

Research Article

Organic Chinese Radish (*Raphanus sativus* L.) Cultivation in Raised Beds with Organic Amendments in Thailand

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ABSTRACT

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This study investigated the effects of combining animal manures and plant-based organic amendments on the growth and yield of Chinese radish under raised-bed cultivation in Thailand, in response to the increasing demand for chemical-free produce and national organic farming initiatives. A 3 × 6 factorial experiment arranged in a Completely Randomized Design (CRD) with three replications was conducted using three animal manures (cattle, poultry, and pig manure) and six plant-based residues (copper pod leaves, dried rice straw, rice husk biochar, rain tree leaves, old mushroom lumps, and filter cake). The results showed that animal manures primarily affected stem growth and root yield, whereas plant residues mainly influenced leaf characteristics. The interaction between animal manures and plant residues significantly affected leaf length, leaf biomass, and root size. Pig manure produced the tallest plants (28.94 cm) and enhanced canopy width, leaf dry weight, and root yield (40.26 cm, 19.31 g, 20.46 g fresh weight, and 1.39 g dry weight, respectively). Rice husk biochar significantly increased leaf width, leaf length, and leaf area (5.54 cm, 12.97 cm, and 45.79 cm², respectively). The combination of poultry manure and rice straw resulted in the highest leaf fresh and dry weights (310.54 and 29.34 g, respectively), while pig manure combined with filter cake produced the largest root diameter (64.16 mm), root circumference (19.33 cm), and root fresh weight (31.79 g). In contrast, poultry manure combined with mushroom lumps resulted in reduced growth and biomass accumulation compared with other treatment combinations. These findings demonstrate that appropriate combinations of organic amendments can improve nutrient availability, plant growth, and root development under raised-bed cultivation systems. The study highlights the potential of locally available organic materials for sustainable and chemical-free Chinese radish production in limited cultivation areas.

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1. Introduction

Chinese radish (*Raphanus sativus* L.) is a widely cultivated root vegetable in Thailand, appreciated for its culinary versatility, nutritional value, and economic significance. Traditionally grown in open-field systems, its production often relies on synthetic fertilizers and pesticides, which can deteriorate soil health, pollute water sources, and pose risks to consumer safety. Particularly concerning is the repeated cultivation of radish in the same plots two to three times per year, which may further deplete soil fertility over time (Thai Post, 2025). In response to growing consumer demand for chemical-free produce and national initiatives to expand organic farming, such as

Thailand's plan to develop over 208,000 hectares of organic farmland (ASEAN Post, 2020). Thus, sustainable cultivation practices have garnered increasing attention. Moreover, limited agricultural land, rising demand for safe and sufficient food, an aging society, and labor shortages in the agricultural sector have collectively driven a shift in production processes and farming techniques. Under these constraints, intensive production systems and technological innovations have become essential to enhance efficiency and productivity. Among these, raised bed systems present a promising alternative to conventional field cultivation, particularly in tropical regions (Norsuwan *et al.*, 2021). Raised-bed cultivation provides another promising solution for small-scale chemical-free vegetable production. By

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elevating the growing medium above ground level. Recent studies indicate that raised-bed systems can increase crop yields compared to conventional planting (Khwunsakun, 2022). These systems improve drainage, reduce soil-borne interference, and allow for precise control of growing media composition (Elizabeth *et al.*, 2018). When paired with organic amendments, raised beds can enhance root development and minimize pest pressure, supporting chemical-free production (Brown, 2023; Sharma, 2021). One of the greatest advantages of raised bed is the ability to amend the soil for the bed. Diverse agricultural by-products can be used for growing substrates for the raised bed. Organic amendments such as rice husk biochar, mushroom waste, and sugarcane filter cake have shown potential to improve soil fertility, microbial activity, and nutrient retention. Rice husk biochar, for instance, increases cation exchange capacity and supports microbial diversity in degraded soils (De la Rosa *et al.*, 2023). Filter cake, a byproduct of sugarcane processing, is rich in phosphorus and potassium, contributing to long-term soil productivity (Ketrot *et al.*, 2026). Mushroom waste also offers high organic matter content and beneficial microbial populations, which can enhance water

