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Practical Guidelines for Farm Waste Utilization in Sustainable Kale Production

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Abstract: Natural amendments from agricultural waste to improve soil physicochemical properties continuously attract research interest in promoting eco-friendly plant production. The present study evaluated the proper use of sawdust, biochar, and compost made from farm waste for kale production from seedling propagation to field conditions. From the seedling propagation process, the results demonstrate that the most suitable growing medium for kale seedings was 0.5:1:1 *v*/*v* of sawdust + biochar + compost, which gave the fastest mean germination times (2.71 days) and the highest seed germination percentage (78.33%). In addition to investigating the selected growing media as the soil amendments at five different rates (0, 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}), the result reveals that the fresh weight of marketable leaves was significantly highest under the 31.25 t ha^{-1} treatment. The application rate that yielded the highest gross profit margins was eight times higher than the control. Moreover, in some harvesting periods, the kale leaf yields under the treatment of 31.25 t ha^{-1} showed higher total chlorophyll and carotenoid contents.

Keywords: kale; agricultural waste management; economic analysis; yield quality

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1. Introduction

Kale (*Brassica oleracea* var. *sabellica*), a member of the Brassicaceae family, is widely consumed in Thailand as a nutritious vegetable; it is rich in minerals and vitamins, particularly calcium, iron, potassium, vitamin C, and vitamin B1 [1,2]. Kale also contains a high total phenolic content and a significant group of antioxidant components. It plays a vital role in free radical inhibition based on its ability to donate hydrogen atoms to free radicals [3]. Furthermore, kale's popularity is also a result of its high protein content, even when contrasted with other high-protein vegetables like spinach or broccoli [2]. Recently, kale has garnered more attention due to its multifarious use (for salads, soups, juices, tea, etc.) as a functional food and its low caloric value [4,5].

Kale is well known as it can withstand an enormous temperature range [6] and is more tolerant to salinity and drought compared to other Brassica plant species [7–9]. Due to its good tolerance to abiotic stresses caused by the negative impact of climate change, kale has gained much popularity among farmers in recent decades. In the current state of kale production in Thailand, however, the cost of planting kale is relatively high because most seeds and planting materials, such as peat moss, are imported. Peat moss is an expensive and non-renewable resource, and cheaper and more readily available alternatives include coconut, coir, and rice husks. Since the cost of growing media and soil nutrient management plays a significant role in kale production, utilizing waste materials on the farm for maximum benefit to use as the growing media or soil conditioner is considered an alternative to reduce production costs and promote the circulation of production factors within the farm [10,11]. Currently, some studies have been conducted on the 'zero waste' concept for sustainable agriculture, for example, utilizing grass clippings and cow manure for making compost [12] or using fermented sawdust as a topsoil alternative for sprout production [13], in order to be a guideline, particularly for small-scale extensive agricultural farms. Biochar production with pyrolysis of solid agricultural waste (wood chips, tree pieces, rice husks, etc.) was also widely promoted in the agriculture sector for use as soil amendment in order to improve less fertile soil conditions due to its favorable properties, such as a high cation exchange capacity (absorption or slow release of nutrients) or highly porous structure (allowing for better moisture absorption and ventilation) [14,15]. Furthermore, it has a sufficient concentration of micro- and macro-elements, increasing crop production [16,17]. Biochar has been demonstrated by some of the literature to be used as an alternative peat replacement for inclusion in growing media, combined with compost [18] and coconut coir dust [19], which showed good evidence of plant fresh and dry weight compared to peat-based media [20].

Due to the widespread promotion of sustainable agriculture, which focuses primarily on managing agricultural waste through various low-cost methods like composting, biochar production, landfilling, or biological decomposition, it is possible to recycle organic waste into valuable products [21,22]. However, it is indispensable to identify a better way to convert farm waste using nutrient and quantity sources to meet the nutrient requirement of plant production. To the best of our knowledge, no prior study has estimated the use of farm waste as a soil amendment or organic fertilizer in addition to being growing media, especially pertinent for kale production. Therefore, this study aimed to ascertain the ideal ratio of decomposed sawdust, biochar, and farm waste compost to use as a growth medium in place of peat moss. We can then examine the optimal rate of the growing medium to be applied to the soil to enable the low-cost and high-yield cultivation of kale in field circumstances as a guideline for future research and development in the sustainable commercial production of kale.

2. Materials and Methods

2.1. Seedling Propagation under Different Growing Media

2.1.1. Growing Media Preparation and Experimental Setup

All materials in growing media consisted of peat moss, biochar, fermented sawdust, and farm waste compost. The commercial peat moss was purchased from the agriculture equipment market in Pathum Thani province, Thailand (Latitude: 14.08308, Longitude: 100.63473). Eucalyptus wood waste from the local furniture industry as pieces (woodcuts) and sawdust was used to produce the biochar and fermented sawdust, respectively. However, the wood industry's byproduct could be a risk toward containing the excessive levels of heavy metals. The examination of these materials revealed that the levels of toxic heavy metals, including arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and mercury (Hg), were not above the permissible limits suggested by Thai agricultural standards (TAS 9503-2005: Compost) [23]. The average amounts of As, Cd, Cu, Pb, and Hg in the eucalyptus wood waste were 0.01, 0.01, 0.05, 0.03, and ND (not detected) mg kg^{-1}, respectively.

In order to prepare the biochar, wood chips or woodcuts were placed in the central chamber of two-layer conventional kilns equipped with an air control system. The process of pyrolysis was then carried out, according to Palakit et al. [24], at a temperature of roughly 500–550 °C for a duration of 48 h. The resulting biochar was then ground to a fine powder using a hammer mill (QC006, Nakarin Bangkok Co., Ltd., Bangkok, Thailand), sieved to 2 mm, and kept in a plastic bag under shading conditions. To prepare fermented sawdust, eucalyptus wood sawdust was added to the composting containers placed in the shaded area. Diluted wood vinegar at a ratio of 1:200 v/v was added to the sawdust pile to adjust the moisture content to approximately 55–60%. The compost pile was turned every seven days using a spading fork and kept for decomposition under aerobic conditions for

90 days. The moisture content in the compost pile was adjusted by watering to maintain optimum composting conditions (approximately 50–55% moisture). The maturity of the compost was evaluated every week by monitoring the temperature with a long probe thermometer to a depth of 0.30 m. At maturity, the compost was tested for toxicity (phytochemical and ecotoxicological) to plants using mustard green seeds' germs [25]. The fermented sawdust was air-dried, sieved to a 2 mm diameter, and then kept in shading conditions. For the farm waste compost preparation, farm wastes were classified mainly into weed grasses, such as Guinea grass (*Megathyrsus maximus*), cogon grass (*Imperata cylindrica* (L.), and para grass (*Brachiaria mutica*). These were placed in thin layers (less than 10 cm) onto the pile, alternating with cow dung in the ratio of 4:1 by volume. The pile was arranged in a triangular shape that was 2.5 m wide at the base and over 1.5 m tall. The humidity in the pile was controlled at a 60–70% moisture content throughout the decomposition process. The farm waste compost pile was left for 60 days without turning, and the compost was finished when the pile was no longer heating up, and the original materials turned earthy and black. The compost was tested for its seed germination index to determine the compost maturity. Then, it was dried in a shading room, collected for sieving, and kept in a plastic bag.

