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Compost maturity and plant response in community-based compost systems from Bali, Indonesia

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Abstract. *Bimantara PO, Adnyana IM, Kartini NL, Prabhaswara IGNM. 2026. Compost maturity and plant response in community-based compost systems from Bali, Indonesia. Asian J Agric 10 (1): g100176. https://doi.org/10.13057/asianjagric/g100176.* This present study focused on determining the quality of compost, its maturity, and the reaction of plants to different types of compost produced by community-run and municipal waste disposal centers in Bali, Indonesia. Compost samples were gathered from four locations of waste disposal facilities, specifically from Panca Lestari, Padang Tegal, PDU DLHK Denpasar, and Kedonganan. The quality of compost was determined according to the SNI 19-7030-2004, consisting of organic carbon, total nitrogen, C/N ratio, organic matter, pH, moisture, and physical aspects. The experiment was conducted in a greenhouse using *Ipomoea reptans* in factorial randomized block design with four levels of compost treatments, i.e., K0=control, K1=1.0 kg polybag^{-1}, K2=1.3 kg polybag^{-1}, and K3=1.6 kg polybag^{-1}. The data related to plant growth was analyzed using a Linear Mixed Model, while final biomass and post-harvest soil analysis were conducted using Factorial ANOVA. There were differences in the quality of compost from different sources. While Padang Tegal met all the SNI requirements, others failed to meet certain criteria including high levels of organic carbon, organic matter, pH value, C/N ratio, or foreign particles. Organic carbon ranged from 26.13% to 34.51%, total nitrogen from 0.72% to 2.84%, and C/N ratio from 11.67 to 47.55. Plant growth responses were strongly time-dependent. Compost dose significantly affected plant height, number of leaves, and stem diameter, whereas SPAD response was influenced by compost source and its interactions with dose and observation time. However, fresh and dry biomass were not significantly affected by compost source, dose, or their interaction. Post-harvest soil organic carbon, total nitrogen, and C/N ratio were significantly affected by compost source, dose, and their interaction. These findings indicate that composts from local waste management facilities differ in quality and produce time-dependent soil-plant responses. Further studies with larger replication and direct measurements of nutrient dynamics are needed before broader agronomic recommendations can be made.

Keywords: Compost quality, soil fertility, soil improvement, tropical soil, waste management

INTRODUCTION

Soil degradation remains a major constraint in tropical agricultural systems, particularly through declining organic matter, nutrient depletion, and poor soil structure. Many soils in Indonesia have low nitrogen availability and suboptimal physicochemical properties, which limit crop productivity and long-term sustainability (Bimantara et al. 2022; Wang et al. 2022; Susanti 2024). The use of organic amendments is therefore important for improving soil fertility and restoring soil function. Previous studies have shown that biological and organic inputs, including *Azolla* and compost, can improve nitrogen cycling, cation exchange capacity, and soil organic carbon accumulation (Wang et al. 2022; Adnyana et al. 2025).

At the same time, organic waste generation is increasing rapidly due to population growth, urbanization, and changes in consumption patterns (Zambrano-Monserrate et al. 2021; Lu et al. 2024). In Indonesia, a large proportion of municipal waste consists of organic materials that could be recycled, but much of it is still disposed of in landfills (Badan Pusat Statistik (BPS) 2021). In Bali, Indonesia, waste management is particularly challenging because of rapid tourism development and urban expansion. There is production of waste exceeding 3,367 tons daily from this province, and several landfill sites are under increasing stress (Dinas Kehutanan dan Lingkungan Hidup Provinsi Bali 2023). Consequently, composting initiatives have been suggested as one of the sources of waste management techniques and that can be used to advance the concept of circular economy as well as for agricultural use (Geissdoerfer et al. 2017; Waqas et al. 2023).

Compost can help increase the physical, chemical, and biological properties of the soil through its ability to add organic matter and nutrients in the soil, and through supporting the activity of microorganisms and nutrient cycling (Sayara et al. 2020; Ho et al. 2022; Wang et al. 2022; Guo et al. 2023). Nevertheless, agronomic efficiency is heavily dependent on compost maturity. C/N ratio is one of the measures of compost maturity since it signifies the relationship of carbon and nitrogen during the compost process (Luo et al. 2020). A higher C/N ratio in the compost could lower the availability of nitrogen, while a more mature compost can provide a more stable nutrient release (Awasthi et al. 2020). This problem is especially important in the case of short-cycle leafy vegetables, which need nutrients that are easy to assimilate (Sogbohossou et al. 2018; Ho et al. 2022).

Although compost quality, soil response, and plant performance have been widely studied, less information is available on how composts produced by different community-based and municipal waste management facilities within the same tropical region differ in quality and agronomic response. In Bali, composting facilities vary in feedstock composition, sorting practice, processing duration, and management system, but their comparative implications for compost maturity, soil chemical properties, and leafy vegetable response remain insufficiently documented. Therefore, the novelty of this study lies in the comparative evaluation of compost products from local waste management facilities in Bali using a common greenhouse testing framework, rather than in claiming that compost quality and plant response have not been studied elsewhere.

This study was based on two hypotheses: (i) composts produced by different community-based and municipal facilities in Bali differ in chemical and physical quality due to variation in feedstock and management practices; and (ii) compost source and dose influence soil chemical properties and plant response, but the magnitude of response depends on compost maturity and growth stage. Therefore, this study aimed to evaluate the quality of compost from different local sources based on national standards and to assess its effects on soil properties and the growth response of *Ipomoea reptans* under controlled greenhouse conditions.

MATERIALS AND METHODS

Study area

The study was conducted at the Soil Chemistry and Fertility Laboratory and the Experimental Farm of the Faculty of Agriculture, Universitas Udayana, Bali, Indonesia. Compost quality analysis and compost effectiveness testing were carried out concurrently for approximately one month. The compost samples were collected from four different waste management facilities in Bali, *viz.* Panca Lestari, Padang Tegal, PDU DLHK Denpasar, and Kedonganan. These sites represented different community-based and municipal composting systems.