retention and plant vigor (Aiduang *et al.*, 2025). The raw materials come from different origins, which may limit the amount of nutrients to crop requirements. The need for it combines with the animal manure, cattle, poultry, and pig manure, which are normally used as organic sources to obtain more nutritionally complete sources (Santos *et al.*, 2025). Although previous studies have demonstrated the benefits of raised-bed cultivation and organic amendments for vegetable production, most studies have focused on the effects of individual organic materials or general organic fertilizer applications. Limited information is available regarding the combined use of locally available animal manures and plant-based residues under raised-bed systems, particularly for Chinese radish production in tropical environments. In addition, the compatibility of different organic amendment combinations and their influence on both vegetative growth and root development remain insufficiently understood. Therefore, this study aimed to evaluate the effects of combining different animal manures and plant-based organic materials on the growth and yield of Chinese radish cultivated under raised-bed conditions in Thailand.

Table 1 Chemical properties of planting materials amended with different animal manures after 60 days of fermentation.

Treatments	pH	EC (mS/cm)	OM (%)	Total N (%)	P (%)	K (%)
1. copper pod leaves + cattle manure	7.48	0.98	20.15	0.61	0.19	0.84
2. dried rice straw + cattle manure	7.80	1.00	11.90	0.47	0.13	1.09
3. rice husk biochar + cattle manure	7.53	0.88	13.70	0.38	0.16	0.47
4. rain tree leaves + cattle manure	7.58	0.89	14.23	0.53	0.13	0.87
5. old mushroom lumps + cattle manure	7.88	0.98	19.65	0.68	0.15	0.58
6. filter cake + cattle manure	7.42	1.01	18.42	0.85	0.74	0.82
7. copper pod leaves + poultry manure	7.65	1.80	21.11	1.01	1.44	0.60
8. dried rice straw + poultry manure	7.72	3.63	17.86	1.05	1.60	0.91
9. rice husk biochar + poultry manure	7.48	0.98	20.15	0.61	0.19	0.46
10. rain tree leaves + poultry manure	7.80	1.00	11.90	0.47	0.13	0.60
11. old mushroom lumps + poultry manure	7.90	2.31	23.44	0.97	1.33	0.82
12. filter cake + poultry manure	6.59	1.70	22.24	0.84	0.71	0.61
13. copper pod leaves + pig manure	7.40	1.92	18.92	1.00	1.50	0.86
14. dried rice straw + pig manure	6.60	1.94	19.78	0.82	1.87	0.62
15. rice husk biochar + pig manure	6.76	1.07	11.50	0.32	0.94	0.43
16. rain tree leaves + pig manure	6.55	1.17	14.30	0.84	0.69	0.49
17. old mushroom lumps + pig manure	7.38	1.32	23.14	0.86	0.73	0.68
18. filter cake + pig manure	6.67	2.16	19.35	0.92	1.28	1.00

Source: adapted from Somniyam *et al.* (2025a)

2. Materials and Methods

The effects of different organic amendments from plant-based and animal manures on the growth and yield of Chinese radish were studied. The study was performed at the plant nursery of the Faculty of Agriculture, Uttaradit Rajabhat

University, Thailand, from May to July 2023. The experimental design was a 3 × 6 factorial arrangement in a Completely Randomized Design (CRD) with three replications. The two factors were: Factor A is the type of animal manure (three levels), including cattle manure, poultry manure, and pig

