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The Potential for Organic Matter and Nutrient Recovery from Broccoli Harvest Residues to Support Sustainable Agriculture

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ABSTRACT

The return of harvest residues to the soil is an essential strategy in supporting sustainable agriculture, particularly for horticultural commodities such as broccoli (Brassica oleracea var. italica). This study aims to analyze the potential return of organic matter and macronutrients (N, P, K) as well as organic carbon (C-organic) from broccoli harvest residues to enhance soil fertility and reduce dependence on chemical fertilizers. The research was conducted in May 2025 in Desa Tani, Cipanjalu, Cilengkrang, Bandung Regency, with laboratory testing performed at the Department of Agronomy and Horticulture, IPB University, Bogor. A quantitative and descriptive approach was employed through observation, interviews, and laboratory analysis. The identification results showed that the total fresh weight of broccoli plants was 1,169 grams, of which only 400 grams were harvested, while the remaining 769 grams consisted of leaves, lower stems, and roots left in the field. The dry weight of the harvest residues was 77 grams per plant. With a planting density of 22,000 plants per hectare, the potential nutrient return was calculated using the formula: Nutrient Return = Dry Weight × Nutrient Content × Population per hectare. The nutrient content analysis showed that the broccoli residues contained 7.03% nitrogen (N), 0.90% phosphorus (P), 4.84% potassium (K), and 33.79% organic carbon (C-organic). Broccoli harvest residues have been proven to possess significant nutrient value and can be utilized as green manure to improve soil structure and reduce the use of synthetic fertilizers.

Keywords: broccoli, harvest residues, organic carbon, NPK return, sustainable agriculture

1. INTRODUCTION

Sustainable agriculture is an approach aimed at meeting food needs while simultaneously improving the quality of life for farmers and communities in a sustainable manner, ensuring long-term environmental conservation and soil fertility (Abobatta & Fouad, 2024; X. Liu, 2023). The principle of sustainable agriculture, particularly in organic farming systems, emphasizes the return of harvest residues to the soil to increase organic matter content and essential nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), and organic carbon (C-organic) (Gamage et al., 2023; Muhie, 2022; Reid et al., 2025). In addition to improving soil structure, this practice also has

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the potential to reduce dependency on chemical fertilizers that may harm long-term soil fertility (Soni et al., 2022).

Agriculture in Indonesia faces one of its major challenges, namely the farmers' dependency on the use of inorganic fertilizers (Dewi et al., 2025). The continuous use of inorganic fertilizers can degrade soil quality and harm the ecosystem (Ilahi, 2021). Therefore, the practice of utilizing organic waste can serve as an alternative source of organic matter and nutrients, offering an environmentally friendly strategy (Islam et al., 2023; Mulyati et al., 2021). Agricultural waste, which often holds no economic value, is frequently discarded, even though it contains essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and organic carbon (C-organic) that can support plant growth and improve soil conditions (Malobane et al., 2020; Sarkar et al., 2020).

Vegetable crops often generate waste, as many parts of the plants are not utilized. One such example is broccoli (*Brassica oleracea* var. italica), a horticultural commodity with high economic value that is widely cultivated in highland areas (Li et al., 2022; Nagraj et al., 2020). Broccoli is consumed as a vegetable, with the dark green head (curd) being the primary edible part (García-Manso et al., 2021; Takahashi et al., 2018). Meanwhile, other parts of the plant, such as stems and leaves, are often left unused and frequently discarded in the field, at markets, or even by consumers (García & Raghavan, 2022; Sayanjali et al., 2024). These unutilized parts have the potential to be returned to the soil as a source of organic matter and to contribute additional nutrients to the soil (Lu, 2020; Pandey et al., 2024).

The internship experience in Japan provided valuable insights into efficient broccoli harvesting practices with a focus on sustainable agriculture. Based on observations and interviews with the company owner, it was found that the harvesting process is carried out selectively, with only broccoli heads measuring a minimum diameter of 10 cm being harvested, and 7 cm of the stem below the head being cut, while the remaining stems and leaves are left in the field. These plant residues are then incorporated back into the soil using machinery, thereby supporting the natural nutrient cycle and increasing the soil's organic matter content. This practice demonstrates the potential of harvest residue management that can be adopted in Indonesia to promote sustainable agriculture.