The experiment was conducted in a completely randomized design with four replications. Nine treatments consisted of T1: peat moss (control); T2: decomposed sawdust (SD); T3: biochar (BC); T4: farm waste compost (CP); T5: SD:BC = 1:1 v/v; T6: SD:CP = 1:1 v/v; T7: SD:BC:CP = 0.5:1:1 v/v; T8: SD:BC:CP = 1:1:1 v/v, T9: SD:BC:CP = 1:2:1 v/v (Table 1). Curly kale seeds (*Brassica oleracea* var. *sabellica*, Chua Yong Seng Seed Co., Ltd., Bangkok, Thailand) were sown in 104-cell plastic seedling trays containing different growing media, from which a different mixed medium from T5–T9 was made by calculating the volume of each component and thoroughly mixing it with a metal spoon before filling the seedling trays. The seed trays were kept in a greenhouse with a constant temperature of 25 ± 3 °C and 60 ± 5% relative humidity (RH). They were exposed to a 16:8 h photoperiod using a cool daylight 6500 K (3070 lumens) fluorescent lamp. Every day, all growing media were watered equally. No fertilizers were added during seedling growth. Pests and diseases were monitored daily. Weeds were suppressed through hand weeding, and pests were controlled using neem oil.

Table 1. Proportions of raw materials in each growing media treatment.

Treatment	Formulation				
	Peat Moss (%)	Decomposed Sawdust (%)	Biochar (%)	Farm Waste Compost (%)	Total (%)
T1	100	0	0	0	100
T2	0	100	0	0	100
T3	0	0	100	0	100
T4	0	0	0	100	100
T5	0	50	50	0	100
T6	0	50	0	50	100
T7	0	20	40	40	100
T8	0	33.34	33.33	33.33	100
T9	0	25	50	25	100

T1: peat moss (control); T2: decomposed sawdust (SD); T3: biochar (BC); T4: farm waste compost (CP); T5: SD:BC = 1:1 v/v; T6: SD:CP = 1:1 v/v; T7: SD:BC:CP = 0.5:1:1 v/v; T8: SD:BC:CP = 1:1:1 v/v, T9: SD:BC:CP = 1:2:1 v/v.

2.1.2. Data Collection

- Physicochemical Properties of Growing Media

All growing media were prepared following the treatment description, mixed thoroughly, and then analyzed for pH, electrical conductivity (EC), organic matter, and some nutrient concentrations. The pH and EC of each growing media sample were measured in water at a ratio of 1:10 w/v and determined by using a pH-EC meter (SciberScanPC510, EU-

TEC, Singapore). The total N concentration was determined by using the Kjeldahl method. The levels of phosphorus (P) and potassium (K) in the samples were measured using a modified version of the standard protocol of the Association of Official Analytical Chemists (AOAC). Briefly, each sample (1.0 g) was mixed with a solution of nitric-perchloric acid (HNO_3:$HClO_4$ in a ratio of 2:1 v/v) and digested. The digestion process was carried out in 15 mL of the solution. After digestion, the samples were diluted with distilled water to a final volume of 50 mL and stored in plastic tubes at room temperature. The determination of P in distilled samples was analyzed by using a spectrophotometer (UV-1280, Shimadzu, Kyoto, Japan) at 420 nm. In contrast, the K concentration was analyzed by an atomic absorption spectrometer (PinAAcle900F, Perkin-Elmer, Waltham, MA, USA). The Walkley and Black [26] method quantified the organic carbon and organic matter.

For the physical properties analysis of each growing medium, bulk density and total pore space were determined following the modified method described by Di Gioia et al. [27]. The growing media were dried at 105 ± 1 °C and transferred in known-volume cylinders. Then, the bulk density of the growing media samples was calculated, which was defined as the dry mass in a given volume. The modified method by Qin et al. [28] was used to investigate each growing media sample's total pore space and water-holding capacity. Briefly, 50 mL of each sample was saturated with distilled water for 6 h. The excess water was allowed to drain for 2 min by gravity. The weight of saturated growing media was recorded, and the total pore space was determined as follows [28]:

$$\text{Total pore space (\%)} = [(\text{Saturated sample weight}/\text{Dry sample weight}) \times 100] \quad (1)$$

The saturated growing media sample was drained naturally by the gravitational water method for 24 h to analyze the water-holding capacity. The drained growing media were weighed, and the water-holding capacity was calculated using the formula shown below [28]:

$$\text{Water-holding capacity (\%)} = [(\text{Drained sample weight} - \text{Dry sample weight}) \times 100] \quad (2)$$

- Seed Germination Test

The study investigated seed emergence in different growing media using four replicates, each containing 100 seeds, under plastic house conditions. The seeds were planted in nursery trays filled with different growing media. Irrigation was applied immediately after sowing the seeds and repeated every day until the final emergences. The nursery trays were kept in controlled temperature conditions of approximately 25 ± 3 °C, 70 ± 5% relative humidity, with a 16:8 h photoperiod using a cool daylight 6500 K (3070 lumens) fluorescent lamp. The number of germinated seeds was recorded daily for ten days. The seeds were considered completely germinated when the radicle emerged at approximately 2 mm in length through the pericarp. Three germination parameters, including germination percentage, germination index, and mean germination time, were calculated using the following equations [28,29]:

$$\text{Germination rate} = [(\text{Number of seeds germinated}/\text{Number of seeds tested}) \times 100] \quad (3)$$

$$\text{Germination index} = \sum (\text{Number of germinated seeds}/\text{Days of the last count}) \quad (4)$$

$$\text{Mean Germination Time} = \sum \text{Dn}/\sum \text{n} \quad (5)$$

where

n = the number of seeds that were germinated on day D;
D = the number of days from the beginning of germination.

- Seedling Growth Characteristics

Curly kale seedlings from each treatment were randomly chosen 15 days after sowing, with four replicates (10 seedlings each). The seedling height, leaf number, and root length were recorded. The fresh weight of the shoot and root was measured after removing the surface moisture.

2.1.3. Statistical Analysis

Experimental treatment effects were analyzed using a completely randomized design with four replications. Data were analyzed through one-way analysis of variance (ANOVA). The mean treatment difference values were compared using Duncan's multiple range tests, with the significance determined at $p \leq 0.05$.

2.2. Efficacy of Selected Growing Media as the Soil Amendment in Different Rates for Kale Production

2.2.1. Soil Amendment Preparation and Experimental Site Setup

The field experiment was conducted at a farmer's field in Pak Chong district, Nakhon Ratchasima province, Thailand (latitude: 14.58593, longitude: 101.24701). The soil in the area was classified as Ultic Haplustalfs (Muak Lek Series). The soil was characterized by a dark brown loam or silt loam and well-drained soils, and the reaction was medium-acid to neutral throughout the soil profile [30]. The selected growing media from the previous experiment were used as the soil amendment in this study, and consisted of decomposed sawdust (SD), biochar (BC), and farm waste compost (CP) at a ratio of 0.5:1:1 v/v. The experiment was laid out in a randomized complete block design with four replicates, totaling 24 plots. The six treatments comprised non-soil amendment and soil amendment applied at rates of 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}. The preparation and selected chemical properties of soil amendment are shown in Section 2.1.1 and Tables 2 and 3 as treatment No. 7 (T7). Each plot was constructed using a 2 m $\times$ 4 m (8 m^2) wooden frame with a height of 30 cm above the ground. The soil amendment was mixed into the topsoil at different rates to a depth of 20 cm and then incubated for seven days before transplanting.

The curly kale seedlings were produced in 104-cell polystyrene trays (1 seed/cell) filled with the same growing media selected from the previous experiment (SD:BC:CP = 0.5:1:1 v/v). Fourteen seedlings with the first pair of true leaves and an 8–10 cm plant height was transplanted into each plot with 50 $\times$ 50 cm spacing between plants and rows 30 days after sowing. All plots were irrigated equally using a micro spray irrigation system with a rate of 8 L h^{-1} for 15–20 min daily. Neem extracts were sprayed to remove insects, while hand weeding was carried out to remove weeds.