The four compost sources were located at Tanjung Benoa, South Kuta, Badung (Panca Lestari; TB); Padang Tegal, Ubud, Gianyar (Padang Tegal; PT); Padangsambian Kaja, West Denpasar, Denpasar (PDU DLHK Denpasar; PS); and Kedonganan, Kuta, Badung (Kedonganan; KD). Compost from each site was collected for field observation, laboratory quality analysis, and pot evaluation of its agronomic efficacy.

Procedures

Field observation and compost sampling

Field visits were conducted at each composting facility to obtain information on compost sources, composting techniques, and supporting operational data. The research team and surveyors conducted observations and interviews. The field survey was intended to provide background information on compost production practices at each site and to support the analysis of compost quality and plant response data.

At every site visit, samples of compost were collected via composite sampling methods, which have been modified from the FCQAO procedures. In all facilities, 5-7 subsamples were taken from several parts of the composting site to take into consideration spatial differences in the composition of the material. The samples taken ranged from surface and interior parts of the pile with an approximate depth range of 20-30 cm.

Each of the subsamples was thoroughly homogenized to form a composite sample from each type of compost. Then, the weight of the entire composite sample was between 1 to 2 kg, after which quartering techniques were used to get subsamples for analysis in the laboratory.

Prior to the analysis process, the samples were first dried and sieved (less than 2mm in particle size). Physical examination included parameters such as color, smell, touch, temperature, percent of foreign substance, moisture retention capability, and soil texture. The physical examination was used to complement laboratory testing of the quality of the soil.

Compost quality assessment

The quality of compost was tested based on the standard of compost produced from organic waste of households (SNI 19-7030-2004) established by the National Standards Commission of Indonesia. Among the measured parameters included were moisture content, temperature, color, smell, texture, particle size, water retention, pH, presence of foreign materials, organic matter, total nitrogen, organic carbon, and C/N ratio.

Qualitative analysis for color, odor, and texture was done via visual inspection, sensory evaluation, and palpation, respectively. Temperature of the compost material was assessed using a thermometer.

The measurement of pH (H_2O) was done using a pH meter for the 1:2.5 compost-to-water suspension (Hendershot et al. 1993). The determination of organic carbon was carried out using the Wet Oxidation Walkley and Black method (Walkley and Black 1934), whereas the measurement of Total Nitrogen was conducted using the Kjeldahl Digestion Method (Bremner 1965). The C/N ratio was the quotient of organic carbon and total nitrogen (Weil and Brady 2016).

The moisture content was determined gravimetrically through the drying of sample pieces at 105°C until a constant weight was attained. The organic matter content was evaluated based on organic carbon content using conversion factors. Water holding capacity was evaluated gravimetrically through saturation of compost with water and subsequent determination of the water content retained after allowing free drainage of water. The size distribution analysis was carried out through sieving, and the amount of fine particles obtained was presented as a percentage of compost passing through the 0.55 mm sieve. The foreign material content was calculated by manually separating inorganics or incompletely decomposed materials from compost and expressing their mass as a percent of the total compost weight. The laboratory analyses of samples were conducted in line with established guidelines for chemical analysis of soil, plants, fertilizers and water described in the Technical Guidelines for the Chemical Analysis of Soil, Plants, Water, and Fertilizers (Balai Pengujian Standar Instrumen Tanah dan Pupuk 2023), to ensure consistency and reliability.

The benchmark criteria which formed the basis of comparison include: maximum moisture content of 50%, pH 6.80-7.49, organic matter of 27-58%, minimum nitrogen content of 0.40%, organic carbon of 9.80-32.00%, and C/N ratio of 10-20. These were compared against the compost qualities from each source in order to assess their ability as fertilizers.

Pot experiment and experimental design

Experiment with pots was done on *I. reptans*. The use of the above plant species is due to their fast growth rate, biomass accumulation, and sensitivity to the availability of nutrients. This will therefore make them an ideal plant species as bioindicators for assessing the effect of compost on plant performance.

The experiment was designed in a factorial Randomized Complete Block Design (RCBD) consisting of two fixed factors of compost source and compost dose. Four levels were used in the compost source factor: TB or TPS 3R Panca Lestari, PT or Padang Tegal Compost House, PS or Recycling Center PDU DLHK Denpasar, and KD or TPS 3R Kedonganan. The compost dose factor consisted of four levels: K0=control without compost, K1=1.0 kg polybag^{-1}, K2=1.3 kg polybag^{-1}, and K3=1.6 kg polybag^{-1}.

There were three replications for each treatment combination, giving rise to 48 experimental units (4 compost types × 4 compost levels × 3 replicates). There was blocking in the study based on the position of the greenhouse, to take into account any possible variation in environmental conditions within the experimental field. In each replicate, all the 16 treatment combinations were randomly allotted to polybags. This was done in order to eliminate any positional effects in the greenhouse.

A polybag containing 10 kg of dried soil and having a diameter of 30 cm constituted the experimental unit. Compost mixture was applied to soils for plant cultivation in different amounts depending on the treatment combinations. No inorganic fertilizers were used during the course of the experiment since the main objective of the study was the evaluation of the effect of the compost mixture.

Compost samples collected from the sites to be used in the experimentation in this research study were taken as fully matured composts from each site based on their state of maturity at those sites. No additional treatment was applied on the samples after harvesting. This is because the objective of this research study is to analyze different compost products in terms of quality and the plant response due to compost produced by different communities and municipality wastes.

Cultivation conditions

Selection was made from healthy and equal seedlings of *I. reptans* based on the strength and height of the seedlings during transplanting. Plants that appeared unhealthy or damaged were excluded to limit heterogeneity in the experimental plots.

Watering of the plants took place every day, ensuring that the level of soil moisture stayed near field capacity. Inside the greenhouse, the usual open conditions of tropical greenhouses were replicated, whereby the temperature ranged from 28°C to 32°C under the sun. Measurement of humidity and intensity of light was irregular because of their influence on plant growth.

In preparing for the pot experiment, the soil sample was first air-dried and then homogenized before placing it in polybags. The initial soil characteristics before the addition of compost included soil organic carbon, total nitrogen, C/N ratio, and moisture content. Soils in the experiment were not categorized into their texture classes, and therefore, the interpretation of soil characteristics was based on the above characteristics only.

