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Effects of pelletized poultry litter fertilizers amended with spent coffee grounds or tea waste on nitrogen release and growth of *Brassica rapa* var. *chinensis*

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Introduction: Poultry litter and beverage by-products, such as spent coffee grounds and tea wastes, are widely recognised as potential organic soil amendments. However, their large volume, high moisture content, slow decomposition, and polyphenol content may cause handling and environmental concerns. Pelletization offers a sustainable strategy by converting these wastes into value-added fertilizers.

Methods: This study evaluated nitrogen release dynamics and the growth of *Brassica rapa* var. *chinensis* in soil amended with pelletized poultry litter fertilizers enriched with coffee grounds or tea wastes. The tested soil belonged to the Erhlin soil series, developed from old slate-derived alluvial deposits, with medium to fine texture, imperfect drainage, and neutral to slightly alkaline pH. Treatments included a control (CK), chemical fertilizer (CF), and pelletized poultry litter with coffee grounds (C) or tea wastes (T) applied at the recommended nitrogen rate (1xRN) or double the recommended rate (2xRN), resulting in six treatments. An incubation experiment and a pot experiment were conducted.

Results: During incubation, the 2xRN treatments significantly increased soil NH_4^+-N and NO_3^--N concentrations over time. In the pot experiment, pelletized treatments enhanced soil nutrient availability compared with CF, increasing available nitrogen by 98–126%, available phosphorus by 27–69%, exchangeable potassium by 69–177%, and bioavailable zinc by 40–100%. The pelletized poultry litter with tea wastes at 2xRN produced the greatest plant biomass and height.

Discussion: Pelletized poultry litter enriched with tea wastes was the most effective amendment, improving soil fertility and promoting *Brassica rapa* var. *chinensis* growth. These findings demonstrate the potential of pelletization as a sustainable waste recycling strategy for enhancing nutrient availability and crop performance.

KEYWORDS

nitrogen release, organic amendment, pelletized poultry litter, plant nutrition, soil fertility

1 Introduction

The poultry industry, driven by the growing demand for meat and eggs, has become one of the largest and fastest-growing agricultural sectors worldwide. Consequently, a massive accumulation of poultry wastes, particularly poultry litter (PL), has raised pressing concerns regarding sustainable waste management (Bolan et al., 2010). In Taiwan, poultry litter accounts for approximately 2,300 kilotons (kt) annually, representing about 32.3% of the country's agricultural waste, with most applied to farmland as organic fertilizer (Tsai and Chang, 2020). Poultry litter consists of poultry manure, bedding materials such as rice husks or wood shavings, spilled feed, and feathers. It is rich in essential nutrients, including nitrogen (N), phosphorus (P), and potassium (K). As a soil organic amendment, poultry litter has been shown to improve soil fertility, increase infiltration, enhance microbial activity, and contribute to soil organic matter (OM) accumulation (Watts et al., 2019; Drózd et al., 2020). Nevertheless, repeated or excessive application of raw poultry litter can lead to heavy metal (HM) accumulation, pathogen spread, ammonia volatilization, and eutrophication of water bodies, thereby threatening environmental and food safety (Sims and Wolf, 1994; Gong et al., 2019). Recent studies indicate that the direct application of poultry litter can introduce pathogenic microorganisms (e.g., *E. coli*, *Salmonella*), antibiotic residues, and heavy metals posing risks to human, animal, and environmental health (Kyakuwaire et al., 2019; Okada et al., 2024). Its high nitrogen and phosphorus content may leach into groundwater or runoff into surface waters, contributing to eutrophication, while long-term use can increase heavy metal accumulation in soil and crops, raising food safety concerns (Akhter et al., 2022).

To overcome these limitations, pelletization has been introduced as a promising strategy for managing poultry litter. Pelletized poultry litter (PPL) reduces odor, volume, and pathogen load while improving storage, transport, and field application. Studies have demonstrated that pelletized poultry litter can improve soil physical properties, such as aggregate stability, bulk density, water infiltration, and water-holding capacity (WHC) (Adeli et al., 2007; Feng et al., 2019). Moreover, the application of pelletized poultry litter has been reported to increase crop yields and nutrient uptake compared with raw poultry litter, with better synchronization between nutrient release and plant demand (Wild et al., 2011; Adeli et al., 2016). Despite these advantages, continuous application of poultry-based fertilizers still raises concerns regarding the accumulation of heavy metals such as copper (Cu) and zinc (Zn), which may adversely affect soil ecosystems and human health if applied excessively (Sungur et al., 2016; Gong et al., 2019). Recent studies have shown that pelletized poultry litter influences nitrogen release dynamics and soil microbial biomass under different soil conditions, suggesting that pelletization can significantly affect nutrient availability and soil biochemical processes (Monaci et al., 2022). In addition, heat-treated or fermented pelletized poultry litter has been reported to affect pathogen survival in soils, highlighting the importance of assessing environmental safety alongside agronomic performance (Kharel et al., 2025). Furthermore, field experiments indicate that

pelletized poultry litter amendments improve soil structure and crop yields (e.g., maize) while enhancing nutrient retention, supporting their value as a sustainable soil amendment (Agbede, 2025).

Alongside livestock residues, beverage industry by-products such as spent coffee grounds (SCG) and tea waste (TW) are produced in enormous quantities due to the widespread consumption of coffee and tea. In Taiwan, the daily disposal of spent coffee grounds is estimated at 30 tons (t), while globally, more than 15,000 kt are generated annually (Kamil et al., 2019). Similarly, tea waste is produced at large scale as a by-product of tea drinks and extracts, with Taiwan alone consuming around 30 kt of tea annually. Spent coffee grounds and tea waste are rich in organic carbon and minerals, but their high moisture content, acidity, caffeine, and polyphenolic compounds hinder direct application, as they may cause phytotoxic effects or environmental problems when incinerated or landfilled (Leifa et al., 2000). Among these compounds, phenolics have been identified as key factors reducing crop biomass. Although composting is commonly recommended to alleviate these effects, the process is both time-consuming and costly. Compared with tea waste, spent coffee grounds has a higher carbon-to-nitrogen (C/N) ratio, acidity, and phenolic content, which may further exacerbate phytotoxicity when applied directly to soil. Nonetheless, studies have shown that modifying spent coffee grounds use—such as producing slow-release formulations, co-composting with animal manure, or pelletization—can mitigate adverse effects and improve nutrient availability (Ciesielczuk et al., 2015; Cervera-Mata et al., 2020; Keeflee et al., 2020). Moreover, polyphenols from spent coffee grounds may act as chelating agents, immobilizing heavy metals in soil, and their co-composting with other wastes has been reported to reduce phytotoxicity, enhance N retention, and improve soil physical properties (Turek et al., 2019; Keeflee et al., 2020).

Integrating spent coffee grounds and tea waste into pelletized poultry litter production represents a strategically relevant approach for sustainable waste recycling, combining multiple by-products into a single, value-added soil amendment. Such blending not only provides a means of adjusting the C/N ratio of the pellets but also enriches organic matter and potentially reduces the risks associated with the direct application of spent coffee grounds and tea waste. In addition, incorporating spent coffee grounds and tea waste into pelletized formulations may improve pellet stability, reduce bulk density, and enhance the diversity of nutrient sources available to crops. The combined use of these materials could also create a more balanced nutrient release pattern, supporting microbial activity and improving soil structure while minimizing nutrient losses to the environment (Cervera-Mata et al., 2018). Although previous research has documented the agronomic potential of pelletized poultry litter (Adeli et al., 2007; Feng et al., 2019) and the soil benefits of spent coffee grounds and tea waste individually (Comino et al., 2020; Cervera-Mata et al., 2022), little is known about their combined pelletization and subsequent effects on nutrient release, soil properties, and crop performance. Addressing this knowledge gap is critical for developing environmentally safe and agronomically effective waste-based fertilizers that integrate the advantages of multiple by-products.