2.2.2. Data Collection and Analysis

- Chemical Properties of Soil Before and After Treatment

Before and after the experiments, soil samples were collected from each plot at 0–20 cm depth and then dried in the shading condition. All soil samples were sieved through a 2 mm sieve and then kept in plastic bags for further analysis. The pH and EC of each soil sample were measured in water at a ratio of 1:1 and 1:5, respectively, and determined by using a pH-EC meter (SciberScanPC510, EUTEC, Singapore). The Kjeldahl method was used to determine the total N concentration. The availability of P and K was determined following the standard protocol of the Natural Resources Conservation Service [31] with some modifications. The available P was extracted from the soil using the Bray II method and measured using a spectrophotometer (UV-1280, Shimadzu, Japan) at 880 nm. On the other hand, the available K was extracted from the soil using a 1 M NH_4OAc pH 7.0 and was measured using a flame photometer (410, Sherwood Scientific Ltd., Cambridge, UK).

- Growth and Yield Assessment

Three plant samples were randomly selected from each plot in different treatments, and the plant height and stem diameter were recorded at 60, 90, 120, and 150 days after transplanting. The leaves of each plant were harvested every week after 60 days of transplanting. The marketable yield for each treatment was calculated by measuring the total fresh weight of the harvested leaves in each month, starting from 60 days after transplanting and continuing at 90, 120, and 150 days.

- Yield Quality Determination

The total chlorophyll and carotenoid were extracted from the fresh leaf sample using 80% acetone as a solvent. After incubation at 4 °C for 72 h in the dark, the supernatant was measured at 645, 663, and 470 nm using an ultraviolet spectrophotometer (UV-1280, Shimadzu, Japan). The absorbances were used to calculate the contents of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid, expressed as mg g^{-1} fresh weight by using the formula as described by Mackinney [32] and Yu et al. [33].

The total phenolic content, flavonoids, and antioxidant activity were determined according to the method of Chutimanukul et al. [34], with modifications. Briefly, the total phenolic content was determined by the Folin–Ciocalteu spectrophotometric method, and the result was expressed as mg gallic acid equivalent (GAE) g^{-1} dry weight. The quantity of flavonoid content was measured by the colorimetric method, and the result was expressed as mg rutin equivalent g^{-1} dry weight. For antioxidant activity, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging was employed. The result was expressed with the inhibition percentage of DPPH absorbance as the following formula [34]:

$$\text{DPPH radical scavenging (\%)} = [(\text{Ac} - \text{As})/\text{Ac}] \times 100 \quad (6)$$

where

Ac = control reaction absorbance; As = sample reaction absorbance.

- Yield Estimation and Economic Benefit Analysis

The total fresh weight of harvested leaves in each month of curly kale production under different treatments was recorded during the study period (four harvesting months). All the harvested leaves were characterized with no physical damage, referring to marketable yield. The net yield (t ha^{-1}) was determined as the average yield from four harvesting months. The net annual yield was calculated using the formula described by Limbu et al. [35] with the modifications as follows:

$$\text{Net annual yield (t ha}^{-1}\text{ year}^{-1}) = [\text{Net yield (t ha}^{-1}) \times 305]/\text{harvesting period (days)} \quad (7)$$

where

305 = 365 (number of days in a year) − 60 (days for a growing period).

The production cost and total income were evaluated for the economic benefit analysis. The production cost was divided into two groups: (1) annual fixed cost, including greenhouse, irrigation system, and labor cost for plot construction, and (2) annual variable cost, including seeds, preparation cost of soil amendment, casual labor (irrigation monitoring, weeding, harvesting), and electric cost. Total income was calculated from the net annual year, based on the central market price of 5.79 USD kg^{-1} for the fresh marketable kale yield. The actual values analysis of revenue and production cost were converted into USD (USD 1 = THB 34.52) using prevailing rates during the study period. The annual net cash flow and gross profit margin were calculated by the following formula [34]:

$$\text{Annual net cash flow (USD)} = [(\text{Net annual yield} \times \text{Price}) - \text{annual variable cost} - \text{annual fixed cost}] \quad (8)$$

$$\text{Gross profit margin (\%)} = (\text{Gross profit}/\text{Net sales}) \times 100 \quad (9)$$

2.2.3. Statistical Analysis

Experimental treatment effects were analyzed using a completely randomized block design with four replications. Data were analyzed through one-way analysis of variance (ANOVA). The mean treatment difference values used Duncan's multiple range tests, with the significance at $p \leq 0.05$ and 0.01.

3. Results

3.1. Seedling Propagation under Different Growing Media

3.1.1. Physicochemical Properties of Growing Media

As shown in Table 2, the different proportions of organic waste substrates in the growing media significantly affected the chemical properties compared to the commercial peat moss as the control treatment. Decomposed sawdust had the significantly lowest pH (5.64), followed by commercial peat moss (pH 6.53), whereas the biochar had the highest pH value of 9.38. In terms of electrical conductivity (EC), the growing media consisting of farm waste compost had the significantly highest EC value (0.12 dS m^{-1}), followed by the growing media consisting of 0.5:1:1 v/v of decomposed sawdust + biochar + farm waste compost (0.103 dS m^{-1}). The significantly highest content of total N in growing media was observed in commercial peat moss (5.69%). In contrast, the highest content of total P was determined in the growing media consisting of farm waste compost (0.47%) and 1:1 v/v of decomposed sawdust + farm waste compost (0.42%). Additionally, the highest content of total K was observed in the biochar growing media (0.70%) and, in contrast, decomposed sawdust and commercial peat moss as the growing media showed the lowest total K, i.e., 0.27% and 0.30%, respectively (Table 2).

Table 2. pH, EC, and nutrient concentrations in different growing media for kale seedling propagation.

Treatment	pH (1:10 H_2O)	EC (dS m^{-1}) (1:10 H_2O)	Total N (%)	Total P (%)	Total K (%)
T1	6.53 ± 0.16 f	0.037 ± 0.000 fg	5.69 ± 0.02 a	0.13 ± 0.04 de	0.30 ± 0.00 e
T2	5.64 ± 0.20 g	0.030 ± 0.000 g	5.20 ± 0.03 b	0.01 ± 0.00 f	0.27 ± 0.02 e
T3	9.38 ± 0.09 a	0.040 ± 0.012 f	3.74 ± 0.15 d	0.06 ± 0.01 ef	0.70 ± 0.00 a
T4	7.31 ± 0.10 e	0.120 ± 0.000 a	4.33 ± 0.03 c	0.47 ± 0.03 a	0.59 ± 0.03 b
T5	7.65 ± 0.01 d	0.050 ± 0.000 e	5.17 ± 0.06 b	0.06 ± 0.03 ef	0.52 ± 0.04 c
T6	7.54 ± 0.29 de	0.090 ± 0.000 c	5.32 ± 0.21 b	0.42 ± 0.05 a	0.47 ± 0.03 cd
T7	8.39 ± 0.24 b	0.103 ± 0.006 b	4.25 ± 0.03 c	0.30 ± 0.06 b	0.62 ± 0.04 b
T8	8.00 ± 0.04 c	0.070 ± 0.000 d	3.78 ± 0.03 d	0.25 ± 0.07 bc	0.52 ± 0.02 c
T9	8.12 ± 0.03 bc	0.070 ± 0.000 d	3.52 ± 0.08 e	0.19 ± 0.06 cd	0.45 ± 0.01 d
p-value	0.000	0.000	0.000	0.000	0.000