manure. Factor B is the type of plant-based organic matter (six levels), consisting of copper pod leaves (*Peltophorum pterocarpum* (DC.) K. Heyne), dried rice straw, rice husk biochar, rain tree leaves (*Samanea saman* (Jacq.) Merr.), old mushroom lumps, and filter cake (a sugarcane processing byproduct). All organic materials were air-dried and chopped or ground as appropriate before being mixed according to the treatment combinations at a ratio of 1:2:3 (soil: animal manure: organic material, v/v). The mixtures were composted for 60 days prior to use. The chemical properties of the composted were previously analyzed and reported by Somniam *et al.* (2025a) as shown in Table 1. Chinese radish seedlings were initially grown in seedling trays for 14 days and subsequently transplanted into black perforated plastic containers (66 cm in diameter and 53 cm in height), each filled with 20 L of the respective growing media. The containers were placed on steel bench shelves positioned 80 cm above ground level to facilitate drainage and reduce soil-borne interference, thereby simulating a raised-bed cultivation system. All containers were arranged randomly in the nursery and managed under standard organic cultivation practices. No synthetic fertilizers or pesticides were applied, and weed control was performed manually. Irrigation was provided via a micro-sprinkler system. Growth and yield data were recorded 45 days after transplanting. Growth parameters included plant height, number of leaves, leaf width and length, leaf area, canopy width, leaf greenness, leaf fresh weight, and leaf dry weight. Leaf greenness was measured using a SPAD-502DL chlorophyll meter (Minolta, Japan). Yield parameters included root length, root diameter, root circumference, root fresh weight, and root dry weight per plant. Root circumference was measured at the widest part of the root using a measuring tape. Leaf and root dry weights were determined after oven drying at 70°C until constant weight was achieved. Growth and yield measurements were recorded from all three plants within each container, and the average value per container was used for statistical analysis. Therefore, each container was considered one experimental unit. All data were subjected to analysis of variance (ANOVA) using IBM SPSS Statistics version 26. When significant differences were detected, means were compared using Duncan's New Multiple Range Test (DMRT) at a significance level of $p \leq 0.05$.

3. Results and Discussion

3.1 Growth characteristics of Chinese radish

The growth performance of Chinese radish was significantly influenced by the type of animal manure and plant-based organic matter used in the growing media. Analysis of variance revealed that animal manure type (Factor A) significantly affected stem height and number of leaves ($p \leq 0.05$), while plant-based organic matter (Factor B) significantly influenced leaf width and leaf length ($p \leq 0.05$ and $p \leq 0.01$, respectively). The interaction between Factors A and B was significant only

for leaf length. Among the animal manures, pig manure resulted in the tallest plants (28.94 cm) and a high number of leaves (16.72), followed closely by poultry manure. In contrast, cattle manure produced significantly lower growth (24.52 cm, 14.17 leaves). These findings are consistent with the higher nutrient content of pig and poultry manures compared with cattle manure; pig manure provides a balanced nutrient profile with moderate nitrogen and phosphorus levels, supporting sustained vegetative growth (Somniam *et al.*, 2025a; Zhang *et al.*, 2020). Both pig and poultry manure are known for their rapid mineralization and availability of N and P, which promote vegetative growth. Poultry manure, on the other hand, is rich in readily available nitrogen, which promotes rapid leaf development but may require careful management due to its high salt content (Bhattacharyya *et al.*, 2015). Leaf width and length were less affected by manure type, with no significant differences detected.

Among plant residues, rice husk biochar produced the largest leaves, with the highest leaf width (5.54 cm) and leaf length (12.97 cm), followed closely by rain tree leaves (5.16 cm width, 12.78 cm length). These results align with biochar's ability to improve soil porosity, aeration, and water-holding capacity (Chen *et al.*, 2017; Wang *et al.*, 2022), creating a more favorable root-zone environment for nutrient and water uptake (Santos *et al.*, 2025). Elshony *et al.* (2025) stated that radish plants cultivated in soil amended with biochar were positively correlated with increasing the added rate of biochar. Rain tree leaves may have contributed additional organic acids and moderate nutrient release, enhancing vegetative growth (Sangchote, 2008). In contrast, copper pod leaves and rice straw tended to produce narrower and shorter leaves (4.18, 4.25 cm width; 10.39, 10.55 cm length). The relatively lower performance of rice straw substrates can be attributed to their higher bulk density and slower decomposition rate, which may have limited nutrient availability during the growth period (Somniam *et al.*, 2025a; Bhattacharyya *et al.*, 2015). The interaction between manure type and plant substrate significantly affected only the leaf length. The longest leaves (14.73 cm) were observed in the cattle manure plus rice husk biochar treatment, suggesting that biochar may have improved the utilization of nutrients supplied by cattle manure. Similarly, cattle manure + rain tree leaves and cattle manure + mushroom lumps also produced longer leaves (13.43, 12.50 cm), indicating synergistic effects when cattle manure is supplemented with nutrients or organic matter-rich residues. In contrast, certain combinations performed poorly: poultry manure + mushroom lumps (8.80 cm) and pig manure + copper pod leaves (8.80 cm) resulted in the shortest leaves. These outcomes suggest possible nutrient imbalances or suboptimal decomposition when these residues were combined with nutrient-rich manures. For example, mushroom lumps, although high in organic matter, may temporarily immobilize nitrogen during decomposition,