By adopting the harvesting techniques practised in Japan and implementing them in Indonesia, there is significant potential for the return of organic matter and nutrients from broccoli harvest residues, thereby supporting sustainable agriculture in Indonesia. This is further supported by previous studies which state that the return of crop residues to the soil can promote plant growth

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and development, as well as optimize the efficiency of inorganic fertilizer use to prevent environmental pollution, as plant residues contain essential nutrients that are crucial for soil fertility (Malobane et al., 2020; Torres et al., 2021).

As stated in the study by Goswami et al., (2020), rice straw contains nutrient residues of N = 0.7%, P = 0.25%, and K = 1.75%. This differs from the study by Yang et al., (2023) which only mentioned that the incorporation and rotation of chopped corn straw into the soil can increase the organic matter, nitrogen, phosphorus, and potassium content in the soil, thereby improving soil pH, but did not analyze the specific amounts of NPK and organic carbon contained in the corn straw. The study by Adimassu et al., (2019) estimated that tropical food crops such as rice, wheat, and corn are generally composed of approximately C = 40%, N = 0.8%, P = 0.1%, and K = 1.3%. In the Brassica family, a study by Marco Tampesta (2022) indicated that cauliflower crop residues serve as an excellent source of nitrogen, contributing significantly to the nitrogen needs of the soil. A previous study conducted by scientists from the University of California, Davis, supported by CDFA-FREP (California Department of Food and Agriculture – Fertilizer Research and Education Program), found that the nitrogen content in broccoli residues left in the field varied between 80–265 lbs N/acre, or approximately 36–120 kg N/ha.

Although numerous studies have examined the benefits of returning harvest residues to the soil and this practice is widely regarded as common, there has been limited specific analysis of the potential return of organic matter and nutrients from broccoli harvest residues to the soil, particularly in terms of quantifying the potential amounts of nitrogen (N), phosphorus (P), potassium (K), and organic matter that can be restored to the soil. Based on this gap, this study aims to analyze the potential return of organic matter (C-Organic) and nutrients (N, P, K) from broccoli harvest residues to support sustainable agriculture.

2. RESEARCH METHOD

The study was conducted in Desa Tani, Cipanjalu, Cilengkrang, Bandung, West Java, in May 2025. The research focused on analyzing broccoli harvesting techniques, the return of harvest residues to the field, and the sampling process. The analysis of nutrient content (NPK and C-Organic) in the plants was carried out at the AGH (Agrotechnology and Horticulture) Laboratory, IPB University. This study employed a quantitative-descriptive approach using interviews, field observations, laboratory analysis, and literature review for data collection. The research procedures are as follows:

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Identification of Harvested Parts of Broccoli

The identification process of the harvested parts of broccoli begins with visual observation and physical measurement of various plant components, including the head (curd), stem, and leaves. This observation aims to determine which parts are harvested and which parts are left behind after harvesting by recording the size, weight, and physical condition of each part. This analysis provides essential information to estimate the potential amount of plant residues that can be returned to the soil.

Nutrient Content Analysis in Broccoli Plants

The nutrient content analysis of broccoli plants was conducted at the Agronomy and Horticulture Laboratory, IPB University. Samples were collected from Desa Tani by selecting harvested broccoli plants for analysis. Nitrogen (N) analysis was performed using the titrimetry method, phosphorus (P) analysis was carried out using the spectrophotometer method, potassium (K) analysis was conducted using the Atomic Absorption Spectrophotometer (AAS) method, and organic carbon (C-Organic) analysis was performed using the spectrophotometer method. These analytical methods are the standard procedures used by the AGH IPB Laboratory. The purpose of this analysis is to determine the macronutrient content, including nitrogen (N), phosphorus (P), potassium (K), and organic carbon (C-Organic) in broccoli, thereby identifying the potential for their return to the soil.

Calculation of Nutrients Returned to the Soil

This calculation was performed based on laboratory analysis data and the dry weight of the plants to determine the total amounts of N, P, K, and C-Organic that can be returned to the soil. The formula used is as follows:

$$\text{Nutrient Return} = \text{Dry Weight} \times \text{Nutrient Content} \times \text{Plant Population}$$

The calculation steps begin with determining the dry weight per plant, the nutrient content per plant, and then multiplying by the plant population per hectare. This calculation results in the total nutrients returned to the soil per hectare. The outcomes of this calculation can also be used to recommend improved agricultural waste management strategies to further support sustainable agriculture.