Plant growth, yield, and soil measurements

The growth parameters of plants include height of the plant, stem diameter, number of leaves, and the degree of chlorophyll in leaves quantified by using a SPAD meter. Measurements were taken four days apart. The parameters for yield analysis include fresh and dry weight of the crop measured after harvest. Post-harvest soil samples were collected to determine soil organic carbon, total nitrogen, and C/N ratio.

The fresh weight was measured directly following harvest, and the dry weight was measured after drying the plants in an oven to constant weight. The soil samples taken after harvesting were air-dried prior to being tested using the same standard methodology used for the chemical analysis.

Data analysis

Compost quality data were compared descriptively with SNI 19-7030-2004 standards. For the greenhouse experiment, plant growth variables measured repeatedly over time were analyzed using a Linear Mixed Model (LMM). Compost source, compost dose, observation time, and their interactions were treated as fixed effects, while block was included in the model to account for greenhouse positional variation.

The LMM was used because measurements of growth-related factors were made repeatedly on the same experimental units, thus violating the independence of observations. The LMM enabled the evaluation of the effects of different sources of compost, different levels of application, time, and their interactions at once while taking into account the correlation between observations over time.

Final biomass variables, including fresh weight and dry weight, were analyzed using factorial analysis of variance with compost source, compost dose, source × dose interaction, and block included in the model. Post-harvest soil properties were also analyzed using factorial analysis of variance when biological replication was available.

Before analysis, data were checked for normality and homogeneity of variance using residual diagnostics. When significant effects were detected, mean comparisons were performed using the Least Significant Difference (LSD) post hoc test at $p<0.05$ based on estimated marginal means. LSD was used to compare treatment means following significant model effects and to maintain consistency with the statistical output generated from the mixed model and factorial ANOVA procedures.

Because the experiment used three replications per treatment combination, the results were interpreted with caution, particularly for higher-order interaction effects. The findings are therefore presented as controlled greenhouse evidence of treatment response patterns rather than definitive field-scale recommendations.

RESULTS AND DISCUSSION

Characteristics of composting facilities and observed compost properties

The four composting facilities differed in management status, operational scale, and composting practice (Table 1). Three facilities were managed by traditional communities, while PDU DLHK Denpasar was managed by a government institution. Worker numbers varied from 23 people in Kedonganan to 53 people in PDU Denpasar.

The daily waste processing capacity differed between 200 kg and more than 4,000 kg. Source-based sorting was carried out in Padang Tegal and Panca Lestari, while manual sorting occurred in the facilities of PDU Denpasar and Kedonganan. Composting time periods varied between 1 and 3 weeks in PDU Denpasar up to more than 3 months in Kedonganan.

Feedstock composition also differed among facilities (Figure 1). Household kitchen waste and yard waste were the dominant feedstock components across all sites. PDU Denpasar and Kedonganan contained a higher proportion of mixed waste, including market and institutional organic waste, whereas Padang Tegal was dominated by source-separated organic waste.

Laboratory quality of compost from different sources

The physical characteristics of compost varied among sources (Table 2). All composts had an earthy odor, while compost color ranged from light brown to black. Texture was generally fine, except for PDU Denpasar, which showed a coarse texture. Compost temperature ranged from 25°C to 26°C.

Foreign material content ranged from 3.39% in Padang Tegal to 38.21% in PDU Denpasar. Water holding capacity ranged from 57.05% in Kedonganan to 64.53% in PDU Denpasar. The proportion of particles smaller than 0.55 mm varied from 11.33% in PDU Denpasar to 57.43% in Kedonganan.

Chemical quality of compost

Chemical compost quality differed among sources (Table 3). Organic carbon ranged from 26.13% to 34.51%, total nitrogen from 0.72% to 2.84%, and C/N ratio from 11.67 to 47.55. Organic matter ranged from 45.06% to 59.49%, pH from 6.88 to 7.57, and moisture content from 9.84% to 41.83%.

Based on SNI 19-7030-2004, Padang Tegal was the only compost source that met all evaluated quality criteria. Panca Lestari exceeded the SNI range for organic carbon, organic matter, and pH. Kedonganan exceeded the standard range for organic carbon, while PDU Denpasar exceeded the range for organic carbon, organic matter, and C/N ratio. All compost sources met the minimum total nitrogen requirement and the maximum moisture content limit.

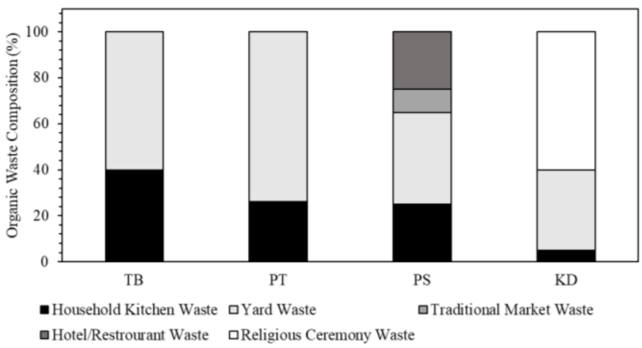

Figure 1. Organic waste composition (%) of feedstocks used in four composting facilities (TB, PT, PS, and KD)

Table 1. Characteristics of composting facilities

Variables	Padang Tegal Compost House	TPS 3R Panca Lestari	Recycling Center (PDU) DLHK Denpasar	TPS 3R Kedonganan Ngardi Resik
Location	Padang Tegal, Ubud, Gianyar	Tanjung Benoa Traditional Village, Kuta Selatan, Badung	Padangsambian Kaja, West Denpasar, Denpasar	Kedonganan Traditional Village, Kuta Selatan, Badung
Year of establishment	2012	2021	2024	2022
Management status	Traditional village	Traditional village	Environmental Agency (DLHK)	Traditional village
Number of workers involved	38	37	53	23

Initial soil properties

The initial soil used in the pot experiment contained 2.61% soil organic carbon, 0.22% total nitrogen, a C/N ratio of 11.86, and 11.60% moisture content. Baseline data were collected prior to the use of composts in determining the effects of compost addition on changes in the soil chemical composition after harvesting. Soil organic carbon and total nitrogen became the key variables in measuring the extent to which the composts contribute to the soil carbon and nitrogen content. C/N ratio gave information regarding the proportion of soil carbon and nitrogen prior to the use of treatments, whereas moisture content indicated the initial water status of the growing medium.