while copper pod leaves have a high C:N ratio that could delay nutrient release (Somniam *et al.*, 2025b; Sangchote, 2008). These results demonstrate that both manure and substrate type contribute uniquely to radish growth. Plants amended with pig and poultry manure exhibited greater vegetative growth, reflected by significantly greater stem height than those receiving cattle manure. This may be associated with their relatively higher nutrient concentrations and EC values (Table 1), which could have enhanced nutrient availability during vegetative growth. Meanwhile, biochar and rain tree leaves improved leaf expansion, likely due to their favorable effects on physical properties and gradual nutrient release. The significant interaction for leaf length indicates that the choice of substrate can modulate the effectiveness of animal manures, either enhancing or suppressing growth depending on compatibility (Santos *et al.*, 2025; Elshony *et al.*, 2025). In practice, pairing cattle manure with biochar or rain tree leaves could overcome the nutrient limitations of cattle manure alone, while careful attention should be given to combinations like poultry manure with mushroom residues that may cause growth suppression (Table 2). The effects of animal manures and plant-based organic substrates demonstrate that both individual and combined organic amendments significantly influenced canopy development, leaf greenness, and biomass accumulation. Animal manure type significantly affected leaf greenness and dry weight. Poultry and pig manures enhanced canopy size (37.43, 40.26 cm) and leaf dry weight (19.31 g), compared with cattle manure, which resulted in smaller canopies (32.53 cm) and lower dry weight (13.89 g). These results are consistent with Zhang *et al.* (2020), who reported improved nutrient availability and vegetative growth under poultry-based amendments. These findings align with Jin *et al.* (2024), who demonstrated that supplementing organic fertilizer with reduced chemical input increased radish yield by 12.92 % and improved nutritional quality. Cattle manure produced the highest SPAD value (39.15), possibly due to slower but sustained N release maintaining chlorophyll levels (Fathi, 2022). No significant differences were observed in leaf area or fresh weight, indicating that manure type alone may not fully determine vegetative expansion. Plant-based type (factor B) significantly influenced leaf area and greenness ($p < 0.01$) and dry weight ($p < 0.05$). Rice husk biochar and rain tree leaves promoted larger leaf areas (45.79 cm² and 41.71 cm²); biochar has been reported to enhance microbial diversity and nutrient retention in amended soils (Chen *et al.*, 2017). Copper pod leaves resulted in the highest SPAD value (40.72), possibly due to their rapid decomposition and nutrient release (Sangchote, 2008).

Rain tree leaves supported higher dry biomass (>20 g), aligning with Bhattacharyya *et al.* (2015), who emphasized the efficacy of lignocellulosic residues in sustaining vegetative

growth. Significant interactions were observed for leaf fresh weight ($p < 0.01$) and dry weight ($p < 0.05$), highlighting the synergistic impact of manure-substrate combinations. The combination of poultry manure + dried rice straw produced the highest leaf fresh weight (310.54 g) and dry weight (29.34 g), suggesting optimal nutrient synergy and microbial activity (Liu *et al.*, 2018; Lesing and Anugoolprasert, 2016). Consistent with this result, Pavitra *et al.* (2024) and Suman *et al.* (2024) reported that poultry manure-based organic amendments improved vegetative growth, yield, and soil fertility. Conversely, some treatment combinations, particularly poultry manure combined with old mushroom substrate, produced relatively low leaf biomass. This response may have been partially associated with temporary nutrient immobilization during organic matter decomposition, which could reduce short-term nutrient availability of essential nutrients for plant uptake. In addition, differences in decomposition rates and nutrient release patterns between poultry manure and old mushroom substrate may have affected nutrient synchronization with crop demand, thereby limiting vegetative growth. These findings suggest that the effectiveness of organic amendment combinations depends not only on their nutrient content but also on the dynamics of nutrient mineralization and availability during plant growth. However, this effect was not clearly reflected in root yield parameters (Table 3, 4).