T1: peat moss (control); T2: decomposed sawdust (SD); T3: biochar (BC); T4: farm waste compost (CP); T5: SD:BC = 1:1 v/v; T6: SD:CP = 1:1 v/v; T7: SD:BC:CP = 0.5:1:1 v/v; T8: SD:BC:CP = 1:1:1 v/v, T9: SD:BC:CP = 1:2:1 v/v. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

The amount of organic matter in the biochar growing media was significantly higher (130.17%) than in the other growing media, as shown in Table 3. Additionally, the C/N ratio in the biochar growing media was also significantly higher (20.20) compared to the growing media made of farm waste compost (6.24) and 1:1 v/v of decomposed sawdust and farm waste compost (6.50). These two media types had a lower C/N ratio than the commercial peat moss (8.07). For the physical properties of different growing media, the decomposed sawdust presented a bulk density similar to the commercial peat moss (control treatment). In contrast, all the other growing media presented a significantly higher (50–131%) bulk density than commercial peat moss. In addition, a higher total pore space was observed in biochar (13%) and the growing media consisting of 1:2:1 v/v of decomposed sawdust + biochar + farm waste compost (14%) compared to commercial peat moss. The total pore space of other growing media was around 36–73% lower than that of the commercial peat moss. Similarly, the water-holding capacity of the growing media consisting of 1:2:1 v/v of decomposed sawdust + biochar + farm waste compost (14%) and biochar (9%) was significantly higher than the commercial peat moss. Contrarily, the water-holding capacity of the other growing media was around 39–84% lower than that of the commercial peat moss (Table 3).

Table 3. Selected physicochemical properties of different growing media for kale seedling propagation.

Treatment	Organic Matter (%)	C/N Ratio	Bulk Density (g m^{-3})	Total Pore Space (%)	Water-Holding Capacity (%)
T1	79.13 ± 0.74 e	8.07 ± 0.05 g	0.16 ± 0.00 f	45.27 ± 0.75 b	41.46 ± 0.86 c
T2	77.46 ± 0.17 f	8.63 ± 0.04 f	0.16 ± 0.01 f	12.35 ± 1.06 f	6.79 ± 0.84 h
T3	130.17 ± 0.42 a	20.20 ± 0.77 a	0.35 ± 0.01 b	51.22 ± 1.00 a	45.19 ± 0.99 b
T4	46.59 ± 0.42 h	6.24 ± 0.04 h	0.37 ± 0.00 a	28.62 ± 1.17 c	25.26 ± 1.14 d
T5	107.26 ± 0.75 b	12.04 ± 0.15 d	0.24 ± 0.00 e	15.89 ± 0.92 e	12.27 ± 0.82 f
T6	59.50 ± 0.89 g	6.50 ± 0.34 h	0.27 ± 0.00 d	23.64 ± 1.18 d	18.48 ± 1.01 e
T7	82.05 ± 1.36 d	11.20 ± 0.23 e	0.31 ± 0.01 c	12.85 ± 0.89 f	8.49 ± 1.24 g
T8	83.40 ± 0.99 d	12.80 ± 0.07 c	0.27 ± 0.00 d	12.55 ± 0.93 f	7.88 ± 0.41 gh
T9	91.28 ± 0.84 c	15.05 ± 0.40 b	0.31 ± 0.00 c	51.63 ± 0.75 a	47.10 ± 0.92 a
p-value	0.000	0.000	0.000	0.000	0.000

T1: peat moss (control); T2: decomposed sawdust (SD); T3: biochar (BC); T4: farm waste compost (CP); T5: SD:BC = 1:1 *v/v*; T6: SD:CP = 1:1 *v/v*; T7: SD:BC:CP = 0.5:1:1 *v/v*; T8: SD:BC:CP = 1:1:1 *v/v*, T9: SD:BC:CP = 1:2:1 *v/v*. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

3.1.2. Germination Index

The different growing media substantially impacted the kale's germination rate. Compared to the other treatments, the lowest recorded germination rate was related to biochar used as the growing media, which showed a reduction of 55% compared to the commercial peat moss (control treatment), whereas the germination rates of kale under the growing media consisting of 0.5:1:1 v/v of decomposed sawdust + biochar + farm waste compost (24%), 1:1 v/v of decomposed sawdust + farm waste compost (18%), and 1:1:1 v/v of decomposed sawdust + biochar + farm waste compost (13%) were higher than the commercial peat moss. Similarly, the significantly highest germination index was observed under the growing media consisting of 0.5:1:1 v/v of decomposed sawdust + biochar + farm waste compost and 1:1 v/v of decomposed sawdust + farm waste compost, with an increase of 51% and 32%, respectively, when compared to the commercial peat moss. However, the highest mean germination time of kale was observed in the biochar used as growing media, with an increase of 15%. Moreover, no noticeable difference was observed in the mean germination time among the other growing media, which decreased by 6–25% compared to commercial peat moss (Table 4).

Table 4. Germination test of kale under different conditions of growing media.

Treatment	Germination Rate (%)	Germination Index	Mean Germination Time (Day)
T1	63.33 ± 5.77 bc	20.79 ± 2.52 de	3.68 ± 0.74 b
T2	65.00 ± 5.00 bc	24.17 ± 1.36 bcd	3.47 ± 0.29 bc
T3	28.33 ± 2.89 e	7.71 ± 1.63 f	4.22 ± 0.20 a
T4	46.67 ± 2.89 d	16.19 ± 2.16 e	3.27 ± 0.49 bc
T5	65.00 ± 5.00 bc	26.03 ± 3.77 bc	2.77 ± 0.22 c
T6	75.00 ± 5.00 a	27.49 ± 3.39 ab	3.13 ± 0.51 bc
T7	78.33 ± 5.77 a	31.44 ± 4.49 a	2.72 ± 0.12 c
T8	71.67 ± 2.89 ab	26.28 ± 0.70 bc	2.81 ± 0.09 c
T9	56.67 ± 5.77 c	21.17 ± 3.10 cde	3.21 ± 0.51 bc
p-value	0.000	0.000	0.005

T1: peat moss (control); T2: decomposed sawdust (SD); T3: biochar (BC); T4: farm waste compost (CP); T5: SD:BC = 1:1 v/v; T6: SD:CP = 1:1 v/v; T7: SD:BC:CP = 0.5:1:1 v/v; T8: SD:BC:CP = 1:1:1 v/v, T9: SD:BC:CP = 1:2:1 v/v. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

3.1.3. Growth Characteristics of Kale Seedling

Growing media significantly affected all indices of kale seedlings' growth parameters (Table 5). The highest recorded plant height of kale seedlings was found for the treatment of 0.5:1:1 v/v of decomposed sawdust + biochar + farm waste compost (T7) and was up to 14% higher than the control treatment (commercial peat moss). However, no significant differences were found in leaf number between this treatment and some other treatments (T4, T6, T8, T9), including the control treatment. When compared to the control treatment, the root length of kale seedlings was significantly increased by 8–14% with the growing media consisting of decomposed sawdust (T2), 1:1 v/v of decomposed sawdust + farm waste compost (T6), and 1:1:1 v/v of decomposed sawdust + biochar + farm waste compost (T8). Furthermore, the shoot fresh weight of kale seedlings grown under T7 showed no striking difference compared to the control treatment, but was 5–76% higher than those in another treatment. In contrast, kale seedlings' lowest shoot and root fresh weight were observed under the biochar growing media, and were considerably lower by 77% and 83%, respectively, compared to the control treatment (Table 5).

Table 5. Kale seedling growth at 15 days after sowing under different conditions of growing media.