Plant growth response to compost application

Plant height, stem diameter, number of leaves, and SPAD value changed over time across treatment combinations (Figures 2-5). The Linear Mixed Model showed that observation time significantly affected all growth variables (Table 4).

In terms of plant height, the factors that had a highly significant effect were the compost dosage and time ($p<0.001$). However, compost source was not significant. Source × time, dose × time, and source × dose × time interactions were all significant, meaning that the plant height response was affected differently depending on the interaction between the compost source and dosage. A pairwise comparison on dose revealed that K0 was significantly different from K1, K2, and K3, while K2 was significantly different from K3. This means that the plant height response was not dependent solely on compost source, but on the interaction of time with compost dose and plant height.

Table 2. Physical characteristics of compost from four composting facilities

Variables	TPS 3R Panca Lestari (TB)	Padang Tegal Compost House (PT)	Recycling Center (PDU) DLHK Denpasar (PS)	TPS 3R Kedonganan (KD)
Color	Dark brown	Light brown	Black	Brown
				
Odor	Earthy	Earthy	Earthy	Earthy
Texture	Fine	Fine	Coarse	Fine
Temperature (°C)	25	25	26	26
Foreign materials (%)	13.38	3.39	38.21	5.67
Water holding capacity (%)	61.64	58.23	64.53	57.05
Particle size (<0.55 mm, %)	44.96	42.18	11.33	57.43

Table 3. Chemical characteristics of compost from four composting facilities compared with SNI standards

Composting facility	Organic C (%)	Total N (%)	C/N ratio	Organic matter (%)	pH (H_2O)	Moisture content (%)
TPS 3R Panca Lestari (TB)	34.51	2.68	12.88	59.49	7.57	26.54
Padang Tegal Compost House (PT)	26.13	2.11	12.38	45.06	6.88	12.55
Recycling Center (PDU) DLHK Denpasar (PS)	34.24	0.72	47.55	59.05	7.38	9.84
TPS 3R Kedonganan (KD)	33.15	2.84	11.67	57.15	7.30	41.83
SNI standard	9.8-32	≥0.40	10-20	27-58	6.80-7.49	≤50

Table 4. Summary of Linear Mixed Model analysis for repeated plant growth measurements of *Ipomoea reptans*

Source of variation	Plant height	Number of leaves	Stem diameter	SPAD value
Block	F=0.390; p=0.681 ns	F=0.133; p=0.876 ns	F=0.272; p=0.764 ns	F=0.204; p=0.816 ns
Compost source (S)	F=1.431; p=0.254 ns	F=0.105; p=0.957 ns	F=0.157; p=0.925 ns	F=3.617; p=0.017 *
Compost dose (D)	F=24.038; p<0.001 **	F=3.882; p=0.021 *	F=15.795; p<0.001 **	F=1.218; p=0.309 ns
Time (T)	F=490.482; p<0.001 **	F=234.867; p<0.001 **	F=605.819; p<0.001 **	F=80.120; p<0.001 **
S × D	F=1.867; p=0.098 ns	F=0.341; p=0.952 ns	F=0.993; p=0.463 ns	F=2.108; p=0.039 *
S × T	F=2.134; p=0.004 **	F=1.877; p=0.015 *	F=1.009; p=0.454 ns	F=13.151; p<0.001 **
D × T	F=5.165; p<0.001 **	F=3.298; p<0.001 **	F=5.117; p<0.001 **	F=2.528; p=0.001 **
S × D × T	F=1.546; p=0.013 *	F=1.266; p=0.116 ns	F=1.593; p=0.009 **	F=2.225; p<0.001 **

Note: ns: Not significant (p>0.05), *: Significant at p<0.05, **: Significant at p<0.01. S: Compost source, D: Compost dose, T: Observation time. Plant growth variables were analyzed using a Linear Mixed Model because repeated observations were taken from the same experimental units over time

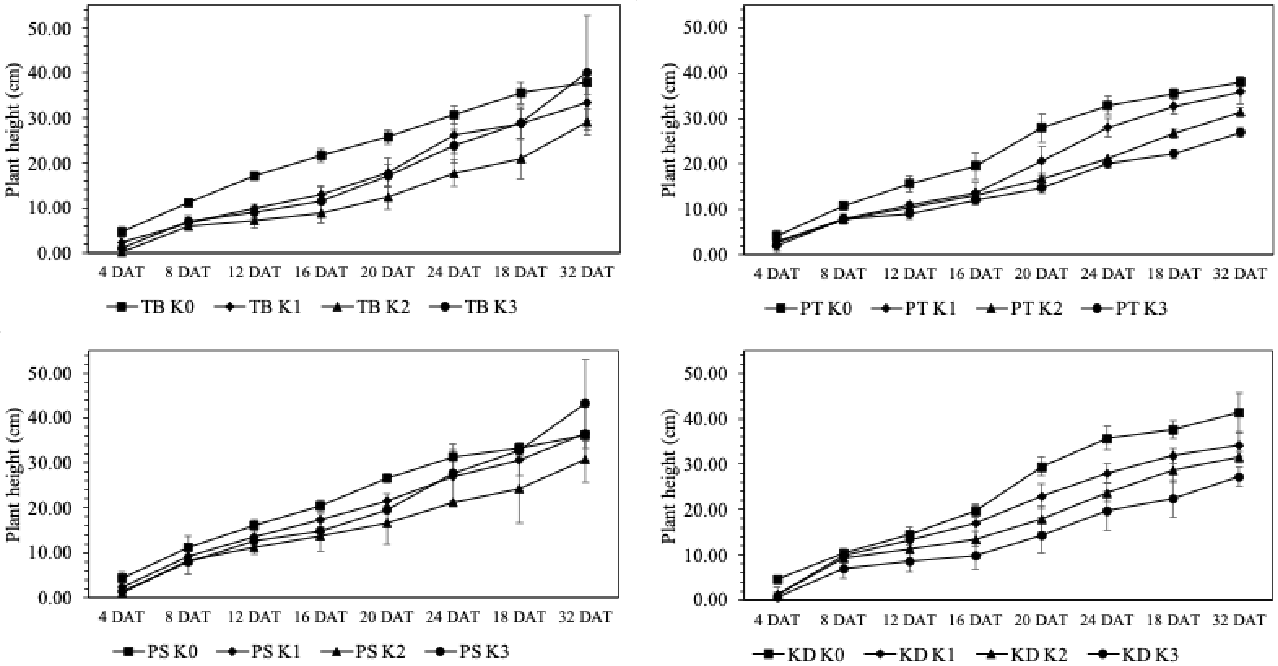

Figure 2. Plant height (cm) of *Ipomoea reptans* under different compost source and dose combinations measured from 4 to 32 days after transplanting. Error bars represent standard deviation. Statistical effects of compost source, dose, time, and their interactions were evaluated using a Linear Mixed Model and are summarized in Table 4