The objective of this study was to evaluate the feasibility of producing pelletized poultry litter blended with spent coffee grounds and tea waste and to assess their effects as soil organic amendments. Incubation and pot experiments were conducted to (i) examine N release during incubation, (ii) investigate changes in soil physicochemical properties, and (iii) evaluate the growth performance and nutrient uptake of *Brassica rapa* var. *chinensis*. By combining multiple agricultural and food wastes into a single fertilizer, this study not only addresses environmental safety concerns associated with raw waste application but also provides practical insights into sustainable nutrient management, soil fertility improvement, and circular economy strategies in agriculture.

2 Materials and methods

2.1 Sources and preparation of fertilizer materials

Poultry litter used in this study was obtained from a broiler farm in Pingtung County, Taiwan. Spent coffee grounds were collected daily from a coffee shop, and tea waste, consisting of a mixture of spent green and black tea residues, was collected from a tea shop; both materials were obtained in Taichung County, Taiwan. The spent coffee grounds and tea waste samples were transported to the laboratory, oven-dried at 60°C, and stored in a cool and dry environment until use, with 10 kg dry weight of each material collected. For pellet production, predetermined amounts of poultry litter, spent coffee grounds and tea waste were weighed and mixed with soybean meal and rice husks to adjust the C/N ratio to 20. The resulting pellets were designated as pelletized poultry litter with coffee grounds (SCG-PPL) and pelletized poultry litter with tea waste (TW-PPL), respectively. Given the material compositions of the two fertilizers—79% poultry litter + 21% spent coffee grounds for pelletized poultry litter with coffee grounds, and 93% poultry litter + 7% tea waste for pelletized poultry litter with tea waste—the mixing ratios were calculated based on the C/N ratios of the individual materials. By adjusting the proportion of poultry litter with the higher C/N materials (spent coffee grounds or tea waste), the overall C/N ratio of the mixtures was estimated to be approximately 20. This adjustment was necessary because organic matters with a C/N ratio higher than 20 may induce N immobilization, thereby limiting crop growth (Van Der Sloot et al., 2022). The materials were thoroughly mixed with an appropriate amount of deionized water and processed into pellets using a rolling granulator (Fertilizer Granulator, CB-78; Chuang Pao, Kaohsiung, Taiwan). The resulting pellets were oven-dried at 70°C for at least 30 min, in accordance with fertilizer regulations (Ministry of Agriculture (MOA), 2020), and then stored in a desiccator until subsequent analyses of basic properties, incubation experiments, and pot experiments.

2.2 Incubation and pot experiments

Soil from the surface layer (0–15 cm) of a field in Pitou Township, Changhua County, Taiwan, an important vegetable

production region in western Taiwan, belonged to the Erhlin series (Eh), which is primarily developed from old alluvial deposits of slate. The subsoil is characterized by medium to fine texture, imperfect drainage, and neutral to slightly alkaline soil reaction. The samples were air-dried, ground, passed through a 10-mesh stainless sieve, homogenized, and stored in plastic containers for subsequent analyses and experiments. The initial soil had an available N content of 2.2 mg kg⁻¹, an Olsen P of 14.7 mg kg⁻¹, and an exchangeable K of 55.4 mg kg⁻¹. Except for the relatively low available N, the other nutrients were within the moderate range (Ilacobi, 1989); therefore, the fertilizer application rate in this study was calculated based on N. The application rate of N was determined according to the recommended N rate (RN) for *Brassica rapa* L. provided in the Vegetable Production Management Manual by the Agriculture and Food Agency, Council of Agriculture, Executive Yuan, Taiwan, which is 200 kg N ha⁻¹.

Six treatments were included: a control without fertilization (control treatment, CK); urea applied at the recommended rate of 0.22 g kg⁻¹ (chemical fertilizers treatment, CF); pelletized poultry litter with coffee grounds applied at 2.9 g kg⁻¹ (C treatment); pelletized poultry litter with tea waste applied at 3.4 g kg⁻¹ (T treatment); and double the recommended rates of pelletized poultry litter with coffee grounds (5.8 g kg⁻¹, 2C treatment) and pelletized poultry litter with tea waste (6.8 g kg⁻¹, 2T treatment). At the recommended rate, the C treatment supplied 100 mg kg⁻¹ N, 14 mg kg⁻¹ P, and 70 mg kg⁻¹ K, whereas the T treatment supplied 100 mg kg⁻¹ N, 14 mg kg⁻¹ P, and 85 mg kg⁻¹ K.

For N and P incubation experiments, 100 g of soil was placed in 150 ml beakers, thoroughly mixed with the designated amendment, and adjusted to 50–70% of water-holding capacity with deionized water. The beakers were covered with plastic film perforated with small holes for aeration and incubated in a growth chamber (25 ± 1°C, 70 ± 10% relative humidity, 12 h light/12 h dark). The incubation lasted 60 days, with seven samplings on days 0, 10, 20, 30, 40, 50, and 60. Each treatment had three replicates, yielding 126 samples in total. At each sampling, soils were air-dried, ground, passed through a 10-mesh stainless sieve, and analyzed for pH, electrical conductivity (EC), ammonium-N (NH₄⁺-N), nitrate-N (NO₃⁻-N), and available P according to the method described in Section 2.3.

For pot experiments, the same six treatments were tested using 1.0 kg of soil in plastic pots (diameter 147 mm, height 130 mm). Five *Brassica rapa* var. *chinensis* seeds were sown per pot and thinned to three seedlings after 10 days. Pots were maintained at 50–70% water-holding capacity by weighing and watering every 2–3 days, and incubated in a growth chamber (25 ± 1°C, 70 ± 10% relative humidity, 12 h light/12 h dark). The experiment lasted 60 days with three replicates per treatment (18 pots in total). Growth parameters measured at harvest included SPAD reading (SPAD-502 Plus, Konica Minolta, Osaka, Japan), plant height, and fresh and dry shoot biomass. Plant tissues were analyzed for N, P, K, calcium (Ca), magnesium (Mg), Cu, and Zn. Post-harvest soils were analyzed for pH, EC, wet aggregate stability (WAS), OM, available N, available P, exchangeable cations (K, Ca, and Mg), as well as total and bioavailable Cu and Zn according to the method described in Section 2.3.

2.3 Analysis of organic amendments, soil, and plant

For the post-experiment soil property analyses, soil texture was determined using the particle-size distribution (hydrometer) method (Gee and Bauder, 1986). The pH and EC were measured in 1:5 soil-to-water suspensions (w/v) using a pH meter (FiveEasy, Mettler Toledo, Greifensee, Switzerland) and an EC meter (inoLAB Cond 7110, WTW, Germany) (Thomas, 1996; Rhoades, 1996). Wet aggregate stability was determined by the wet-sieving method (Kemper and Rosenau, 1986), and organic matter was quantified using the Walkley–Black method (NelsonSommers, 1996). Available concentrations of NH_4^+ -N and NO_3^- -N were extracted with 2 M KCl and analyzed via Kjeldahl distillation method (Mulvaney, 1996; Bremner, 1996). Available P was determined using the Olsen method and molybdenum blue method (Olsen et al., 1954; Murphy and Riley, 1962). Exchangeable cations (K, Ca, and Mg) were extracted with 1.0 M ammonium acetate. K was determined using a flame photometer (FA; Model 410, Sherwood, Cambridge, UK), whereas Ca and Mg were measured using a flame atomic absorption spectrometer (FAAS; PinAAcle 900F, PerkinElmer, Waltham, USA) (HelmkeSparks, 1996). Total concentrations of Cu and Zn were determined after aqua regia digestion using FAAS, and bioavailable concentrations of Cu and Zn were extracted with 0.05 M EDTA and then measured by FAAS (Mench et al., 1994).