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3. RESULTS AND DISCUSSION

Identification of Harvested Parts of Broccoli

Generally, the part of broccoli that is utilized is the head, while the remaining parts are not used (Shinali et al., 2024). Based on the identification results, broccoli is typically harvested at 60 days of age, selecting broccoli with dark green heads, tightly packed florets, and an adequate diameter. There are no specific requirements regarding plant height or head diameter. As shown in Figure 1(a), the harvested parts of broccoli include the head (curd) and half of the stem, while the leaves are entirely pruned, leaving only the stalk.

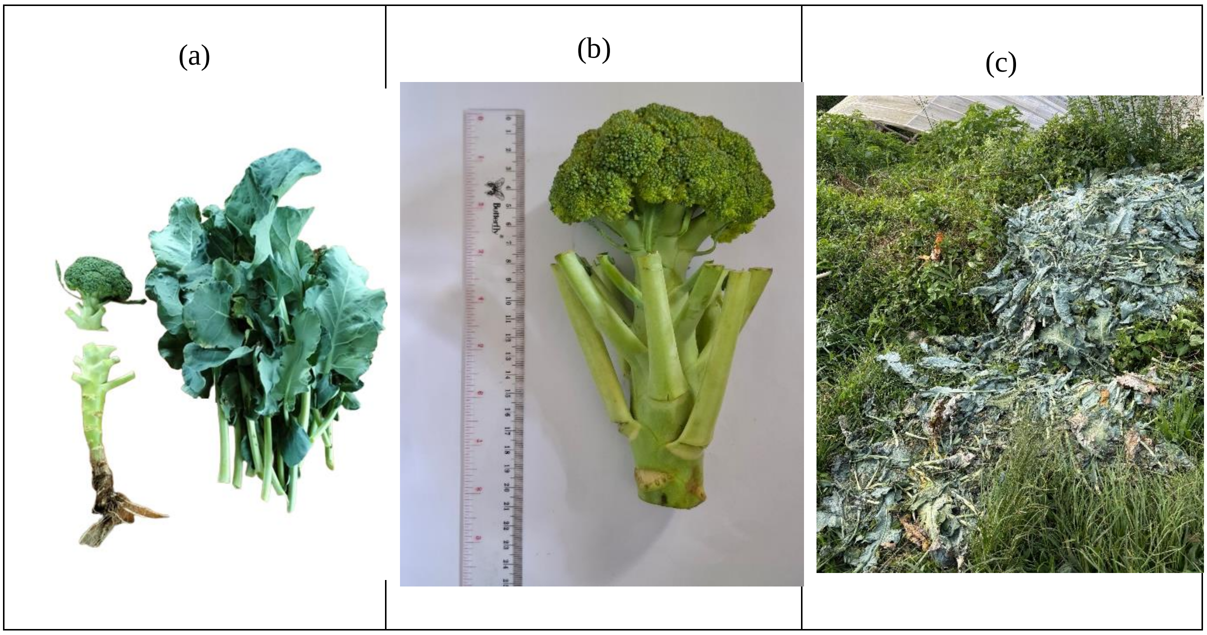

Figure 1. (a) The parts of the broccoli plant, (b) the harvested broccoli, and (c) the unused broccoli leaves

In Figure 1(a), the main components of the broccoli plant are displayed. The head (curd), as shown in Figure 1(a), represents the commonly consumed part, while the stem and roots are typically not utilized and are discarded as food waste. The leaves, which are completely pruned during the harvesting process, are left behind in the field without further processing.