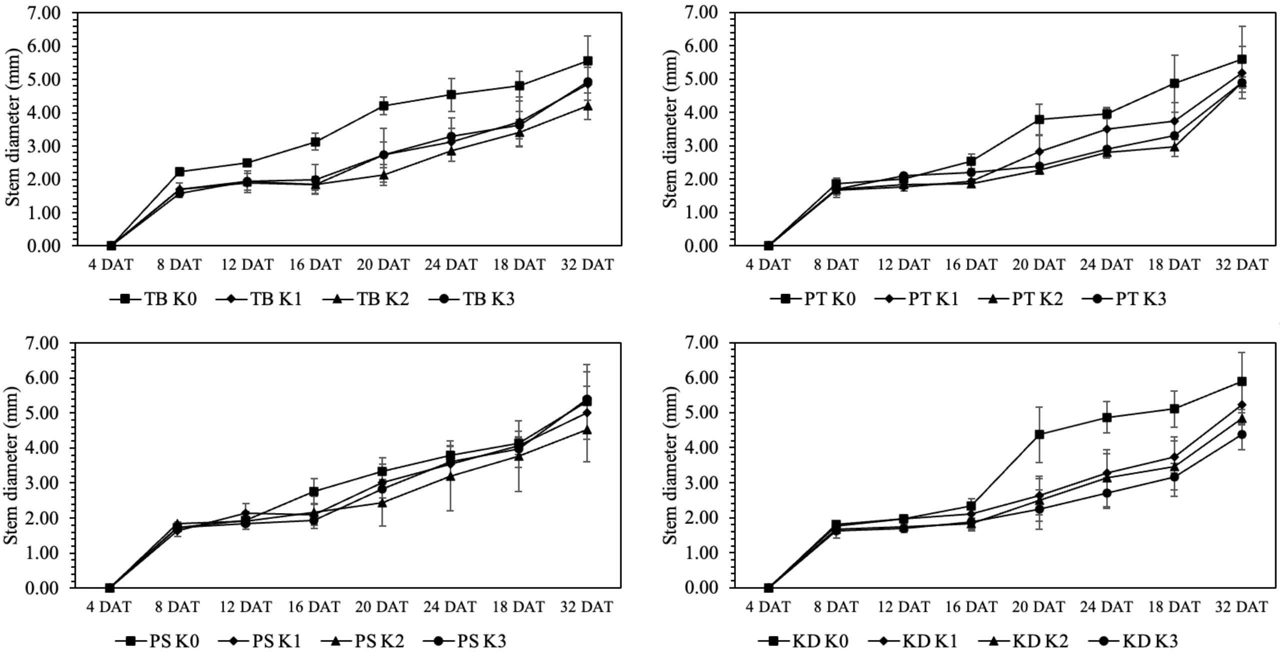

Figure 3. Stem diameter (mm) of *Ipomoea reptans* based on varied compost source and treatment dosage from day 4 to day 32 after transplanting. Error bars represent standard deviation. Statistical effects of compost source, dose, time, and their interactions were evaluated using a Linear Mixed Model and are summarized in Table 4

Stem diameter was significantly influenced by compost dose and time, whereas compost source and source × dose interaction were not significant. However, the significant dose × time and source × dose × time interactions indicated that stem diameter response changed during plant development depending on treatment combinations. Pairwise comparison showed that K0 differed significantly from all compost-amended treatments, while differences among K1, K2, and K3 were not significant.

For the number of leaves, compost dose and time significantly affected leaf formation, while compost source alone was not significant. Highly significant relationships between source x time and dose x time showed that differences in leaf number depended on source and dose, respectively, in terms of time. However, the three-factor relationship was not significant, implying that the combined effect of source and dose on leaf number remained unchanged over time when compared to other growth traits.

The SPAD value responded to more complex effects as compared to morphological growth parameters. The SPAD value significantly depended on compost type and time, while compost dose was non-significant. Nevertheless, compost type × dose, compost type × time, compost dose × time, and compost type × dose × time interaction were all found to be significant. Thus, it appears that the degree of leaf greenness resulted from the effects of all three factors: compost type, compost dose, and observation time.

Overall, the mixed model analysis showed that plant growth responses were not controlled by compost source or dose independently. Instead, the responses depended strongly on temporal dynamics. Compost dose had a stronger influence on plant height, leaf number, and stem diameter, whereas SPAD response was more strongly associated with compost source and its interaction with dose and time.