For pelletized poultry litter analyses, fertilizer samples were analyzed for water content, pH, EC, and organic matter. Water content was determined by oven-drying samples at 105°C for 24 h (Gardner, 1986), while organic matter was measured by dry combustion, where samples were oven-dried, ground, sieved, and ashed in a muffle furnace (NelsonSommers, 1996). The fertilizers were then digested with sulfuric acid and hydrogen peroxide (Jones and Case, 1990), after which total concentrations of N, P, K, Ca, and Mg were determined. Specifically, total N was determined using the Kjeldahl distillation method. The C/N ratio was calculated by dividing the organic carbon content by the total N content. Total P was analyzed using the molybdenum blue method. Total K was measured by FA, while total Ca and Mg were determined using FAAS. Heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES; Avio 200, PerkinElmer, Waltham, MA, USA). Moreover, the most probable number (MPN) of coliform bacteria was estimated by the Soil Survey and Testing Center of National Chung Hsing University, following Loncarevic et al. (2005).

After harvest, dried plant tissues were ground and digested with sulfuric acid and hydrogen peroxide, and N, P, K, Ca, Mg, Cu, and Zn were measured using Kjeldahl distillation method, molybdenum blue method, FA, and FAAS, following the same procedures as those used for pelletized poultry litter analysis.

To elucidate the nutrient uptake efficiency of pelletized poultry litter with coffee grounds and pelletized poultry litter with tea waste, total nutrient uptake and nutrient uptake efficiency were calculated using Equations 1, 2.

Total nutrient uptake

$$= \text{Shoot nutrient concentration (\%)} \times \text{Dry weight} \quad (1)$$

Nutrient uptake efficiency (%) = ((Total uptake in pelletized poultry

$$\text{litter or CF treatment} - \text{Uptake in CK treatment}) / \text{Total nutrient input from fertilizer} \times 100$$

2.4 Statistical analysis

Data were collected following a completely randomized design (CRD) with three replicates per treatment. Data were analyzed using one-way ANOVA with the GLM procedure in SAS 9.4 to assess differences among treatments. Mean comparisons among treatments were performed using Duncan's New Multiple Range Test at $p < 0.05$. For selected pairwise comparisons in certain tables, T-test was applied at $p < 0.05$. Data are presented as the mean $\pm$ standard deviation of three replicates; if no standard deviation is shown, all replicates were identical or $\text{SD} < 0.1$. Graphs were generated using SigmaPlot 12.5 and PowerPoint, with different letters indicating significant differences among treatments.

3 Results

3.1 Fertilizer properties

The pelletized poultry litter fertilizers used in both the incubation and pot experiments were the pelletized poultry litter with coffee grounds and pelletized poultry litter with tea waste (Table 1). These two fertilizers exhibited generally similar physicochemical characteristics, although minor differences were evident. The organic matter content was 86% for pelletized poultry litter with coffee grounds and 84% for pelletized poultry litter with tea waste, indicating that both materials were rich in carbonaceous components derived from the poultry litter and organic by-products. Total N content was slightly higher in pelletized poultry litter with coffee grounds (3.4%) than in pelletized poultry litter with tea waste (2.9%), while total P contents were 0.5% and 0.4%, respectively. In general, pelletized poultry litter with coffee grounds showed marginally higher water content, organic matter, total N, and total P levels, as well as elevated heavy metals (Cd 0.3 mg kg⁻¹, Cr 0.2 mg kg⁻¹, and Ni 5.7 mg kg⁻¹).

Importantly, no *Escherichia coli* was detected in either pelletized poultry litter fertilizer, which was likely attributed to the pelletization process. During granulation, internal temperatures can reach approximately 70°C, sufficient to inactivate most pathogenic microorganisms, thereby improving product hygiene and biosafety. After pelletization, the fertilizers were further dried at 70°C to reduce residual moisture and prevent microbial regrowth. The dried pellets were subsequently stored in a vacuum desiccator prior to use, ensuring stability and safety during the experimental period. Such thermal treatment and controlled storage conditions

TABLE 1 Basic properties of the fertilizers used in this study.

Properties ¹	Fertilizer ²		G508 Standards ³
	SCG-PPL	TW-PPL	
C/N ratio	14.6 ± 0.02a	17.0 ± 0.01a	10-20
Water content (%)	3.8 ± 0.02a	2.9 ± 0.06b	<20
pH	7.2 ± 0.04b	7.6 ± 0.05a	5-9
OM (%)	85.5 ± 0.06a	84.0 ± 0.07a	>40.0
TN (%)	3.4 ± 0.05a	2.9 ± 0.04b	>2.5
P (%)	0.5 ± 0.02a	0.4 ± 0.01b	0.2-1.3
K (%)	2.4 ± 0.03a	2.5 ± 0.03a	0.4-4.0
As (mg/kg)	ND	ND	<25.0
Cd (mg/kg)	0.3 ± 0.01	ND	<2.0
Cr (mg/kg)	0.2 ± 0.01	ND	<150
Cu (mg/kg)	44 ± 5.7	50 ± 3.1	<100
Hg (mg/kg)	<1.0	<1.0	<1.0
Ni (mg/kg)	5.7 ± 0.02	ND	<25.0
Pb (mg/kg)	ND	ND	<150
Zn (mg/kg)	291	293	<500
Total enterobacteria (MPN/g)	ND	ND	<1×10 ³

Different letters indicate significant differences among treatments based on T-test at $p < 0.05$.

¹OM, organic matter; TN, total nitrogen; ND, not detectable.

²Granular poultry litter with spent coffee grounds (SCG-PPL), granular poultry litter with tea waste (TW-PPL).

³G508 Standards, as announced by the Agriculture and Food Agency of Agriculture of Council of Taiwan.

⁴Each value represents the mean of three replicates ± SE; ND, Not detectable.

not only minimized the risk of contamination but also maintained consistent nutrient availability for the subsequent soil and plant experiments.

3.2 Soil pH and EC dynamics during incubation

Temporal variations in soil pH during the incubation experiment differed among treatments (Figure 1a). Except for the

CF treatment, soil pH remained relatively stable, fluctuating between 8.2 and 8.8 throughout the 60-day period. The CF treatment, in contrast, showed a noticeable decline in pH from day 10 to day 30, followed by gradual recovery, which can likely be attributed to nitrification processes releasing protons during ammonium oxidation.

For all treatments except CF, EC values ranged from 0.1 to 0.3 dS m⁻¹ (Figure 1b). In the CF treatment, EC increased sharply up to day 30 and subsequently decreased. The higher application rates of pelletized poultry litter fertilizers (2C and 2T treatments) resulted in proportionally higher EC values, suggesting that ion release was influenced by the quantity of pellets applied and the gradual release of their organic components.

3.3 Soil N and P dynamics during incubation

The temporal changes in soil inorganic N forms are presented in Figures 2a, b. At the beginning of incubation (day 0), the CF treatment exhibited the highest NH₄⁺-N concentration (41.33 mg kg⁻¹), reflecting the immediate availability of inorganic N from synthetic sources. However, this concentration rapidly decreased to 0–8.9 mg kg⁻¹ between day 10 and day 60 as ammonium was converted to nitrate or assimilated by soil microorganisms.

In contrast, pelletized poultry litter treatments exhibited delayed but sustained NH₄⁺-N release patterns, characteristic of organic slow-release fertilizers. The 2C treatment reached its peak at 10.4 mg kg⁻¹ on day 20, whereas the 2T treatment peaked slightly later, at 9.8 mg kg⁻¹ on day 30. Thereafter, NH₄⁺-N concentrations gradually declined across all treatments. For NO₃⁻-N (Figure 2b), CF treatment peaked on day 10 and then decreased, while pelletized poultry litter treatments maintained lower levels throughout days 20–30, reflecting the slower nitrification rate and gradual nutrient release from organic matrices.