3.2 Root growth and yield characteristics of Chinese radish

Root traits showed moderate responses. Pig manure produced the largest root diameter (44.57 mm) and highest root fresh and dry weight (20.46 and 1.39 g), statistically similar to poultry manure (1.34 g), while cattle manure was lowest (1.04 g). This reflects pig and poultry manure's greater nutrient contributions (Somniam *et al.*, 2025a; Bhattacharyya *et al.*, 2015). Among the plant residues, filter cake produced the highest radish yield, with the longest roots (139.51 mm) and greatest root biomass, confirming its effectiveness as a nutrient-rich organic amendment (Inthasan *et al.*, 2023). Rice straw resulted in shorter roots and the lowest biomass, consistent with its slower mineralization. Significant interactions occurred for root diameter and circumference. Pig manure + filter cake produced the most vigorous roots (151.70 mm length, 64.16 mm diameter, 19.33 circumference, 31.79 g fresh weight, 1.60 g dry weight), showing strong synergy between high-nutrient manure and filter cake. By contrast, the combination of cattle manure and copper pod leaves produced relatively small roots, possibly due to low nutrient availability and reduced nutrient retention. Limited nutrient supply may have restricted carbohydrate allocation to the storage root, resulting in reduced root growth (Dong *et al.*, 2025; Liang *et al.*, 2024) (Table 1, 4).

Table 2 Effects of animal manures and plant-based organic materials on vegetative growth of Chinese radish grown in raised beds.

Source of variation	Treatment	Stem height (cm)	Number of leaves	Leaf width (cm)	Leaf length (cm)
A	cattle manure	24.52±3.15 ^b	14.17±2.94 ^b	4.85±1.11	12.06±2.23
Animal manures	poultry manure	26.73±3.57 ^{ab}	16.94±2.08 ^a	4.89±0.92	11.61±2.16
	pig manure	28.94±4.08 ^a	16.72±2.86 ^a	4.64±1.03	11.18±1.90
B	copper pod leaves	27.78±3.23	15.44±2.29	4.18±0.82 ^b	10.39±2.11 ^b
Plant-based organic materials	dried rice straw	26.56±6.41	16.22±4.35	4.25±0.65 ^{bc}	10.55±1.68 ^b
	rice husk biochar	27.33±5.29	15.55±3.28	5.54±1.01 ^a	12.97±1.60 ^a
	rain tree leaves	25.26±2.95	16.11±5.75	5.16±1.19 ^{ab}	12.78±1.64 ^a
	old mushroom lumps	25.87±1.84	15.22±1.85	4.84±0.96 ^{abc}	11.35±2.65 ^{ab}
	filter cake	27.58±2.90	17.11±3.01	4.78±0.89 ^{abc}	11.65±1.69 ^{ab}
A x B interaction	cattle manure+copper pod leaves	25.50±1.48	16.66±1.52	4.79±1.01	10.92±1.12 ^{bcd}
	cattle manure+dried rice straw	20.60±3.56	12.00±2.00	4.06±0.51	9.00±0.52 ^{cd}
	cattle manure+rice husk biochar	27.43±3.82	15.00±5.19	4.10±0.78	14.73±0.50 ^a
	cattle manure+rain tree leaves	22.90±1.65	13.33±3.78	5.86±0.61	13.43±1.90 ^{ab}
	cattle manure+old mushroom lumps	24.77±1.40	13.66±1.15	6.20±1.32	12.50±1.08 ^{ab}
	cattle manure+filter cake	25.90±2.46	14.33±2.30	4.60±0.36	11.80±2.46 ^{abcd}
	poultry manure+copper pod leaves	29.57±4.71	15.66±1.15	4.30±0.88	11.46±3.21 ^{abcd}
	poultry manure+dried rice straw	29.50±8.07	18.66±3.51	4.90±0.96	11.40±1.05 ^{bcd}
	poultry manure+rice husk biochar	31.73±3.62	13.66±0.57	4.33±0.20	12.43±1.45 ^{ab}
	poultry manure+rain tree leaves	28.70±1.32	20.00±8.88	5.56±1.62	12.83±2.15 ^{ab}
	poultry manure+old mushroom lumps	25.77±1.56	15.00±1.73	4.93±0.80	8.80±2.06 ^d
	poultry manure+filter cake	28.37±2.96	18.66±2.08	4.40±0.95	12.76±0.40 ^{ab}
	pig manure+copper pod leaves	27.77±3.23	14.00±3.46	5.23±0.68	8.80±0.52 ^d
	pig manure+dried rice straw	26.56±6.41	18.00±4.35	3.60±0.45	11.26±2.12 ^{bcd}
	pig manure+rice husk biochar	27.33±5.28	18.00±1.00	4.33±1.01	11.76±0.83 ^{abcd}
	pig manure+rain tree leaves	25.26±2.95	15.00±1.73	5.20±0.88	12.10±1.12 ^{abc}
	pig manure+old mushroom lumps	25.87±1.84	17.00±1.00	4.36±0.80	12.76±2.84 ^{ab}
	pig manure+filter cake	27.58±2.90	18.33±3.05	5.53±1.25	10.40±1.00 ^{bcd}
F-test	A	*	*	ns	ns
	B	ns	ns	*	**
	A x B	ns	ns	ns	*
C.V. (%)		12.76	20.91	19.07	14.51

