Review. *Environmental Pollutants and Bioavailability*, *37*(1). https://doi.org/10.1080/26395940.2025.2533900

Live to Plant. (2025, July 9). The Role of Fibers in Improving Soil Aeration and Drainage | Live to Plant. Livetoplant.com; *Live to Plant*. https://livetoplant.com/the-role-of-fibers-in-improving-soil-aeration-and-drainage/

Lu, N., Zhou, Z., Song, J., Yuan, W., Wang, W., & Yan, J. (2016). Main components of tea residues and grass rot fungi cultivated using the tea residues. *Edible Fungi of China*, *35*(2), 36–39. cnki:SUN:ZSYJ.0.2016-02-014

Negi, T., Kumar, Y., Sirohi, R., Singh, S., Tarafdar, A., Pareek,

ISSN 2959-6157

S., Kumar Awasthi, M., & Alok Sagar, N. (2021). Advances in bioconversion of spent tea leaves to value-added products. *Bioresource Technology*, *346*, 126409. https://doi.org/10.1016/j.biortech.2021.126409

Qingdao Wo'an Ecology Co., Ltd. (2020). *Home gardening nutrient soil* (Q/370211QWA006-2020). https://static1.tianyancha.com/czd_file/fs/947d4107-cc8e-4fab-ad69-a94ba3dfc1eb.pdf

Saiu, V., & Blecic, I. (2020). NeighbourHub. Un circuito aperto di spazi per usi temporanei e a rotazione, per un distretto culturale diffuso nei quartieri di Is Mirrionis e San Michele a Cagliari. *IV Congresso Internazionale Dell'Abitare Collettivo Sostenibile*. https://www.researchgate.net/publication/344512110_NeighbourHub_Un_circuito_aperto_di_spazi_per_usi_temporanei_e_a_rotazione_per_un_distretto_culturale_diffuso_nei_quartieri_di_Is_Mirrionis_e_San_Michele_a_Cagliari

Tarashkar, M., Matloobi, M., Qureshi, S., & Rahimi, A. (2023). Assessing the growth-stimulating Effect of Tea Waste Compost in Urban Agriculture While Identifying the Benefits of Household Waste Carbon Dioxide. *Ecological Indicators*, *151*(151), 110292. https://doi.org/10.1016/j.ecolind.2023.110292

UMass Extension. (2011, May). *UNDERSTANDING FERTILIZER LABEL*. UMass Extension Center for Agriculture; United States Department of Agriculture. https://www.umass.edu/agriculture-food-environment/sites/ag.umass.edu/files/fact-sheets/pdf/understanding_fertilizer_label.pdf

Xu, Y., Qiao, F., & Huang, J. (2022). Black Tea Markets worldwide: Are They integrated? *Journal of Integrative Agriculture*, *21*(2), 552–565. https://doi.org/10.1016/s2095-3119(21)63850-9

Yan, Z., Zhong, Y., Duan, Y., Chen, Q., & Li, F. (2020). Antioxidant mechanism of tea polyphenols and its impact on health benefits. *Animal Nutrition*, *6*(2), 115–123. https://doi.org/10.1016/j.aninu.2020.01.001

Zheng, X., Xie, X., Yu, C., Zhang, Q., Wang, Y., Cong, J., Liu, N., He, Z., Yang, B., & Liu, J. (2019). Unveiling the Activating Mechanism of Tea Residue for Boosting the Biological Decolorization Performance of Refractory Dye. *Chemosphere*, *233*, 110–119. https://doi.org/10.1016/j.chemosphere.2019.05.205

Zhou, L., Yue, Q., Zhao, L., Cui, R., & Liu, X. (2018). Effect of Nitrogen Level on Growth and Metabolism of Allium fistulosum L. *Proceedings of the 2018 7th International Conference on Energy, Environment and Sustainable Development (ICEESD 2018).* https://doi.org/10.2991/iceesd-18.2018.224