Olsen-P concentrations ranged from 9.3 to 31.8 mg kg⁻¹ (Figure 2c). Among all treatments, 2T treatment consistently exhibited the highest available P levels, followed by 2C treatment, which was higher than those in CF and CK treatments. The overall sequence of P release was 2T > 2C > T ≈ C > CF ≈ CK, highlighting

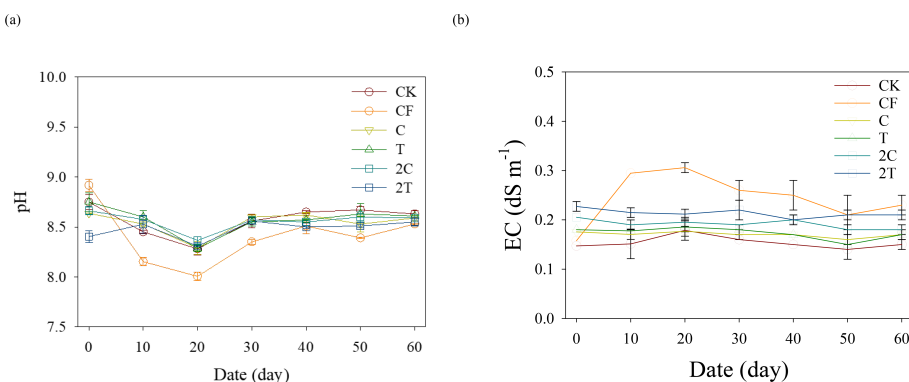


FIGURE 1

Changes in pH (a) and EC (b) in soils during the incubation experiment under different treatments ($n = 3$). Control (CK), chemical fertilizer with urea at the recommended rate (CF), granular poultry litter with spent coffee grounds at the recommended rate (C), granular poultry litter with tea waste at the recommended rate (T), double the recommended rate of poultry litter with spent coffee grounds (2C), and double the recommended rate of poultry litter with tea waste (2T).

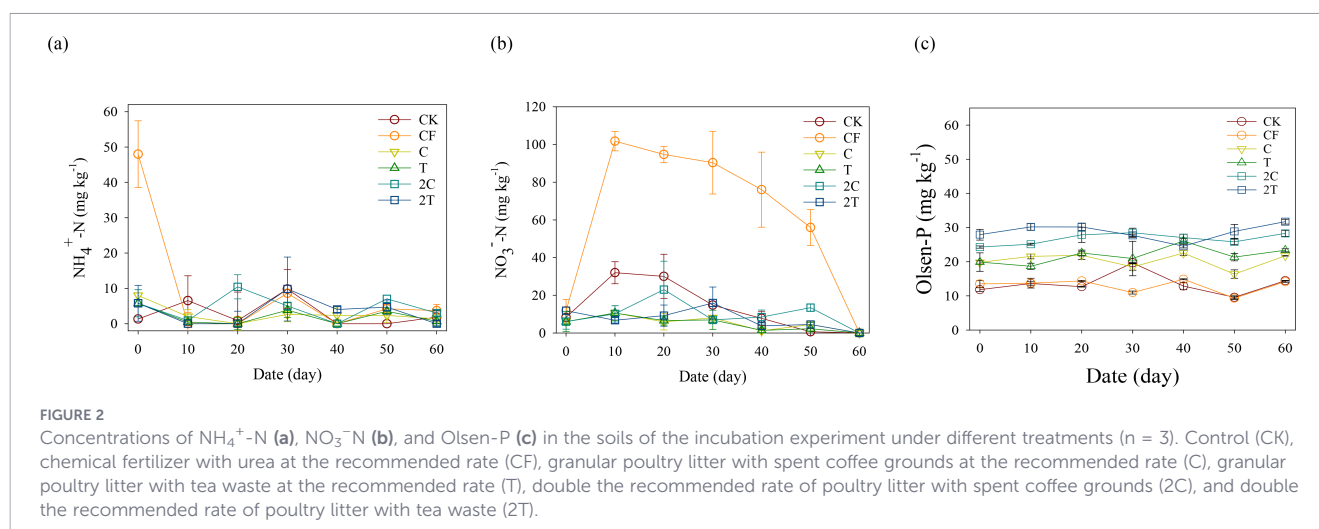


FIGURE 2

Concentrations of $\text{NH}_4^+\text{-N}$ (a), $\text{NO}_3^-\text{-N}$ (b), and Olsen-P (c) in the soils of the incubation experiment under different treatments ($n = 3$). Control (CK), chemical fertilizer with urea at the recommended rate (CF), granular poultry litter with spent coffee grounds at the recommended rate (C), granular poultry litter with tea waste at the recommended rate (T), double the recommended rate of poultry litter with spent coffee grounds (2C), and double the recommended rate of poultry litter with tea waste (2T).

the superior P availability from pelletized organic formulations, particularly at higher application rates.

3.4 Soil properties after the pot experiment

Following the pot experiment, the soil, classified as silty loam, remained alkaline ($\text{pH} > 8.5$) across all treatments (Figure 3a). The CF treatment retained the highest pH, followed by C and T treatments, whereas CK, 2C, and 2T treatments exhibited slightly lower values, possibly due to enhanced microbial activity and organic acid formation during pellet decomposition.

Soil EC showed a clear dependence on fertilizer dosage (Figure 3b). The 2C and 2T treatments produced the highest EC values, followed by C and T treatments, yet all remained below the 2.0 dS m^{-1} threshold that might adversely affect plant growth. Wet aggregate stability ranged from 28.5% to 50.8%, with no significant differences among treatments (Figure 3c), indicating that pelletized poultry litter addition did not negatively impact soil structure.

Soil organic matter contents were higher in pelletized poultry litter treatments (2.3–2.8%) than in CF and CK treatments (Figure 3d), demonstrating the carbon-enriching effect of organic amendments. Available N was highest in T (6.19 mg kg^{-1}) and 2T (5.31 mg kg^{-1}) treatments, but lowest in CF treatment (2.88 mg kg^{-1}) (Figure 3e), suggesting sustained N release from the pelletized poultry litter matrices. Similarly, available P peaked in 2C and 2T treatments ($36.1\text{--}38.8 \text{ mg kg}^{-1}$), markedly exceeding CF treatment (23.0 mg kg^{-1}) (Figure 3f).

Exchangeable K was maximized under 2T treatment (133.7 mg kg^{-1}) (Figure 4a), while Ca and Mg ranged $3781\text{--}5348 \text{ mg kg}^{-1}$ and $178\text{--}368 \text{ mg kg}^{-1}$, respectively (Figures 4b, c). Total Cu concentrations were elevated in T, 2C, and 2T treatments ($21.3\text{--}22.7 \text{ mg kg}^{-1}$) compared to CK and CF treatments ($16.3\text{--}17.5 \text{ mg kg}^{-1}$), with available Cu increasing by 10–17% (Figure 4d). Although total Zn remained comparable across treatments, available Zn significantly increased under 2T treatment (4.0 mg kg^{-1}) and 2C treatment (3.8 mg kg^{-1}), representing up to a 99% improvement relative to CK treatment. These results demonstrate that pelletized poultry litter not only enhance soil fertility but also improve micronutrient bioavailability.

3.5 Growth performance and elemental content of *Brassica rapa* var. chinensis

Growth parameters of *Brassica rapa* var. chinensis (shoot fresh and dry weights and height) showed distinct responses to fertilizer treatments. The 2T treatment achieved the best performance, with mean shoot fresh weight of $3.69 \text{ g plant}^{-1}$, dry weight of $0.35 \text{ g plant}^{-1}$, and height of 24.03 cm, indicating that pelletized poultry litter with tea waste applied at a double rate most effectively supported plant growth. SPAD readings, representing relative chlorophyll content, did not differ significantly among treatments (Table 2).

Elemental analysis revealed treatment-dependent nutrient accumulation patterns (Figure 5). N concentration was highest in CF treatment (2.7%), consistent with the immediate availability of inorganic N, while C and 2T treatments exhibited lower values (1.8–1.9%), similar to CK treatment (Figure 5a). P concentrations were markedly elevated in 2C and 2T treatment (1.1–1.2%) (Figure 5b), whereas K was highest in 2T treatment (5.2%) (Figure 5c). Ca concentration was greatest in CK treatment (13.9%), while Mg ranged from 0.4–0.7% across treatments (Figures 5d, e). Cu was undetectable in plant tissues, whereas Zn ranged from 84 to 100 mg kg^{-1} in pelletized poultry litter treatments (Figure 5f).