Treatment	Plant Height (cm)	Leaf Number	Root Length (cm)	Shoot Fresh Weight (mg plant^{-1})	Root Fresh Weight (mg plant^{-1})
T1	5.00 ± 0.50 b	3.83 ± 0.29 a	5.60 ± 0.26 de	7.60 ± 0.30 a	1.40 ± 0.10 de
T2	3.83 ± 0.29 c	2.53 ± 0.15 c	6.03 ± 0.15 bc	2.93 ± 0.12 e	2.63 ± 0.15 b
T3	1.77 ± 0.25 d	2.20 ± 0.20 c	0.70 ± 0.26 h	1.77 ± 0.15 f	0.23 ± 0.15 f
T4	5.03 ± 0.25 b	3.77 ± 0.15 a	5.17 ± 0.15 fg	7.00 ± 0.20 b	1.53 ± 0.15 d
T5	3.73 ± 0.25 c	2.97 ± 0.15 b	5.33 ± 0.15 ef	3.50 ± 0.20 d	1.27 ± 0.06 e
T6	4.90 ± 0.17 b	3.80 ± 0.26 a	6.40 ± 0.26 a	6.83 ± 0.15 b	3.17 ± 0.15 a
T7	5.70 ± 0.36 a	3.87 ± 0.23 a	5.73 ± 0.15 cd	7.37 ± 0.12 a	2.67 ± 0.15 b
T8	4.60 ± 0.36 b	3.57 ± 0.12 a	6.23 ± 0.06 ab	6.87 ± 0.12 b	3.07 ± 0.12 a
T9	3.83 ± 0.35 c	3.50 ± 0.30 a	4.97 ± 0.15 g	5.60 ± 0.20 c	1.93 ± 0.15 c
p-value	0.000	0.000	0.000	0.000	0.000

T1: peat moss (control); T2: decomposed sawdust (SD); T3: biochar (BC); T4: farm waste compost (CP); T5: SD:BC = 1:1 v/v; T6: SD:CP = 1:1 v/v; T7: SD:BC:CP = 0.5:1:1 v/v; T8: SD:BC:CP = 1:1:1 v/v, T9: SD:BC:CP = 1:2:1 v/v. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

As a result, the growing media consisting of 0.5:1:1 v/v of decomposed sawdust + biochar + farm waste compost (T7) performed better in kale seed germination rates and also possessed higher growth rates of kale seedlings, particularly in plant height and shoot fresh weight. Therefore, these growing media could be used as a soil amendment to investigate the appropriate rate for kale production in the field conditions.

3.2. Efficacy of Selected Growing Media as the Soil Amendment in Different Rates for Kale Production

3.2.1. Selected Chemical Properties of Soil before and after Treatment for Kale Production

The chemical properties of the soil samples before and after treatments are presented in Table 6. The soil pH at the experimental site was slightly acidic, with a pH of 6.29. In addition, the soil electrical conductivity (EC) was at 0.14 dS m^{-1} (non-saline soil), and the soil organic matter was moderate (34.10–55.00 g kg^{-1}). For the soil nutritional levels, the total nitrogen and potassium levels were moderate (0.81–2.70 g kg^{-1} for total nitrogen and 41–80 mg kg^{-1} for available potassium), while the phosphorus level was very high (>41 mg kg^{-1}) according to the information from the soil survey staff [36] and Rosen and Eliason [37]. After applying soil amendment at different rates, the soil pH decreased from 6.29 to 5.65–5.84. Conversely, the absolute control (no soil amendment) presented a higher pH value rather than that of the soil amendment application. In addition, the soil EC and organic matter treated with soil amendment at all rates were between 0.23 and 0.30 dS m^{-1} and 36.12 and 40.70 g kg^{-1}, respectively, which were significantly higher when compared to the control treatment. Interestingly, the results showed that the total N and available P of the after-treated soil, both absolute control and soil amendment applying at all rates, were lower than before transplanting. For the available K results, only the application of soil amendment at a rate of 25.00 and 31.25 t ha^{-1} improved the available K of the after-treated soil compared to the soil before transplanting (Table 6). It seems to be that the soil amendment has a negligible impact on the soil's chemical properties.

Table 6. Selected soil chemical properties before and after planting under different soil amendment rates.

Treatment	pH (1:1 H_2O)	EC (dS m^{-1}) (1:5 H_2O)	Organic Matter (g kg^{-1})	Total N (g kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
			Soil before treatment			
	6.29 ± 0.04	0.14 ± 0.02	37.00 ± 1.01	1.90 ± 0.08	32.08 ± 0.49	418.81 ± 7.42
			Soil after treatment			
T1	5.97 ± 0.05 a	0.20 ± 0.01 d	34.97 ± 1.17 d	1.01 ± 0.03 d	12.10 ± 0.28 c	339.02 ± 8.13 c
T2	5.65 ± 0.07 d	0.23 ± 0.01 c	37.15 ± 1.56 bc	1.08 ± 0.05 bc	20.45 ± 4.77 b	332.39 ± 20.46 c
T3	5.74 ± 0.03 bcd	0.25 ± 0.02 b	37.84 ± 0.56 b	1.10 ± 0.02 b	24.61 ± 2.15 a	352.30 ± 9.39 c
T4	5.69 ± 0.08 cd	0.26 ± 0.01 b	36.12 ± 0.74 cd	1.05 ± 0.02 cd	20.33 ± 1.28 b	408.72 ± 21.50 b
T5	5.77 ± 0.08 bc	0.29 ± 0.00 a	40.36 ± 0.71 a	1.17 ± 0.02 a	14.66 ± 1.64 c	421.99 ± 4.70 ab
T6	5.84 ± 0.05 b	0.30 ± 0.01 a	40.70 ± 1.44 a	1.18 ± 0.04 a	15.12 ± 2.41 c	435.27 ± 4.69 a
p-value	0.000	0.000	0.000	0.000	0.000	0.000

T1: no soil amendment (control); T2–T6: soil amendment at a rate of 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

3.2.2. Growth and Yield Characteristics

The effect of different soil amendment rates on growth performance is presented in Figures 1–3. The higher rates of soil amendment elicited increments in the plant height, which was observed from 120 days after transplanting. The highest plants were produced from the 31.25 t ha^{-1} soil amendment treatment, while the lowest plant height was consistently observed in the control treatment. Compared with the control (no soil amendment added) at 150 days after transplanting, the application of soil amendment from 18.75 to 31.25 t ha^{-1} exhibited a significant enhancement in plant height by 31%, 35%, and 51%, respectively (Figure 1). The stem diameter of kale supplied with all application rates of soil amendment was significantly higher than that of the control-treated plants at all determined times, although there were no significant differences in stem diameter among the different soil amendment rates (Figure 2). Apart from the physical characteristics 150 days after transplanting, the expansion of the kale canopy was seen to rise with the increasing rates of soil amendment. This phenomenon may be ascribed to the increased quantity and length of leaves, as illustrated in Figure 3.

As shown in Table 7, there were significant differences in the yield of kale grown under the different soil amendment rates at all the harvesting periods. In terms of 60 and 90 days after transplanting, the yield of kale provided by all soil amendments exhibited an enhancement of two to three times compared to the absolute control, and they were slightly higher than those at the highest application rate of soil amendment (31.25 t ha^{-1}). At 120 and 150 days after transplanting, the yield increased with the increase in soil amendment rates. The significantly highest yield occurred under the soil amendment applied at 31.25 t ha^{-1}, more than two times higher than the control plants. More specifically, the harvested period at 120 days after transplanting presented higher yield values at all soil amendment rates (Table 7).

Table 7. Total marketable yield at different days after transplanting (DAT) of kale production under different soil amendment rates.