The composition of broccoli parts consists of approximately 70% leaves, 18% stems, and only about 12% of the plant is the commonly consumed head. This indicates that most parts of the plant are not harvested and have the potential to become agricultural waste (Artés-Hernández et al., 2023; M. Liu et al., 2018). This waste, which amounts to 769 grams per plant, holds significant potential as additional organic material if properly managed and returned to the soil. Returning this waste to the soil can help replenish nutrient deficiencies and increase soil organic carbon content

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(Huang et al., 2021; Ninkuu et al., 2025). Furthermore, this practice contributes to reducing excessive reliance on chemical fertilizers. Throughout the cultivation process, broccoli plants require nutrient intake for growth and development. In the context of sustainable agriculture, recycling plant residues in the field is an essential component of nutrient cycling systems and plays a critical role in improving long-term soil fertility (Panwar et al., 2021).

The harvested broccoli shown in Figure 1(b) has an average weight of 400 grams and an average height of 20 cm per plant. The total height of the broccoli plant, from the head to the roots, is approximately 30 cm, with an average weight of 1,169 grams. The parts left behind in the soil include the remaining 10 cm of the stem, which weighs approximately 400 grams, roots weighing around 130 grams, and pruned leaves left on the field as seen in Figure 1(c), with an average weight of 439 grams per plant (Takahashi & Sasaki, 2019). The amount of waste that can be returned to the soil is 769 grams per plant. The amount of post-harvest waste depends on the harvesting techniques applied by farmers.

Nutrient Content Analysis in Broccoli Plants

Laboratory analysis results, as shown in Table 1, reveal that the unharvested parts of the broccoli plant still contain significant amounts of macronutrients. Based on the **T**itrimetry**,** spectrophotometry, and AAS (Atomic Absorption Spectrophotometry) analysis, the nutrient content in the broccoli residues is as follows: nitrogen (N) at 7.03%, phosphorus (P) at 0.90%, potassium (K) at 4.84%, and organic carbon (C-Organic) at 33.79%.

Table 1. NPK and C-Organic Analysis Results

No	Parameters	Contains (%)
1.	N (Nitrogen)	7, 03
2.	P (Phosphorus)	0, 90
3.	K (Potassium)	4, 84
4.	C-Organikc	33,79

These nutrient contents indicate that broccoli absorbs macronutrients for its growth, and upon harvesting, these macronutrients remain stored in the plant residues. These nutrients are retained in the unharvested plant tissues, as the entire plant absorbs nutrients from the soil throughout its growth period. Although the broccoli head is harvested and consumed, the remaining stems, leaves, and roots still contain residual nutrients that can be returned to the soil.

These findings are consistent with previous studies on similar plants, such as cauliflower, which is known to have high nitrogen content in its residues (Tampesta, 2022). If these residues are

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returned to the field, they will decompose and release nutrients back into the soil in forms available to subsequent crops, partially replacing the need for chemical fertilizers.

The high nitrogen (N) content in the residues plays a crucial role in supplying the plants' nutrient needs without full dependence on inorganic fertilizers (Ekbic & Kose, 2024). Nitrogen is essential for plant protein synthesis, enzyme production, and chlorophyll formation, which directly influence vegetative growth (Akanksha et al., 2023). By contributing nitrogen from the residues, the use of chemical fertilizers such as urea or ammonium sulfate can be reduced.

The potassium (K) content is also vital in supporting physiological processes in plants, such as photosynthesis, the translocation of photosynthates, and fruit formation. The availability of potassium from the residues offers additional benefits, including enhanced plant resilience to environmental stress (Metwaly, 2017). Meanwhile, phosphorus (P) provided by the residues supports root development and cell division, particularly in the early stages of plant growth (Yaseen, 2018).

In addition to macronutrients, the organic carbon (C-Organic) from plant residues plays a key role in improving soil quality. Organic carbon contributes to strengthening soil aggregate structure, enhancing soil water retention, and serving as an energy source for soil microorganisms involved in decomposition and nutrient cycling processes. The increase in soil organic matter content from the direct return of plant residues significantly contributes to improving cation exchange capacity (CEC) and the overall stability of the soil (Uwamahoro et al., 2023).

Calculation of Nutrient Return to the Soil

Observations showed that from the total fresh weight of broccoli, which is 1,169 grams, only about 400 grams were harvested. Thus, approximately 769 grams, consisting of the leaves, lower stem, and roots, were left in the field. After being oven-dried, it was found that the plant residues contained 90% moisture content, resulting in a dry weight of 77 grams per plant or approximately 1,694 kg/ha based on a population of 22,000 plants per hectare.