3.6 Nutrient uptake efficiency of plants

As summarized in Table 3, N uptake efficiency reached its highest value under 2T treatment (5.9%), while P uptake ranged from 0.1% to 4.7%, and K uptake peaked at 10.0% in the T treatment. Zn uptake efficiency was also greatest in T treatment (4.4%). Despite these improvements, nutrient uptake efficiencies for N, P, K, Cu, and Zn were generally below 10%, and negative values were observed for N, K, and Zn in the C treatment, possibly due to nutrient immobilization or antagonistic interactions within the soil matrix.

Compared with the CF treatment, most pelletized poultry litter treatments exhibited lower N uptake efficiency, reflecting the inherently slower nutrient release of organic fertilizers. Nonetheless, pelletized poultry litter treatments provided sustained

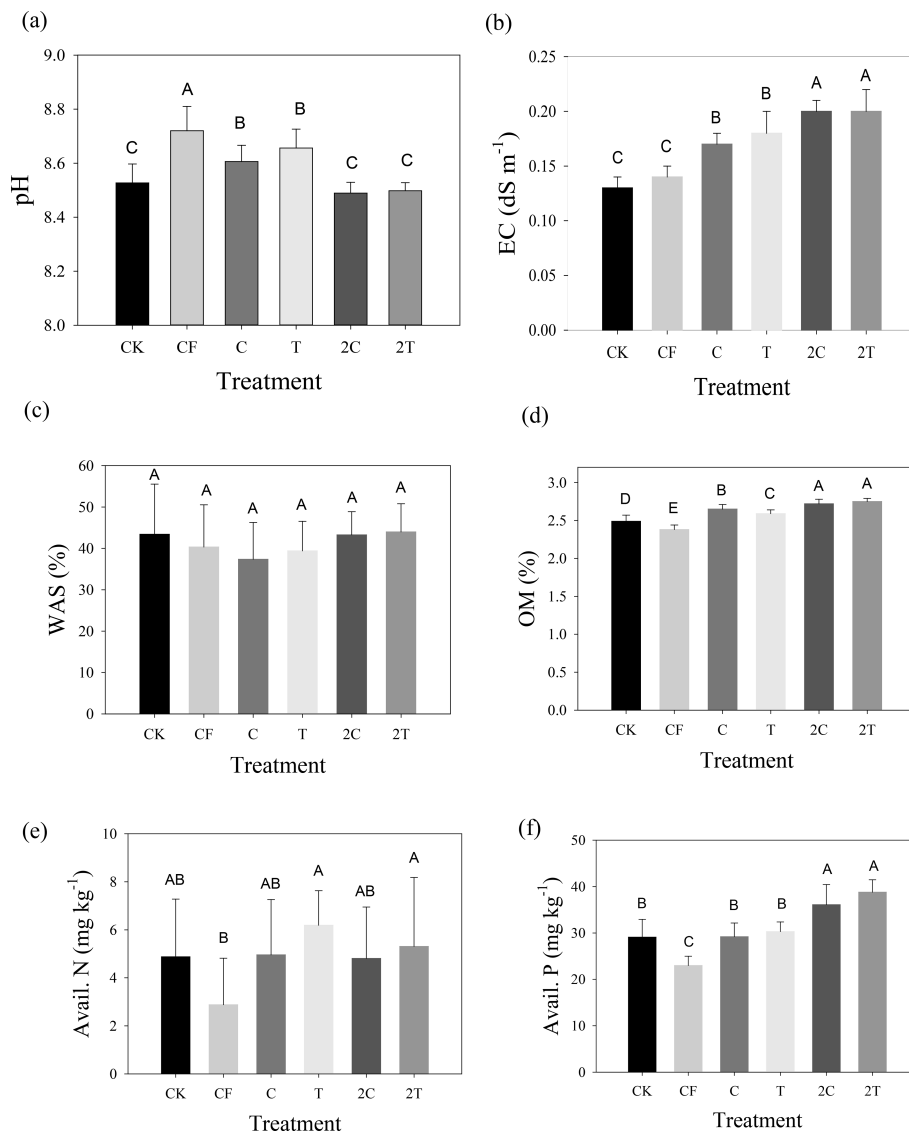


FIGURE 3

The pH values (a), EC values (b), wet aggregate stability (WAS) (c), organic matter content (OM) (d), and the contents of available N (Avail. N) (e) and available P (Avail. P) (f) of the soils after the pot experiment under different treatments. The different letters indicate the significance among the treatments obtained through one-way ANOVA analysis (Duncan test, $p < 0.05$, $n = 3$). Control (CK), chemical fertilizer with urea at the recommended rate (CF), granular poultry litter with spent coffee grounds at the recommended rate (C), granular poultry litter with tea waste at the recommended rate (T), double the recommended rate of poultry litter with spent coffee grounds (2C), and double the recommended rate of poultry litter with tea waste (2T).

nutrient release and improved P and K uptake over time, supporting gradual plant growth and soil fertility improvement.

3.7 Disposal of PL, SCG, and TW

The potential of utilizing poultry litter, pelletized poultry litter with coffee grounds, and pelletized poultry litter with tea waste as raw materials for fertilizer recycling was evaluated based on agricultural data. According to the 2022 report from the Department of Agriculture and Food Administration of Taiwan, *Brassica rapa* var. chinensis was cultivated on 5322 ha, with a total production of approximately 100 kt. Using the recommended N rate of 200 kg ha⁻¹ (equivalent to 100 mg N kg⁻¹ soil), and considering total N contents of 3.4% and 2.9% for pelletized poultry litter with coffee grounds and

pelletized poultry litter with tea waste, respectively, the required application rates were calculated to be 2.9 g pelletized poultry litter kg⁻¹ soil for pelletized poultry litter with coffee grounds and 3.5 g pelletized poultry litter kg⁻¹ soil for pelletized poultry litter with tea waste (Equation 3).

These application rates correspond to approximately 29 kt of pelletized poultry litter with coffee grounds and 30 kt of pelletized poultry litter with tea waste for the total *Brassica rapa* var. chinensis cultivation area in Taiwan. Given the material compositions of the two fertilizers—79% poultry litter + 21% spent coffee grounds for pelletized poultry litter with coffee grounds, and 93% poultry litter + 7% tea waste for pelletized poultry litter with tea waste—this would recycle approximately 23 kt poultry litter and 6 kt spent coffee grounds, or 28 kt poultry litter and 2 kt tea waste, respectively. In