Treatment	Yield (t ha^{-1})			
	60 DAT	90 DAT	120 DAT	150 DAT
T1	1.59 ± 0.15 c	3.02 ± 0.46 c	6.74 ± 0.30 c	4.06 ± 0.75 d
T2	3.78 ± 0.95 b	6.61 ± 1.10 b	6.95 ± 0.38 c	6.06 ± 0.96 c
T3	4.79 ± 0.67 ab	9.04 ± 0.95 a	10.31 ± 0.96 b	6.52 ± 1.07 c
T4	3.96 ± 0.61 b	9.73 ± 0.59 a	11.13 ± 0.87 b	6.86 ± 1.05 bc
T5	3.94 ± 0.60 b	9.36 ± 0.44 a	11.61 ± 0.82 b	8.09 ± 0.56 b
T6	5.40 ± 0.56 a	9.89 ± 0.47 a	15.24 ± 1.33 a	10.53 ± 0.82 a
p-value	0.000	0.000	0.000	0.000

T1: no soil amendment (control); T2–T6: soil amendment at a rate of 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

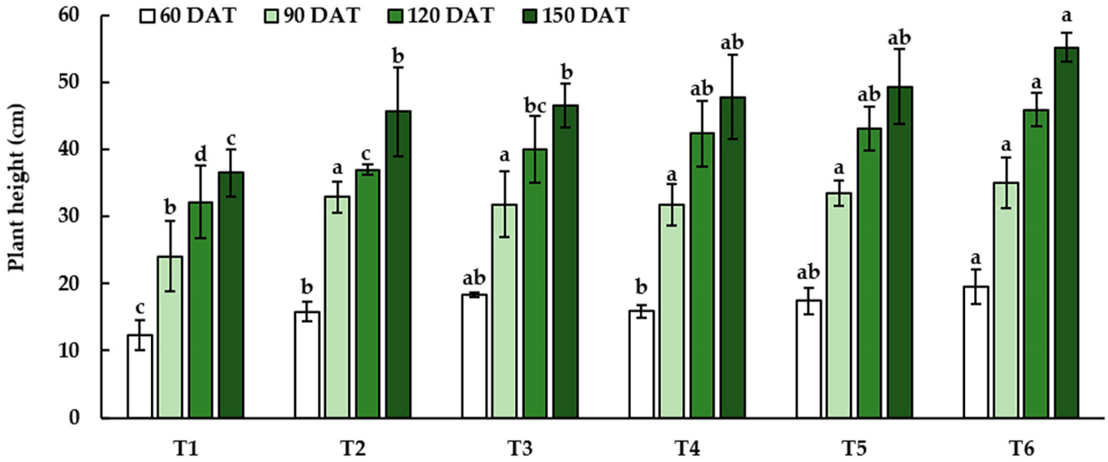

Figure 1. Plant height of kale at different days after transplanting (DAT) under various rates of soil amendment in the field conditions (T1–T6 referred to as 0 (control), 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively). Different letters marked above the bars of each DAT indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

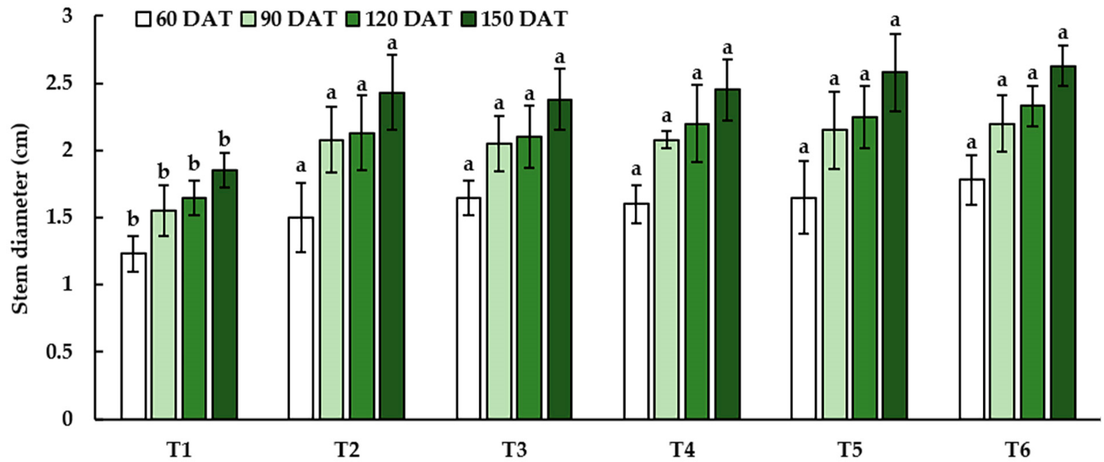

Figure 2. Stem diameter of kale at different days after transplanting (DAT) under various rates of soil amendment in the field conditions (T1–T6 referred to as 0 (control), 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively). Different letters marked above the bars of each DAT indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

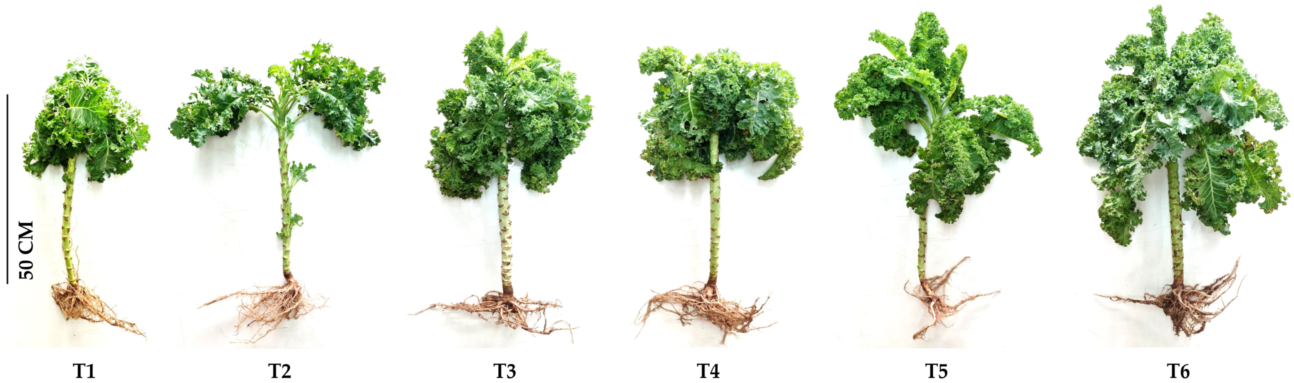

Figure 3. Growth characteristics of kale under different soil amendment rates in the field conditions (T1–T6 referred to as 0 (control), 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively).

3.2.3. Yield Quality

The ANOVA results demonstrated that the application rates of soil amendment had an influence ($p \leq 0.05$) on some biochemical compositions of the kale at 150 days after transplanting (Table 8). In terms of chlorophyll content, chlorophyll a, chlorophyll b, and total chlorophyll contents were slightly enhanced by the increment in soil amendment rates. The total chlorophyll of kale provided with 31.25 t ha^{-1} of soil amendment exhibited an enhancement of 21% compared with the control (no soil amendment). In addition, the carotenoid content tended to increase with the increase in soil amendment rates. The carotenoid content presented the highest values in the treated plants with the soil amendment at 31.25 t ha^{-1} and 25.00 t ha^{-1}, which increased by 57.60% and 54.40%, respectively, compared with the control-treated plants. Contrarily, the total phenolic, flavonoid, and DPPH radical scavenging of the kale were slightly decreased with the increase in soil amendment rates, with the highest total phenolic and flavonoid content occurring in the control-treated plants. In addition, the highest DPPH radical scavenging was observed under the control treatment, followed by soil amendment treatment at the rates of 6.25 and 18.75 t ha^{-1}, respectively, with no significant differences (Table 8).