Data are presented as mean ± standard error (n = 3). ns, *, and ** indicate non-significant, significant at P < 0.05, and significant at P < 0.01, respectively. Means followed by different letters within the same column are significantly different according to Duncan's Multiple Range Test (DMRT) at P ≤ 0.05.

Table 3 Effects of animal manure and organic planting substrate on leaf morphology and biomass of Chinese radish grown in raised beds.

Source of variation	Treatment	Leaf area (cm ²)	Canopy width (cm)	Greenness (SPAD)	Leaf fresh weight (g)	Leaf dry weight (g)
A	cattle manure	37.91±15.43	32.53±5.10 ^b	39.15±2.61 ^a	161.77±66.32	13.89±5.58 ^b
Animal manures	poultry manure	35.87±12.89	37.43±5.61 ^a	35.28±5.79 ^b	180.02±86.08	19.31±9.13 ^a
	pig manure	32.75±11.63	40.26±6.81 ^a	33.63±6.77 ^b	177.62±69.99	19.31±8.20 ^a
B	copper pod leaves	27.59±11.63 ^b	35.47±6.81	40.72±5.31 ^a	182.32±64.09	19.09±8.20
Plant-based organic materials	dried rice straw	28.02±6.58 ^b	32.90±7.37	32.93±8.59 ^b	200.08±104.64	19.72±8.76
	rice husk biochar	45.79±12.85 ^a	39.96±8.48	36.84±2.22 ^{ab}	141.55±26.15	14.55±3.64
	rain tree leaves	41.71±15.13 ^a	35.83±4.76	35.95±3.87 ^b	197.17±53.96	21.01±5.30
	old mushroom lumps	35.34±14.61 ^{ab}	36.92±6.82	35.61±4.96 ^b	163.29±87.48	14.35±7.65
	filter cake	34.59±10.16 ^{ab}	39.35±2.98	34.08±5.65 ^b	154.41±80.31	16.29±10.07
A x B interaction	cattle manure+copper pod leaves	26.22±5.66	29.00±4.67	40.83±4.18	184.71±33.08 ^{bcd}	16.81±2.95 ^{abcd}
	cattle manure+dried rice straw	23.40±5.75	26.10±2.00	40.73±0.20	125.45±77.60 ^{bcd}	10.16±6.12 ^{cd}
	cattle manure+rice husk biochar	55.58±3.82	35.73±1.47	37.26±1.45	162.55±5.59 ^{bcd}	13.29±2.55 ^{bcd}
	cattle manure+rain tree leaves	52.38±18.10	34.90±1.47	36.73±3.68	179.82±31.55 ^{bcd}	17.29±2.79 ^{abcd}
	cattle manure+old mushroom lumps	35.86±3.49	31.26±4.18	38.96±0.23	236.82±75.47 ^{ab}	18.42±6.16 ^{abcd}
	cattle manure+filter cake	34.00±16.49	38.20±4.27	40.40±0.72	81.25±46.08 ^d	7.36±4.53 ^d
	poultry manure+copper pod leaves	36.79±16.76	38.10±1.91	38.50±5.11	226.01±48.68 ^{abc}	24.40±5.06 ^{ab}
	poultry manure+dried rice straw	29.18±2.10	34.53±4.90	32.53±8.83	310.54±54.20 ^a	29.34±3.89 ^a
	poultry manure+rice husk biochar	43.04±18.84	38.96±11.00	37.33±1.96	117.98±29.80 ^{cd}	13.92±4.09 ^{bcd}
	poultry manure+rain tree leaves	41.94±14.80	38.53±8.44	39.30±1.15	178.28±47.37 ^{bcd}	19.71±5.32 ^{abcd}
	poultry manure+old mushroom lumps	24.91±11.28	34.96±2.50	33.36±6.92	77.29±21.88 ^d	7.19±1.13 ^d
	poultry manure+filter cake	39.36±5.21	39.50±2.71	30.70±5.80	170.03±59.81 ^{bcd}	21.30±12.70 ^{abc}
	pig manure+copper pod leaves	19.77±2.50	39.33±8.03	42.83±7.43	136.24±83.15 ^{bcd}	16.06±14.45 ^{abcd}
	pig manure+dried rice straw	31.48±9.17	38.06±8.73	25.53±6.63	164.26±79.13 ^{bcd}	19.66±10.07 ^{abcd}
	pig manure+rice husk biochar	38.74±7.84	45.20±9.75	35.93±3.45	144.14±17.67 ^{bcd}	16.44±4.62 ^{abcd}
	pig manure+rain tree leaves	30.83±4.57	34.06±0.76	31.83±1.44	233.40±73.83 ^{ab}	26.03±3.90 ^{ab}
	pig manure+old mushroom lumps	45.24±20.10	44.53±4.67	34.50±4.92	175.74±70.74 ^{bcd}	17.45±8.89 ^{abcd}
	pig manure+filter cake	30.42±7.32	40.36±2.51	31.16±2.01	211.95±82.09 ^{abc}	20.22±6.56 ^{abcd}
F-test	A	ns	**	**	ns	*
	B	**	ns	*	ns	ns
	A x B	ns	ns	ns	**	*
C.V.(%)		32.09	15.24	12.53	33.11	38.98