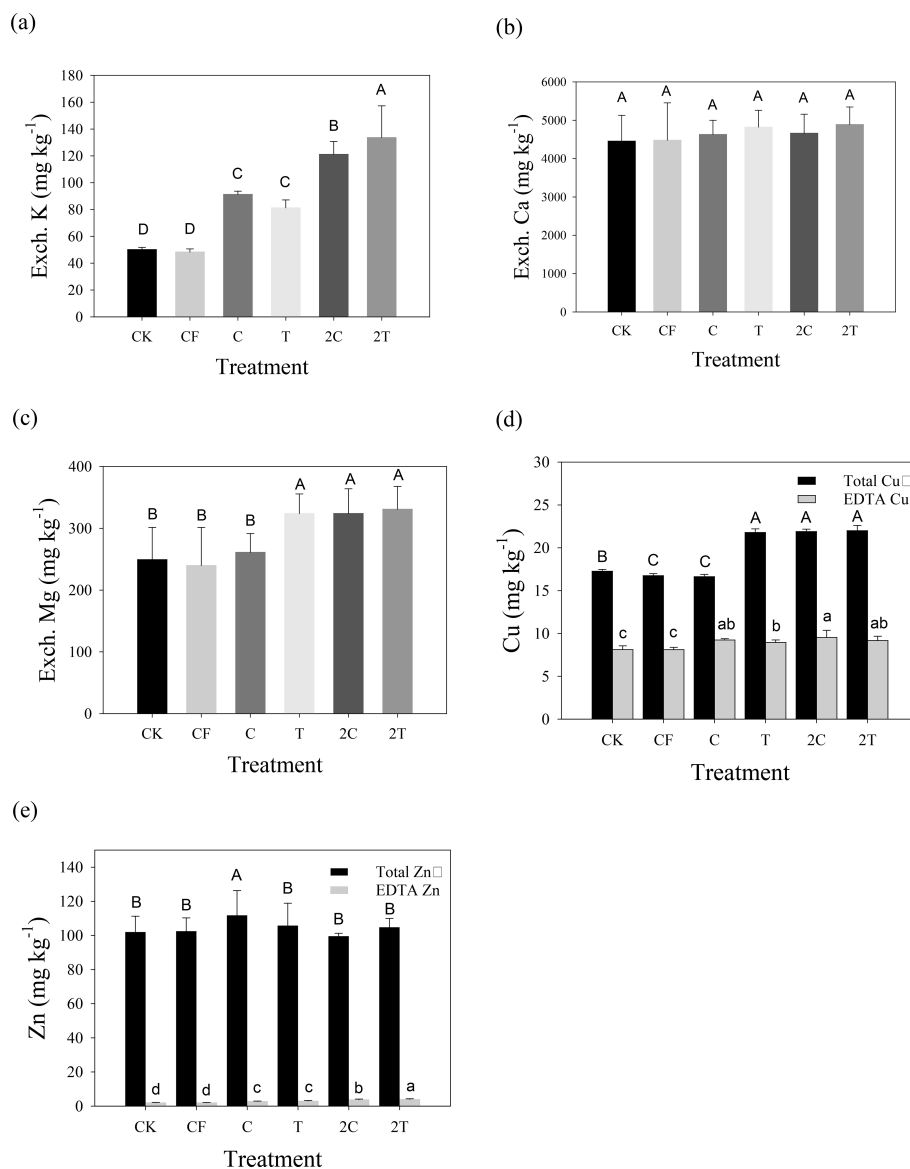


FIGURE 4

The concentrations of exchangeable K (a), exchangeable Ca (b), exchangeable Mg (c), total and EDTA extractable Cu (d), and total and EDTA extractable Zn (e) in the soil after the pot experiment under different treatments. The different letters indicate the significance among the treatments obtained through one-way ANOVA analysis (Duncan test, $p < 0.05$, $n = 3$). Control (CK), chemical fertilizer with urea at the recommended rate (CF), granular poultry litter with spent coffee grounds at the recommended rate (C), granular poultry litter with tea waste at the recommended rate (T), double the recommended rate of poultry litter with spent coffee grounds (2C), and double the recommended rate of poultry litter with tea waste (2T).

2022, Taiwan generated about 40 kt of poultry litter, 29 kt of spent coffee grounds, and 22 kt of tea waste. Therefore, the application of pelletized poultry litter with coffee grounds and pelletized poultry litter with tea waste in *Brassica rapa* var. chinensis production could potentially recycle around 20% of national spent coffee grounds and 58% of poultry litter, or 11% of tea waste and 70% of poultry litter, respectively (Table 4). These findings highlight the environmental and circular economy benefits of reusing organic residues as sustainable fertilizer resources.

Fertilizer application rate (kg ha⁻¹)

= Required nutrient amount in fertilizer (kg ha⁻¹)

× (100 / (Nutrient content of the fertilizer (%))) (3)

4 Discussions

Pelletized poultry litter with coffee grounds and pelletized poultry litter with tea waste fertilizers exhibited only minor differences in their chemical and physical properties. pelletized poultry litter with coffee grounds showed slightly higher levels of organic matter, total N, total P, and heavy metals, likely due to its higher spent coffee grounds content (19% vs. 6.5% tea waste), as well as the presence of minor components such as rice husk and soybean meal, combined with small random variations in nutrient distribution during the granulation process. Pelletization reduced water content and bulk volume, which facilitated storage, handling, transport, and application, while fresh manure is typically associated with environmental risks such as N volatilization and

TABLE 2 The agronomic traits of *Brassica rapa* var. *chinensis* under different treatments (mean ± standard error; n = 3).

Treatment	Height cm	SPAD reading	Fresh weight ---g/plant---	Dry weight
CK	16.05 ± 2.78 b	10.5 ± 1.4 a	1.30 ± 0.21 c	0.12 ± 0.02 b
CF	18.96 ± 3.33 b	9.70 ± 2.4 a	1.96 ± 0.39 c	0.15 ± 0.04 b
C	16.38 ± 1.59 b	11.6 ± 3.5 a	1.04 ± 0.94 c	0.10 ± 0.02 b
T	19.21 ± 3.92 b	11.1 ± 2.2 a	3.48 ± 0.3 bc	0.30 ± 0.05 a
2C	23.51 ± 5.92 a	11.3 ± 1.5 a	3.56 ± 0.9 ab	0.28 ± 0.10 b
2T	24.03 ± 3.73 a	11.2 ± 1.3 a	3.69 ± 1.32 a	0.35 ± 0.17 a

Different letters indicate a significant among treatment by one-way ANOVA analysis (Duncan test, $p < 0.05$). Control (CK), chemical fertilizer with urea at the recommended rate (CF), granular poultry litter with spent coffee grounds at the recommended rate (C), granular poultry litter with tea waste at the recommended rate (T), double the recommended rate of poultry litter with spent coffee grounds (2C), and double the recommended rate of poultry litter with tea waste (2T).

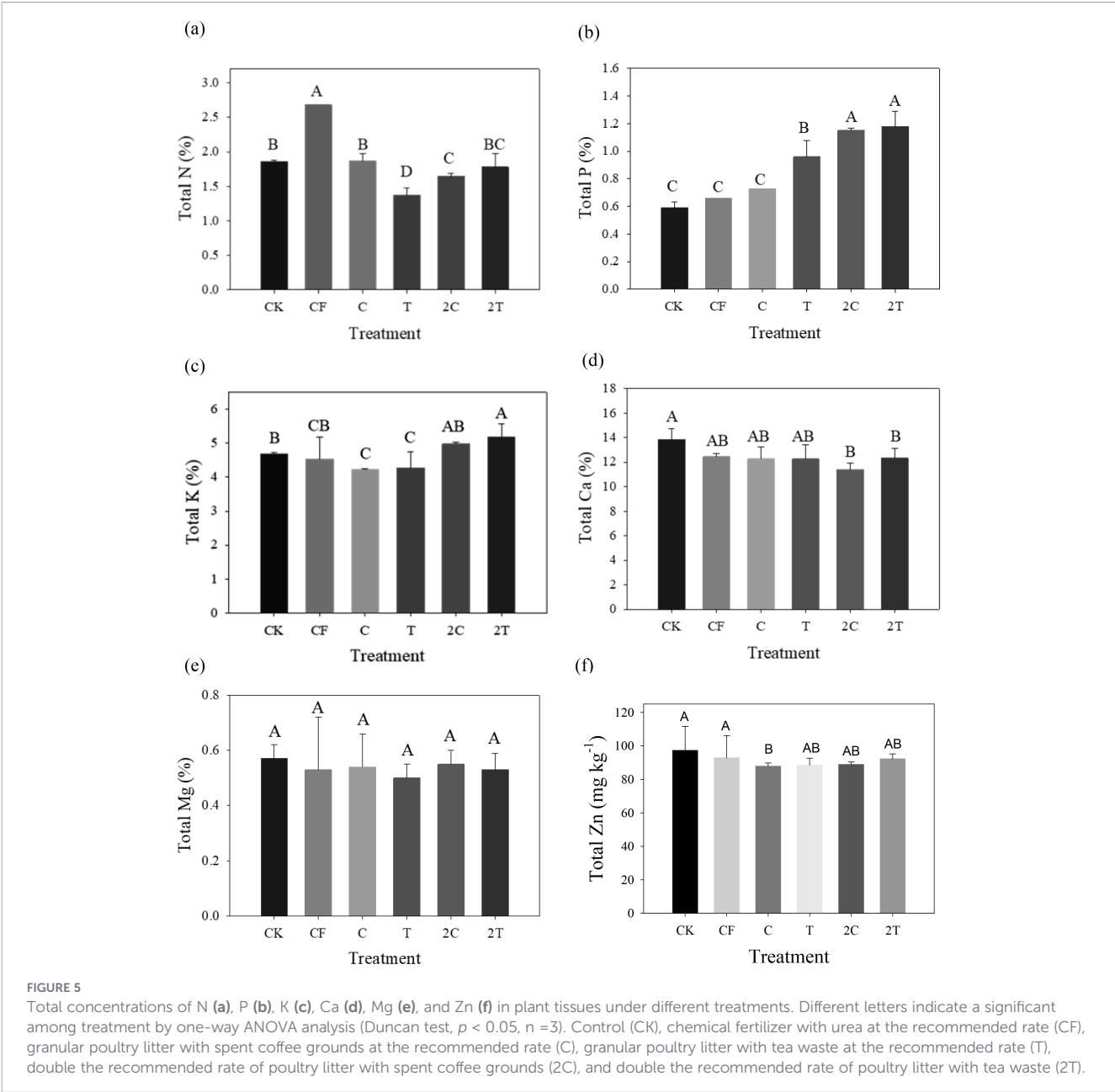


TABLE 3 Nutrition uptake efficiency of *Brassica rapa* var. *chinensis* under different treatments.