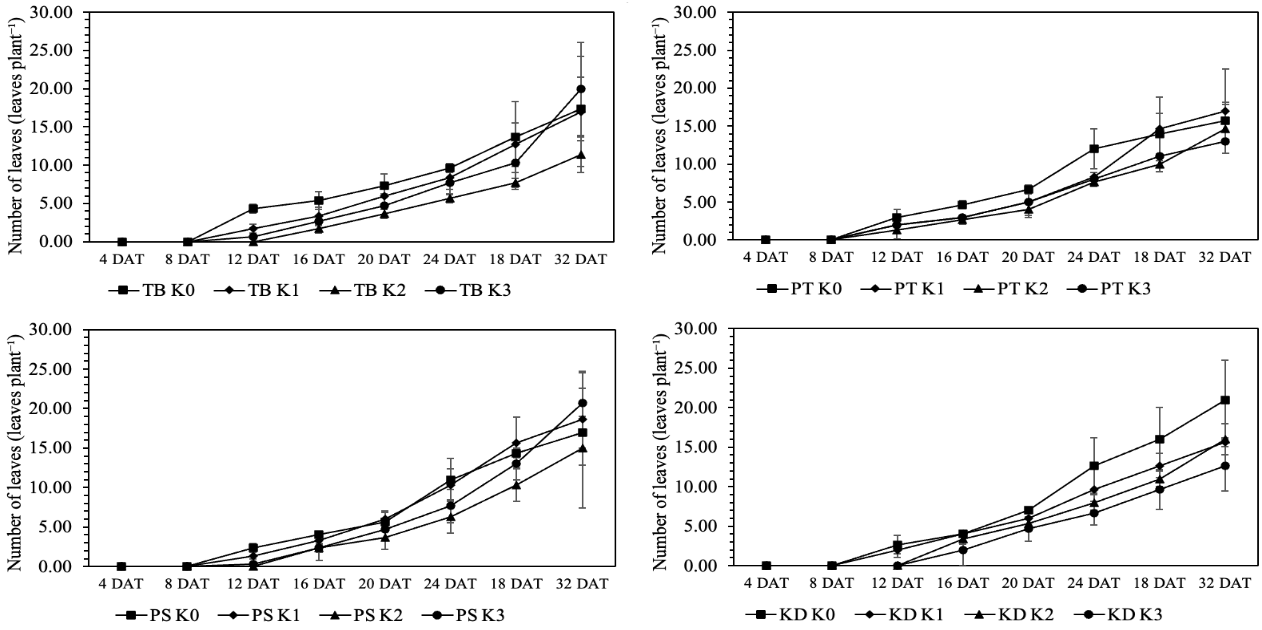

Figure 4. Number of leaves (leaves plant^{-1}) of *Ipomoea reptans* under different compost source and dose combinations measured from 4 to 32 days after transplanting. Error bars represent standard deviation. Statistical effects of compost source, dose, time, and their interactions were evaluated using a Linear Mixed Model and are summarized in Table 4

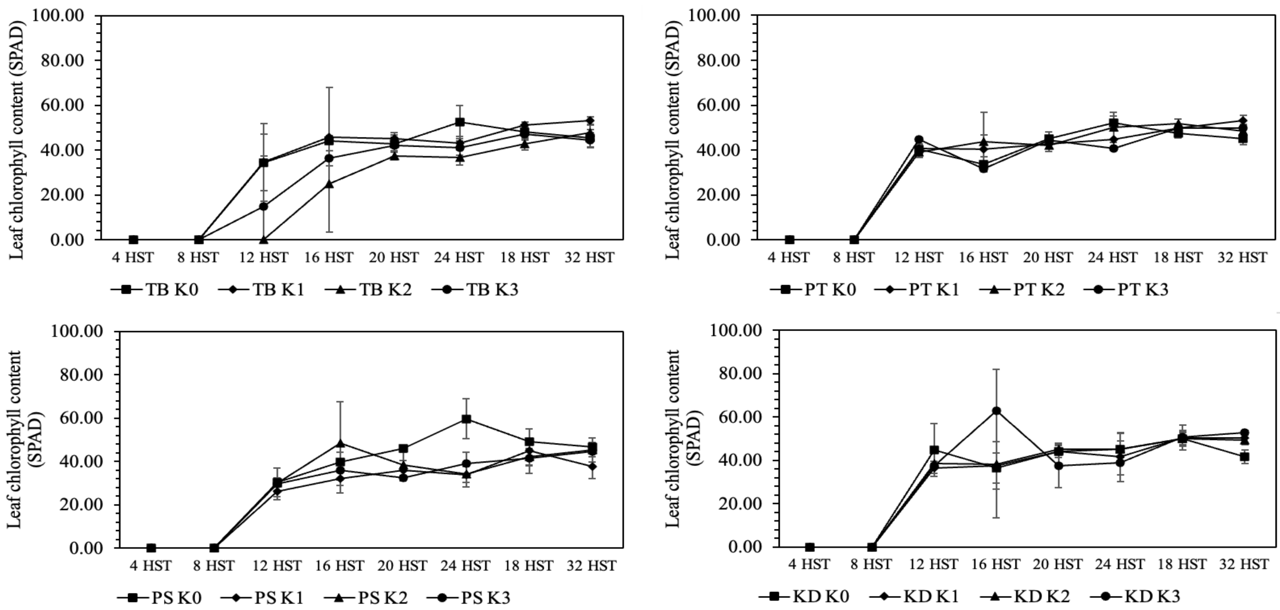

Figure 5. *Ipomoea reptans* chlorophyll content in leafs (SPAD) at varying levels of compost sources and rates determined between days 4 and 32 after transplanting. Error bars indicate standard deviations. The statistical impact of compost source, rate, duration, and interaction effects was assessed using a Linear Mixed Model, and presented in Table 4

Table 5. Factorial ANOVA summary for biomass and post-harvest soil properties of *Ipomoea reptans* under different compost source and dose treatments

Source of variation	Fresh weight	Dry weight	Soil organic C	Total N	C/N ratio
Block	F=1.175; p=0.323 ns	F=0.019; p=0.981 ns	F=1.667; p=0.206 ns	F=0.000; p=1.000 ns	F=1.469; p=0.246 ns
Compost source (S)	F=0.105; p=0.956 ns	F=1.939; p=0.145 ns	F=17280.937; p<0.001 **	F=4031.250; p<0.001 **	F=35022.446; p<0.001 **
Compost dose (D)	F=2.452; p=0.083 ns	F=0.690; p=0.566 ns	F=235252.604; p<0.001 **	F=89677.500; p<0.001 **	F=108516.793; p<0.001 **
S × D	F=1.368; p=0.246 ns	F=1.103; p=0.390 ns	F=27618.160; p<0.001 **	F=3041.250; p<0.001 **	F=29614.137; p<0.001 **
R²	0.427	0.373	1.000	1.000	1.000