Data are presented as mean ± standard error (n = 3). ns, *, and ** indicate non-significant, significant at P < 0.05, and significant at P < 0.01, respectively. Means followed by different letters within the same column are significantly different according to Duncan's Multiple Range Test (DMRT) at P ≤ 0.05.

4. Conclusion

This study demonstrates that the combination of specific animal manures and plant-based residues significantly influences the growth and yield of Chinese radish under raised bed systems. The results indicated that animal manures mainly influenced stem growth and root yield, while plant residues

primarily affected leaf characteristics. Their combinations significantly influenced leaf length, leaf biomass, and root size. Among the tested manures, pig manure was the most effective in promoting plant growth and root yield. Among residues, rice husk biochar improved structural conditions and leaf expansion, rain tree leaves promoted both leaf and root development, and filter cake provided high nutrient content for robust root growth.

These findings highlight the importance of matching nutrient-rich manures with suitable plant residues to optimize growing media conditions. Effective combinations enhanced plant growth, whereas unsuitable mixtures reduced crop performance.

The raised bed system likely further improved root-zone conditions, contributing to greater yield and root development in Chinese radish and potentially other edible root crops.

Table 4 Effects of animal manures and plant-based organic materials on root growth and yield characteristics of Chinese radish grown in raised beds.

Source of variation	Treatment	Root length (mm)	Root diameter (mm)	Root circumference (cm)	Root fresh weight (g)	Root dry weight (g)
A	cattle manure	114.34±34.98	41.25±8.53	13.96±2.61	17.13±7.18	1.04±0.36 ^b
	poultry manure	130.45±27.71	42.24±8.84	14.25±2.47	18.75±5.54	1.34±0.39 ^a
	pig manure	129.58±31.83	44.57±14.48	14.44±3.48	20.46±7.92	1.39±0.35 ^a
B	copper pod leaves	110.39±36.74	44.68±8.56	14.78±2.65	19.91±5.72	1.34±0.35
	dried rice straw	107.11±42.95	38.20±8.96	13.04±2.73	16.27±7.42	1.07±0.42
	rice husk biochar	134.26±22.72	41.69±10.43	13.70±2.47	16.43±6.94	1.14±0.36
	rain tree leaves	130.88±33.42	43.80±8.83	14.60±2.40	18.37±4.69	1.44±0.27
	old mushroom lumps	126.59±14.50	40.38±9.04	13.68±2.81	19.60±7.29	1.14±0.37