Treatment	N	P	K -----%-----	Cu	Zn
CF	5.5 ± 0.05b	–	–	–	–
C	-1.1 ± 0.03e	0.1 ± 0.02d	-2.3 ± 0.06d	ND	-0.1 ± 0.02d
T	2.8 ± 0.11d	4.7 ± 0.08a	10.0 ± 0.12a	ND	4.4 ± 0.03a
2C	3.6 ± 0.06c	2.9 ± 0.03c	7.1 ± 0.09c	ND	2.3 ± 0.05c
2T	5.9 ± 0.01a	3.4 ± 0.02b	7.9 ± 0.12b	ND	3.0 ± 0.02b

Different letters indicate a significant among treatment by one-way ANOVA analysis (Duncan test, $p < 0.05$).

ND, not detectable.

Control (CK), chemical fertilizer with urea at the recommended rate (CF), granular poultry litter with spent coffee grounds at the recommended rate (C), granular poultry litter with tea waste at the recommended rate (T), double the recommended rate of poultry litter with spent coffee grounds (2C), and double the recommended rate of poultry litter with tea waste (2T).

P leaching or runoff (Sims and Wolf, 1994). Microbiological safety was confirmed, as no *Escherichia coli* was detected in either fertilizer, likely owing to the granulation process reaching temperatures of approximately 70°C, with further drying and vacuum storage prior to experiments ensuring complete inactivation of potential pathogenic microorganisms.

During the incubation period, soil pH dynamics varied among treatments. Most treatments maintained relatively stable pH values between 8.2 and 8.8, whereas the CF treatment experienced a pronounced decline from day 10 to 30, followed by a gradual recovery (Figure 1a). This pattern is consistent with the release of H^+ during nitrification of the applied fertilizer (Maticic et al., 2024), while the subsequent pH rebound likely reflects the buffering capacity of the soil. Pelletized poultry litter treatments slightly lowered pH at the beginning, but minor changes afterward indicated that nitrification was limited during the incubation period. Soil EC also varied among treatments, reflecting the accumulation of cations (K, Ca, Mg) in the soil solution. Similar effects on soil pH and cation availability following organic amendments have been documented (Ali et al., 2023). Increasing pelletized poultry litter application rates corresponded to higher EC values, which likely indicates enhanced solubilization of exchangeable cations from the decomposing pellets. In this study, however, EC values remained within the acceptable range for crop

production, indicating that the applied rates did not cause adverse salinity effects ($<2 \text{ dS m}^{-1}$; Maas and Grattan, 1999).

The temporal patterns of NH_4^+-N concentrations showed initial peaks followed by declines in all treatments, reflecting the combined influences of ammonification, nitrification, microbial immobilization, and volatilization processes (Borken and Matzner, 2009; Gu et al., 2012). $NO_3^- -N$ concentrations remained lower in all pelletized poultry litter treatments compared with the chemical fertilizer (CF) treatment, particularly on days 20 and 30. This is likely due to the inhibitory effects of polyphenols, lignin, and caffeine present in spent coffee grounds and tea waste, which suppress microbial decomposition of organic matter and limit nitrification (Cruz and Marques Dos Santos Cordovil, 2015; Hardgrove and Livesley, 2016). The inhibitory effects of residual polyphenols and other compounds on microbial decomposition and nitrification are also widely reported for spent coffee grounds, where low application rates can benefit plant growth and soil health, whereas higher rates may suppress growth without pretreatment (Hu et al., 2025). Thus, while PPL may suppress initial N release, compared with CF it enables nitrogen to be released more gradually and sustainably, providing a slower but steady N supply. In contrast, CF, lacking these inhibitory compounds, allowed more rapid N release and nitrification, resulting in higher $NO_3^- -N$ availability. Combined amendment studies indicate that co-applications of biochar with organic fertilizers can influence nitrogen release dynamics, suggesting that amendment composition and interactions may modify N release patterns in amended soils (Pulliam et al., 2025). Olsen-P concentrations, reflecting plant-available P, were enhanced in pelletized poultry litter treatments through release and competition for sorption sites on soil particles (Rishid, 2019), following the order $2T > 2C > T \approx C > CF \approx CK$ (Figure 2c).

Available N was significantly higher in T treatment (6.19 mg kg^{-1}) and 2T treatment (5.31 mg kg^{-1}), while CF treatment was lowest (2.88 mg kg^{-1}) (Figure 3e). This difference may be attributed to processes such as microbial immobilization, plant uptake, N volatilization, denitrification, leaching, and other related processes. The relatively low levels (optimal: $40\text{--}60 \text{ mg kg}^{-1}$; Ilacob, 1989) may be due to lignin, polyphenols, and caffeine in spent coffee grounds and tea waste, which slow decomposition and

TABLE 4 Recovery rates of poultry litter, spent coffee grounds, and tea waste.

Materials	Required application rate (kt)	Recovery rates (%)
SCG-PPL		
PL	23	58
SCG	6	20
TW-PPL		
PL	28	70
TW	2	11

Poultry litter (PL), tea waste (TW), spent coffee grounds (SCG), granular poultry litter with spent coffee grounds (SCG-PPL), granular poultry litter with tea waste (TW-PPL), kiloton (kt).

promote microbial immobilization. In addition, the high pH of the tested soil could have facilitated NH_3 volatilization and N losses through the nitrification process (He et al., 1999). In addition, available P was highest in 2C and 2T treatments ($36.1\text{--}38.8\text{ mg kg}^{-1}$) and lowest in CF treatment (23.0 mg kg^{-1}) (Figure 3f). Although soil pH ($8.2\text{--}8.8$) favors P precipitation with Ca (Rishid, 2019), the decomposition of pelletized poultry litter can release available P and compete with phosphate for sorption sites on soil surfaces, thereby reducing fixation and enhancing availability (Wang et al., 2022). These findings align with recent studies demonstrating that co-composted poultry litter biochar increases soil nutrient availability and plant uptake (Ali et al., 2023). Consequently, sufficient available P was maintained in this study (Tian et al., 2019). Exchangeable K was highest in 2T treatment (133.7 mg kg^{-1}), significantly exceeding CK and CF treatments ($46.0\text{--}51.8\text{ mg kg}^{-1}$) (Figure 4a). All pelletized poultry litter treatments were within the suitable range (Akbas et al., 2017). Exchangeable Ca ($3781\text{--}5348\text{ mg kg}^{-1}$) exceeded the ideal range ($1120\text{--}2240\text{ mg kg}^{-1}$; Jones, 2001) (Figure 4b), reflecting the calcareous nature of the soil, with T and 2T treatments showing higher values, although the differences were not significant. Exchangeable Mg ($178\text{--}368\text{ mg kg}^{-1}$) was highest in T, 2C, and 2T treatments, mostly within the recommended range ($150\text{--}350\text{ mg kg}^{-1}$; Jones, 2001) (Figure 4c), suggesting pelletized poultry litter also improved Mg availability. For micronutrients, total Cu was higher in T, 2C, and 2T treatments ($21.3\text{--}22.7\text{ mg kg}^{-1}$) than in CK and CF treatments ($16.3\text{--}17.5\text{ mg kg}^{-1}$) (Figure 4d). Available Cu increased by 10–17% under pelletized poultry litter treatments compared with CK treatment. Similarly, total Zn did not differ significantly, but available Zn increased markedly, especially under 2T treatment (4.0 mg kg^{-1}) and 2C treatment (3.8 mg kg^{-1}), representing up to 99% higher than CK treatment. High soil pH, CaCO_3 , clay, and phosphates often cause Zn immobilization, whereas humic substances in organic matter, such as humic acid and fulvic acid, contain multiple functional groups that can form complexes with Zn^{2+} , increasing Zn solubility and mobility. At the same time, small molecules such as amino acids, hydroxy acids, and phosphates can also enhance Zn availability (Hafeez et al., 2013). Similar patterns of improved nutrient cycling with organic amendments have also been reported in greenhouse studies with pelletized poultry litter and cover crop integration, emphasizing the role of organic sources in enhancing soil nutrient dynamics (Freidenreich et al., 2024). Overall, short-term pelletized poultry litter application significantly improved soil nutrient availability, particularly for N, P, K, Mg, Cu, and Zn, while physical properties such as aggregate stability require longer-term application for noticeable effects.