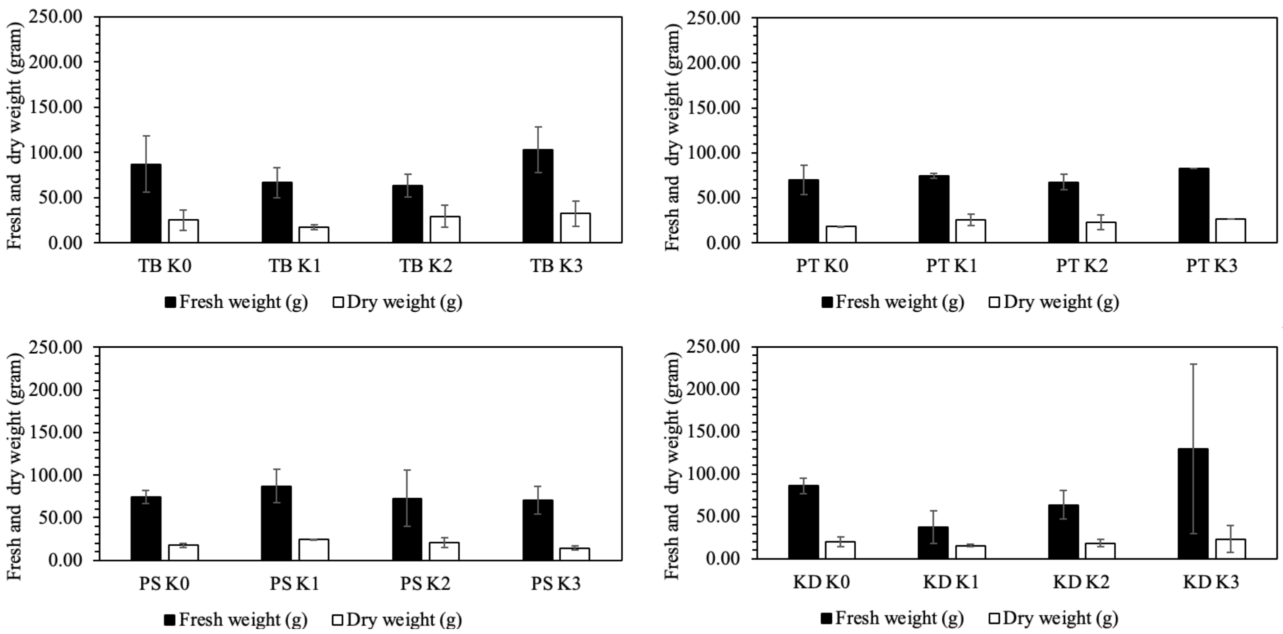

Figure 6. Fresh and dry weight (g) of *Ipomoea reptans* under different compost source and dose combinations. Error bars represent standard deviation. Factorial ANOVA showed no significant effect of compost source, dose, or source × dose interaction on fresh and dry biomass

Fresh and dry biomass at harvest

The factorial ANOVA results for final biomass and post-harvest soil properties are summarized in Table 5. Fresh and dry biomass were not significantly affected by compost source, compost dose, or their interaction, whereas soil organic carbon, total nitrogen, and C/N ratio were significantly affected by compost source, dose, and source × dose interaction.

Fresh and dry biomass at harvest varied among treatment combinations (Figure 6). However, factorial ANOVA showed that compost source, compost dose, and source × dose interaction did not significantly affect fresh weight or dry weight. Therefore, biomass differences observed in the figure should be interpreted as treatment trends rather than statistically confirmed treatment effects.

Although some combinations, such as K3 in Kedonganan and Panca Lestari, showed relatively higher fresh biomass, the overall factorial analysis did not support a consistent significant effect of compost source or dose on biomass. It suggests that variability in the final biomass measure is higher than variability in the repeated vegetative growth measures, and needs to be carefully considered, given the restricted replication level of the greenhouse study.

Changes in soil properties after compost application

Post-harvest soil properties differed among compost source and dose combinations (Figure 7). Factorial ANOVA showed that compost source, dose, and source × dose interaction significantly affected soil organic carbon, total nitrogen, and C/N ratio ($p<0.001$). These results indicate that changes in soil chemical properties were influenced by both the origin of compost and the amount applied.

Compost amendments resulted in increased soil organic carbon relative to the control treatment, but it did not show a strict dose-related increase. Total nitrogen was increased and the C/N ratio was decreased in most compost-amended treatments. This suggests that compost additions were associated with an alteration in soil carbon and nitrogen balances post-harvest.

However, because several soil variables exhibited very strong model fits, the statistical findings of the soil data must be taken with caution and considered only as supportive evidence to indicate the effects of the treatments on the growing media.

Discussion

Variation in compost quality among sources

Quality of the compost differed among the four sites, implying that compost made from community-based and municipal composting facilities in Bali showed variability regarding their maturity and physical quality. While Padang Tegal offered compost that complied with all the standards of SNI 19-7030-2004, Panca Lestari, PDU Denpasar, and Kedonganan exceeded one standard for the compost made at their facilities. In this case, the variation should not be surprising, given the fact that different characteristics could be observed regarding feedstock composition, sorting, composting period, and management system. This observation was already documented elsewhere in connection with compost studies, when feedstock type and level of control exercised in the process influenced compost quality and stability (Awasthi et al. 2020; Guo et al. 2023).

The largest variation based on maturity is evident in the case of PDU Denpasar compost, which had high contents of C/N and extraneous substances. The C/N ratio may serve as an indicator of un-stabilized compost because of the degradation of carbon and transformation of nitrogen through composting (Luo et al. 2020). Nevertheless, the C/N ratio by itself may not serve as a comprehensive indicator of compost maturity. Physical characteristics such as particle size, texture, and foreign material content also influence compost uniformity and potential behavior after incorporation into soil. In this study, the high foreign material content in PDU Denpasar suggests that sorting and post-processing refinement were less effective than in the other facilities.

Physical contamination may influence compost performance through several pathways. It can reduce the proportion of biologically active organic material, increase heterogeneity in the compost matrix, and limit contact between decomposable substrates and microbial communities. Therefore, the lower quality of PDU Denpasar compost should not be interpreted only as a chemical maturity issue, but also as a physical quality problem. This supports the view that compost readiness should be evaluated using both chemical indicators, such as C/N ratio, pH, moisture content, organic carbon, and total nitrogen, and physical indicators, such as texture, particle size, and foreign material content (Azim et al. 2017; Policastro and Cesaro 2022).