	filter cake	139.51±27.26	47.93±17.00	15.48±3.82	22.10±9.02	1.39±0.49
A x B interaction	cattle manure+copper pod leaves	82.23±41.86	39.50±2.65 ^b	13.00±1.12 ^b	17.97±3.39	1.21±0.26
	cattle manure+dried rice straw	83.13±42.65	35.30±9.84 ^b	12.16±3.19 ^b	13.79±9.83	0.92±0.59
	cattle manure+rice husk biochar	138.03±16.45	41.66±3.54 ^b	14.40±1.77 ^b	17.59±7.50	1.13±0.43
	cattle manure+rain tree leaves	116.06±8.45	47.16±11.25 ^{ab}	15.30±2.85 ^{ab}	17.52±2.33	1.25±0.12
	cattle manure+old mushroom lumps	136.30±19.97	47.23±13.26 ^{ab}	15.86±4.24 ^{ab}	22.16±13.49	0.80±0.34
	cattle manure+filter cake	130.29±33.69	38.38±4.85 ^b	13.03±1.10 ^b	13.78±3.76	0.91±0.35
	poultry manure+copper pod leaves	123.66±16.21	51.25±9.67 ^{ab}	16.76±2.80 ^{ab}	20.66±6.22	1.44±0.44
	poultry manure+dried rice straw	131.76±28.03	44.69±8.98 ^b	15.03±2.60 ^{ab}	19.81±7.47	1.23±0.47
	poultry manure+rice husk biochar	123.65±20.24	34.84±6.80 ^b	11.93±0.75 ^b	10.78±0.27	0.84±0.05
	poultry manure+rain tree leaves	144.01±60.72	46.85±9.25 ^{ab}	15.56±2.61 ^{ab}	21.91±6.20	1.59±0.33
	poultry manure+old mushroom lumps	123.04±4.18	34.52±2.36 ^b	12.10±0.60 ^b	18.61±1.99	1.28±0.10
	poultry manure+filter cake	136.56±28.49	41.26±4.15 ^b	14.10±1.20 ^b	20.73±0.86	1.67±0.31
	pig manure+copper pod leaves	125.30±39.99	43.30±9.20 ^b	14.60±2.87 ^{ab}	21.11±8.48	1.38±0.45
	pig manure+dried rice straw	106.43±54.77	34.63±7.01 ^b	11.93±2.00 ^b	15.23±6.21	1.07±0.30
	pig manure+rice husk biochar	141.10±33.53	48.56±15.34 ^{ab}	14.76±3.70 ^{ab}	20.91±7.52	1.46±0.24
	pig manure+rain tree leaves	132.56±10.81	37.40±2.69 ^b	12.93±1.37 ^b	15.67±3.68	1.48±0.27
	pig manure+old mushroom lumps	120.43±14.44	39.40±4.70 ^b	13.10±1.37 ^b	18.03±3.43	1.35±0.41
	pig manure+filter cake	151.70±25.76	64.16±22.73 ^a	19.33±4.68 ^a	31.79±7.95	1.60±0.47
F-test	A	ns	ns	ns	ns	*
	B	ns	ns	ns	ns	ns
	A x B	ns	*	*	ns	ns
C.V. (%)		25.44	22.63	17.97	34.59	28.63

Data are presented as mean ± standard error (n = 3). ns, *, and ** indicate non-significant, significant at P < 0.05, and significant at P < 0.01, respectively. Means followed by different letters within the same column are significantly different according to Duncan's Multiple Range Test (DMRT) at p < 0.05

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6. References

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