Table 8. Yield quality of kale at 150 days after transplanting (DAT) under different soil amendment rates.

Treatment	Chlorophyll A (mg g^{-1} FW)	Chlorophyll B (mg g^{-1} FW)	Total Chlorophyll (mg g^{-1} FW)	Carotenoid (mg g^{-1} FW)	Total Phenolic (mg GAE g^{-1} DW)	Flavonoid (mg g^{-1} DW)	DPPH Radical Scavenging (%)
T1	0.92 ± 0.01 e	0.40 ± 0.04 b	1.31 ± 0.05 d	1.25 ± 0.07 d	22.08 ± 0.88 a	29.02 ± 0.36 a	47.05 ± 2.49 a
T2	0.91 ± 0.01 e	0.35 ± 0.00 c	1.26 ± 0.01 e	1.53 ± 0.01 b	19.84 ± 1.06 b	28.08 ± 0.34 b	46.71 ± 0.81 ab
T3	0.94 ± 0.01 d	0.37 ± 0.01 bc	1.31 ± 0.01 d	1.44 ± 0.01 c	16.59 ± 0.51 c	27.12 ± 0.31 c	44.86 ± 0.78 bc
T4	1.04 ± 0.01 c	0.39 ± 0.01 b	1.43 ± 0.02 c	1.56 ± 0.01 b	17.76 ± 0.24 c	27.94 ± 0.17 b	45.04 ± 1.03 abc
T5	1.13 ± 0.02 b	0.40 ± 0.01 b	1.53 ± 0.02 b	1.93 ± 0.02 a	17.29 ± 1.59 c	27.30 ± 0.75 c	43.57 ± 0.30 c
T6	1.15 ± 0.00 a	0.44 ± 0.01 a	1.59 ± 0.01 a	1.97 ± 0.01 a	17.02 ± 2.22 c	28.07 ± 0.40 b	44.44 ± 0.65 c
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.012

T1: no soil amendment (control); T2–T6: soil amendment at a rate of 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively. Mean with different letters in the same column indicates a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

3.2.4. Economic Profitability

The ANOVA results of the economic benefits demonstrated that all rates of soil amendment application gave a significantly higher net annual yield than that of the control. The tendency observed in the net yearly yield is also seen in the annual net cash flow (ANCF), computed to characterize the highest revenue-generating rates of soil amendment application. The ANCF was USD 64.14 when soil amendments were applied at a rate of 31.25 t ha^{-1}, which exhibited an eight-fold increase over the control (no soil amendment application). However, the soil amendment application at the rate from 12.50 to 25.00 t ha^{-1} resulted in comparatively similar ANCF (Figure 4).

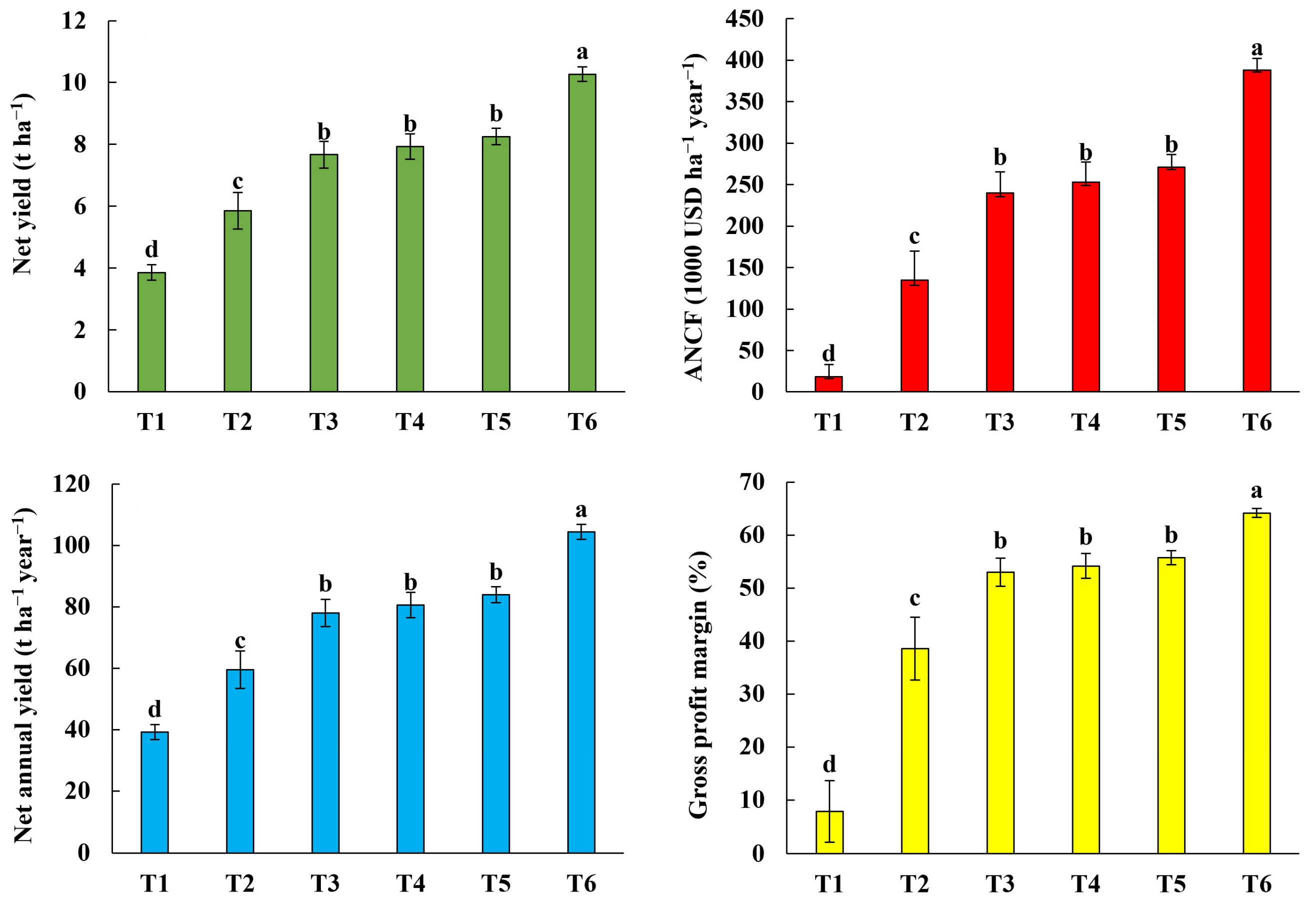

Figure 4. Economic profitability of kale production under different soil amendment rates in the field conditions (T1–T6 referred to as 0 (control), 6.25, 12.50, 18.75, 25.00, and 31.25 t ha^{-1}, respectively). Different letters marked above the bars of each DAT indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

The gross margin results indicated positive profits for the control and soil amendment treatments. However, the gross profit margins from all rates of soil amendment application were five to eight times significantly higher than those of the control, with the highest gross profit margins obtained in soil amendment treatment at a rate of 31.25 t ha^{-1}. As expected, there were no significant differences in the gross profit margins among the soil amendment treatment at the rate from 12.50 to 25.00 t ha^{-1} (Figure 4).