Laboratory analysis of the plant residues indicated that the unharvested parts still contained significant amounts of macronutrients and organic matter, specifically nitrogen (N) at 7.03%, phosphorus (P) at 0.90%, potassium (K) at 4.84%, and organic carbon (C-Organic) at 33.79%. These results were multiplied by the dry weight and plant population per hectare. The potential nutrient return to the soil from broccoli harvest residues per hectare is presented in table.

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Table 2.Potensi pengembalian hara

No	Nutrients	Contains (%)	Nutrient Return Total (kg/ha)
1	Nitrogen (N)	7.03	119.08
2	Phosphorous (P)	0.9	15.24
3	Potassium (K)	4.84	81.98
4	C-Organic	33.79	572.4

Table 2 shows that broccoli plant residues make a substantial contribution to returning nutrients and organic matter to the soil. The largest proportion returned is C-Organic, totaling 572.4 kg/ha, followed by nitrogen (N) at 119.08 kg/ha, potassium (K) at 81.98 kg/ha, and phosphorus (P) at 15.24 kg/ha. These amounts demonstrate the significant potential of broccoli residues as an alternative nutrient source that can directly improve soil fertility naturally.

The return of broccoli residues to the soil the need for chemical fertilizers in the next growing season can be significantly reduced. If the nitrogen fertilizer requirement for broccoli plants in one season reaches 72 kg of urea/ha and 314 kg of ZA/ha ((Tri Indriyati, 2018), then by returning residues containing 119 kg/ha of nitrogen, the urea fertilizer requirement can be reduced proportionally. Considering that urea fertilizer contains 46% N and ZA contains 21% N, approximately 215 kg of urea per hectare is required to meet the 99 kg N requirement. However, if the residues contribute 119 kg N per hectare, the urea requirement can be reduced to approximately 135 kg of urea per hectare. This means that broccoli residues have contributed approximately 55% of the total nitrogen requirement of the plants, so farmers no longer need to rely on full amounts of chemical fertilizer.

Similarly, for potassium and phosphorus, if the recommended application of KCl fertilizer (which contains 60% K) is 200 kg/ha (Tri Indriyati, 2018), and broccoli residues return 82 kg K/ha, then only about 63.3 kg KCl/ha is needed, instead of the usual 200 kg. This indicates that broccoli plant residues can replace approximately 41% of the total potassium fertilizer requirement, offering direct cost efficiency and enhancing agricultural sustainability.

Phosphorus returned through the residues also makes a significant contribution. If the phosphorus requirement is met using SP-36 fertilizer (which contains 36% P_2O_5 or approximately 15.8% P) at 250 kg/ha (Tri Indriyati, 2018), the phosphorus content of 15 kg P/ha from the residues is equivalent to about 95 kg SP-36/ha. Consequently, farmers would only need to apply approximately 155 kg SP-36/ha instead of 250 kg, indicating that plant residues can replace about 38% of the phosphorus fertilizer requirement.

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Reducing fertilizer requirements not only offers economic savings but also has a direct positive impact on the environment and long-term soil quality by reducing the accumulation of chemical residues in the soil. Thus, broccoli residues serve as an effective natural nutrient source, enriching the soil, reducing farmers' fertilizer costs, and supporting the principles of sustainable agriculture that emphasize low external input and soil resource conservation. Returning broccoli residues to the field can reduce dependence on inorganic fertilizers and increase fertilization efficiency. This practice aligns with the principles of sustainable agriculture by lowering input costs, maintaining long-term soil fertility, and minimizing the risk of soil degradation due to excessive chemical fertilizer use.

4. CONCLUSIONS

Broccoli harvest residues, such as unharvested leaves, stems, and roots, have significant potential to be returned to the soil as additional organic matter and nutrient sources, containing nitrogen at 7.03%, phosphorus at 0.90%, potassium at 4.84%, and C-Organic at 33.79%. With a dry weight of approximately 77 grams per plant and a plant population of 22,000 plants/ha, the total potential nutrient return reaches 119 kg N/ha, 15 kg P/ha, 82 kg K/ha, and 572 kg C-Organic/ha. Utilizing these residues can improve soil fertility, reduce dependency on chemical fertilizers, and support sustainable agricultural systems in Indonesia.

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