Results from the pot experiment showed that, except for SPAD reading, shoot fresh weight, dry weight, and plant height of *Brassica rapa* var. chinensis were highest under the 2T treatment (fresh weight 3.69 g plant^{-1} , dry weight 0.35 g plant^{-1} , height 24.03 cm), while differences among other treatments were not significant, and SPAD reading did not differ among treatments (Table 2). The superior growth under 2T may be associated with higher soil nutrient availability, although the differences were not statistically significant (Figures 3, 4). In addition, the sustained nutrient release characteristics of pelletized poultry litter combined with tea waste

(2T) can provide a continuous supply of N, P, and K over time. In contrast, chemical fertilizer provides nutrients in readily available forms, which can be rapidly absorbed by plants or lost through leaching or volatilization, potentially limiting longer-term growth benefits. Furthermore, the organic amendments in 2T may improve soil structure, water retention, and microbial activity, all of which can support plant growth. These factors together likely contributed to the observed enhanced biomass under the 2T treatment. Previous studies have reported that spent coffee grounds application can inhibit plant growth due to polyphenols and caffeine (Cervera-Mata et al., 2020), but processing into pelletized poultry litter mitigates these negative effects. The results further indicate that increasing pelletized poultry litter application rates effectively enhanced *Brassica rapa* var. chinensis growth, performing better than CK and CF treatments.

Regarding nutrient content, N concentration was highest in CF treatment (2.7%), while C and 2T treatments (1.9% and 1.8%) did not differ significantly from CK treatment (Figure 5a), all below the optimum range (4.0–5.0%) (Jones, 1964) and exhibiting typical N deficiency symptoms. This may be attributed to the slower and limited N release from organic amendments, with spent coffee grounds and tea waste treatments suppressing nitrification and enhancing microbial immobilization, thereby reducing plant-available N. P concentration was highest under 2C and 2T treatments (1.1–1.2%) (Figure 5b), exceeding the optimum range (0.3–0.7%) (Jones, 1964) and indicating no P deficiency. K concentration peaked in 2T treatment (5.2%) (Figure 5c), above the optimum range (3.3–4.5%) (Jones, 1964), and the higher application rate also enhanced soil exchangeable K, promoting uptake. Ca concentration was highest in CK treatment (13.9%) (Figure 5d), lowest in 2C and 2T treatments, but all exceeded the optimum range (2.8–3.5%) (Jones, 1964), consistent with high exchangeable soil Ca. Mg concentration ranged from 0.4–0.7% with no significant differences among treatments (Figure 5e), within the adequate range (0.3–0.5%) (Jones, 1964).

Cu concentration was undetectable in *Brassica rapa* var. chinensis leaves in this study. This is likely due to the high soil pH limiting Cu availability and uptake, as alkaline conditions reduce Cu solubility and mobility in the soil. Cu concentration was below the adequate range of $5\text{--}30\text{ mg kg}^{-1}$ (Jones, 1964), and leaf curling, chlorosis, and V-shaped folding were observed, consistent with Cu deficiency symptoms. Zn concentration was highest in CK treatment (97 mg kg^{-1}) (Figure 5f), followed by CF treatment, while pelletized poultry litter treatments ranged from $84\text{--}100\text{ mg kg}^{-1}$, slightly lower than CK and CF treatments but within the adequate range ($32\text{--}213\text{ mg kg}^{-1}$) (Jones, 1964), with no deficiency symptoms observed. Although organic amendments increased soil EDTA-extractable Zn, shoot Zn decreased, potentially due to polyphenols and other organic compounds in spent coffee grounds, tea waste, or pelletized poultry litter forming stable Zn complexes that limit root uptake. These chelated Zn forms, while extractable by EDTA, may not be bioavailable, and alkaline soil conditions may further promote formation of poorly soluble Zn compounds. Similar observations were reported by Keeflee et al. (2020), where spent coffee grounds-cow manure compost increased soil pH and phenolic groups, chelating and

immobilizing metals, thereby reducing plant uptake of Zn, Cu, and other heavy metals.

Nutrient uptake efficiency remained below 10% across all treatments, with negative values observed in the C treatment, likely due to the phytotoxic effects of polyphenols and caffeine as well as heavy metal complexation in pelletized poultry litter, which can reduce nutrient bioavailability. While CF treatment enhanced release and nutrient release, pelletized poultry litter treatments generally induced microbial immobilization, limiting plant uptake. The overall low nutrient uptake efficiency is consistent with the alkaline soil conditions and limited shoot biomass, in agreement with previous reports for *Brassica crops* (<5%) (Hsu and Lai, 2022).

5 Conclusion

N incubation showed that pelletized poultry litter made from spent coffee grounds and tea waste slowed the initial N release of organic matter, with the 2C treatment releasing the most N among pelletized poultry litters. However, all pelletized poultry litter treatments caused strong microbial immobilization, likely due to high soil pH and spent coffee grounds/tea waste-mediated nitrification inhibition. Nonetheless, this slower N release provided a more gradual and sustained nutrient supply, supporting improved soil fertility and enhanced growth of *Brassica rapa* var. *chinensis*. Pot experiments indicated that pelletized poultry litter application improved soil organic matter, available N and P, and exchangeable K, Ca, and Mg, as well as available Cu and Zn. These effects were stronger at higher application rates. Total soil Cu and Zn increased by 26.8% and 2.9%, respectively, while their available forms rose by 13.7% and 70.0%. *Brassica rapa* var. *chinensis* nutrient uptake was generally lower than under CF, but pelletized poultry litter with tea waste outperformed pelletized poultry litter with coffee grounds. High soil alkalinity likely restricted N and Cu uptake, limiting growth, whereas uptake of K, Ca, and Mg remained unaffected. Notably, pelletized poultry litter reduced shoot Zn concentration but still improved yield. Among the tested fertilizers, pelletized poultry litter with tea waste performed best by enhancing soil fertility, reducing nutrient antagonism, and supporting growth comparable to or exceeding CF. Tea waste-derived organic chelates may also help regulate Cu and Zn, lowering heavy metal risks. However, nutrient uptake was still constrained by high soil pH, suggesting the importance of matching organic amendments with soil conditions. Pre-composting or vermicomposting spent coffee grounds and tea waste before pelletized poultry litter production could further reduce growth-inhibiting effects and improve N availability. At the production scale, applying pelletized poultry litter with coffee grounds or pelletized poultry litter with tea waste in Taiwan's *Brassica rapa* var. *chinensis* cultivation could recycle about 20% of spent coffee grounds and 58% of poultry litter, or approximately 11% of tea waste and 70% of poultry litter annually, achieving both nutrient supply and sustainable waste utilization.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Y-SH: Data curation, Formal analysis, Investigation, Writing – original draft. K-SC: Writing – original draft. H-YL: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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