4. Discussion

The current study's results indicate the proper ratio of organic farm waste, specifically decomposed sawdust (SD), biochar (BC), and farm waste compost (CP), as a growing medium and soil amendment from kale production's seed to harvest. In every growing medium, kale seedling emergence was measured at the seedling stage around three days after sowing; the exception was the biochar medium, which explained why kale seeds took the longest to emerge (4.22 days). The growth and germination rate of kale seedlings appear to be similarly enhanced by the growing media T6–T8 (T6: SD:CP = 1:1 v/v, T7: SD:BC:CP = 0.5:1:1 v/v, and T8: SD:BC:CP = 1:1:1 v/v) as opposed to those under the other treatments; however, the concentration of nutrients (e.g., total N and K) in these growing media differed slightly from the biochar media (T3), which showed the significantly lowest emergence. At this point, it could be partly related to the pH, where the biochar medium had the significantly highest pH (9.38), which is classified as extreme alkalinity. It seems that the adverse pH of biochar media was a limitation for the kale seedling in the present study, and this tendency was also observed in wheat [38] and oregano [39]. Although the seed germination of most plants has occurred within a wide pH range of 3.5 to 9.0 for many years, the suggested range of pH values for leafy green growth was 5.5 to 6.5 [40]. Nonetheless, Pacheco et al. [41] stated that kale (*B. oleracea)* seedlings prefer neutral media (pH = 7). However, the current study shows that the maximum germination was observed at a pH range between 7.54 and 8.39 (T6-T8), which was qualified as the optimal pH of germination. Furthermore, when computed the C:N ratio of T6–T8 growing media in the current study, it was discovered to range from 6.50 to 12.80; this value is similar to that of the peat moss medium (8.07). In contrast, the C:N ratio in the biochar medium that gave the lowest kale seedling growth was 20:20. According to Rosen et al. [42], the C/N ratio of the growing media for the ideal plant growth ranged between 15:1 and 20:1, whereas Jo et al. [43] obtained the optimal C:N ratio for Chinese cabbage growth as approximately 20:40. Although there are numerous factors that could influence the appropriate C:N ratio for seedling growth, including plant physiology and other physicochemical characteristics of the growing medium, our findings suggest that a higher C:N ratio (>20:1) could have an impact on the growth of kale seedlings. This could be attributed to a lack of nitrogen, as a high C/N ratio of the growing medium could lead to N immobilization and restricted microbial activity [44], even though the growing medium (T7), which consists of 0.5:1:1 *v/v* of decomposed sawdust + biochar + farm waste compost, was chosen to be used as the soil amendment applied from 0–31.25 t ha^{-1} for kale production in the field conditions, based on the seed emergence findings at the kale seedling stage.

Generally, applying organic amendments to agricultural soils usually improves the soil structure, nutrient composition, and microbiological processes [45]. In the current results, the soil EC and organic matter, as well as the total N and available K of the soil after planting, were positively affected by applying the soil amendment, particularly at higher rates. A possible explanation for this is that the positive effect of soil amendment on soil physicochemical properties involves better soil aggregation by enhancing microbial activity [46], increasing nutrient availability due to organic matter decomposition [47], and enhancing soil water retention by optimizing the soil's structure and physical attributes [48], which accounted for higher crops yields. Nevertheless, Antonious et al. [49] demonstrated that kale (*Brassica oleracea* cv. Winterbar) and collard (*Brassica oleracea* cv. Top Bunch) grown in amended soil with chicken manure and sewage sludge produced the most significant number of premium grade yields according to USDA standards and also enhanced the total phenols and ascorbic content compared to the non-treated native soil. As observed in our study, higher doses of soil amendment promoted a higher yield, which was perceived at the increased harvest age. In addition, the supply of higher soil amendment doses increased the chlorophyll and carotenoid contents, which could be partly attributed to an increase in the photosynthetic ability, contributing to the rise in productivity. This observation is in concordance with the findings of Dalorima et al. [50], who stated that chlorophyll is strongly related to nitrogen concentration in the soil, where organic amendment could increase the microbial decomposition and nitrogen mineralization rates, as well as the nutrient content in the soil, supportively reflected in plant growth. However, organic amendment or fertilizer exhibited a stimulating effect on the biosynthesis of phenolics or a potential activity of scavenging DPPH free radicals, which has also been documented in broccoli [51], tomato [52], and artichoke herb [53]. Several plant species have been found to have reduced levels of phenolic compounds when organic amendments containing nitrogen are applied. This reduction can be attributed to the increased availability of nutrients, which promotes biomass growth, thereby decreasing enzymatic activity and non-structural carbohydrates, leading to a lower content of carbon-based secondary metabolites like phenylpropanoids. Additionally, the application of nitrogen decreases the activity of phenylalanine, which is a precursor for synthesizing phenolic and flavonoid compounds, resulting in a lower accumulation of polyphenolic compounds. These findings have been reported in studies conducted by Ibrahim et al. [54] and Majid et al. [55]. Similar trends were noted in our research for kale plants supplemented with higher rates of soil amendment, in which the absence of any soil amendments (control) produced the 7–33% increase in total phenolic and flavonoid contents of kale plants compared to those achieved in the respective soil amendment treatments.

In general, the harvested yield, net return, and gross profit margin can be used to determine the economic profitability of vegetable crop farming management [56]. Crop yield price and production cost directly impact crop production, impacting farmer profit. Nonetheless, most farmers cannot regularly and dependably manage the price that they obtain for their produce. Therefore, lowering production costs relative to the investment in fertility inputs is an additional way to obtain more advantages. This is especially true when turning farm waste into a fertilizer or soil amendment, which could increase farmers' profits. In line with our findings, the maximum gross profit margin, eight times greater than the control, was obtained by applying soil amendment at a rate of 31.25 t ha^{-1}. The observed outcomes could be attributed to increasing crop yields and applying farm waste as a soil amendment at a higher rate, which offers the best chance to optimize profits. The results obtained are consistent with the findings of El-Shony et al. [57]. They discovered that the average net profit of peanut and wheat production progressively increased with an increase in the rate of the applied soil amendment. Moreover, when compost and biochar were combined as a soil amendment, further significant increases in economic returns were observed compared to the application of each amendment. However, the application of biochar as a soil amendment has been hindered by its cost, particularly when purchasing it. In Thailand, biochar is sold for approximately 0.80 USD kg^{-1}, which means that it would require around USD 10,000 to apply this soil amendment (0.5:1:1 v/v of decomposed sawdust + biochar + farm waste compost) at a rate of 31.25 t ha^{-1}. Here, the research's findings encourage the use of compost and biochar as low-cost soil amendments on farms by offering a method for producing them on-site.

5. Conclusions

The finding of this research further exhibits the utilization of farm waste, mainly decomposed sawdust, biochar, and farm waste compost, at the optimal ratio for use as growing media and at the appropriate rate for use as a soil amendment in kale production. The ideal ratio of decomposed sawdust, biochar, and farm waste compost as growing media for kale seedlings was 0.5:1:1 v/v, which resulted in a higher germination rate of kale seeds and also possessed a higher growth of kale seedlings, particularly the plant height and shoot fresh weight. When using these growing media to be a soil amendment, the application of soil amendment at 31.25 t ha^{-1} was regarded as the optimum rate for producing both a high yield and the maximum gross profit margin for kale production, which was 8-fold higher than that in the absence of soil amendment (control). Although the biochar has numerous positive effects on the soil physicochemical properties and plant growth, using it alone as a growing medium produced the lowest germination rate and seedling growth, which may be partially attributed to the unfavorable high pH of the biochar. Nonetheless, even with the optimal ratio of decomposed sawdust, biochar, and farm waste compost (0.5:1:1 v/v), which provided the highest germination rate of kale seedlings (78.33%), the growth of kale seedlings is still lower. Further analyses of the macro- and micro-elements in various growing media that affect the growth of kale-treated plants are necessary to gain a better understanding of the enhanced seed germination and seedling growth.

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