Comparison among the facilities further reveals that compost quality was not solely influenced by composting method. Both Padang Tegal and PDU Denpasar adopted the aerobic method; however, their compost quality was vastly different. Process management, feedstock mixture composition, length of composting period, moisture level, and consistency of process seem more important than composting type. Turnover frequency, moisture level, feedstock mixture composition, and additives are known to affect decomposition and stability of the composted material (Azis et al. 2023; Noor et al. 2024). Thus, the reason behind the higher quality of compost from Padang Tegal could have been related to superior management of the process and feedstock rather than the aerobic composting type.

Time-dependent plant response and possible mechanisms

Based on the results from the Linear Mixed Model, it is clear that plant growth was highly dependent on time. This means that the parameter "time" played an important role on all parameters of growth as well as some time interactions. This means that plant growth after adding compost is time-dependent because of varying effects of the source and rate of added compost as the plants developed.

Lower growth rates recorded at the early stages of compost application treatments can be attributed to nutrient shortage as a consequence of decayed organic material caused by addition of the compost. The high C/N ratio of compost results in the increased utilization of nitrogen by microbes, thus, reducing nitrogen availability for plants' use (Luo et al. 2020). It should be pointed out that no direct measurements were carried out concerning mineral nitrogen, ammonium, nitrate, microbial biomass, respiration, and mineralization processes. Thus, nitrogen immobilization is worth considering a possible factor but not the reason.

There might be other reasons for the early response of plants to the application treatments. The presence of solvable salts, organic acid, or phytotoxic compounds within fresh or immature compost might influence the plant's root growth and nutrient uptake. With more compost applied, the soil will have a changed physical property in regards to aeration and moisture movement, which would lead to oxygen deficiency or osmosis stress. In addition, early compost decomposition would affect the nutrients in addition to the total amount of nitrogen or C/N ratio. Nevertheless, these explanations could not be considered due to the lack of investigation on salinity, phytotoxicity, microorganism activity, and nitrogen mineralization.

Furthermore, the tropical environment might bring yet another dimension to compost performance following soil incorporation. Although warm and moist environments accelerate decomposition processes, whether the direction and duration for nutrient runoff would be governed by the maturity of the compost, quality of the substrates used, as well as microbial activity in soils. Unmatured compost will decay faster, resulting in the initial stage of competition for nutrients and gradual nutrient release into the soil, while mature compost would exert better results due to decomposition of larger portions of organic materials prior to incorporation. Such phenomena can be explained by the theory that compost maturity affects plant reaction to its use as a fertilizer both physically and chemically (Awasthi et al. 2020; Ho et al. 2022).

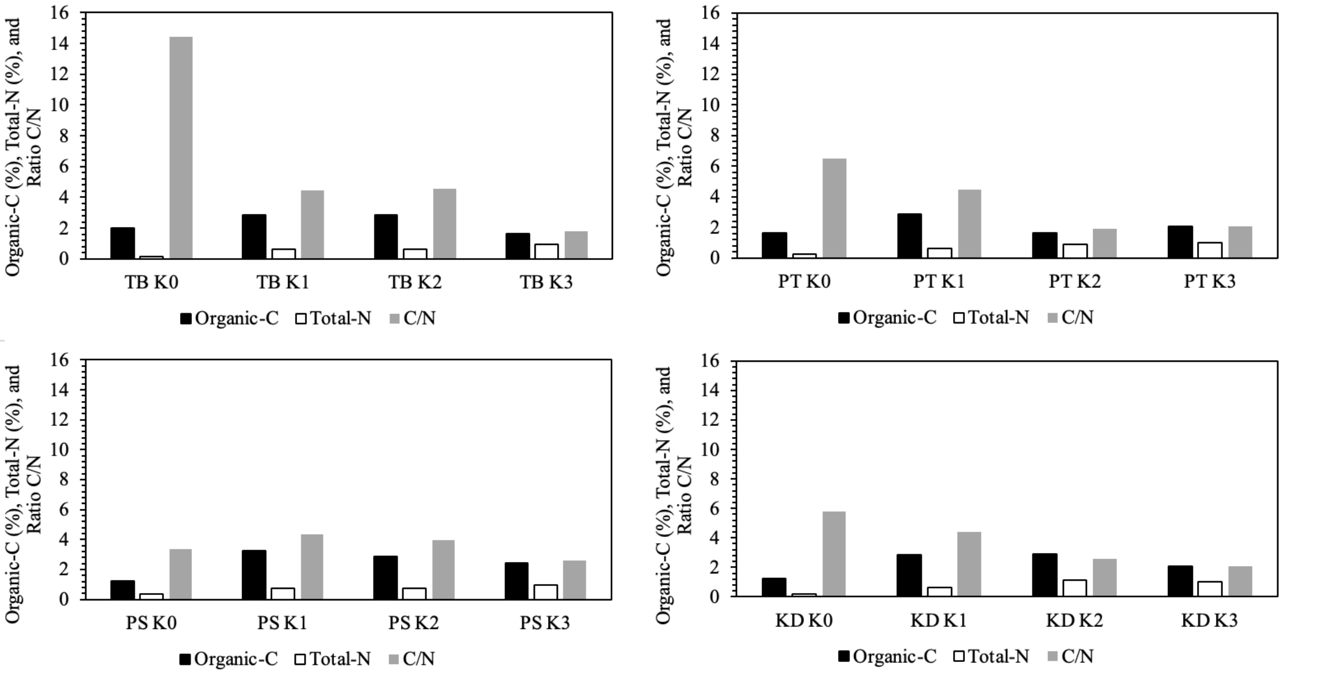

Figure 7. Post-harvest soil organic carbon, total nitrogen, and C/N ratio under different compost source and dose combinations. Error bars represent standard deviation. Factorial ANOVA results for source, dose, and source × dose effects are summarized in Table 5

Biomass response at harvest

Although certain observable differences were noted in both wet and dry biomass under various treatments, there was no significant impact of any of the three factors considered under factorial analysis on biomass. This is critical because it weakens the ability to make an agronomic interpretation from the findings. The temporal differences that were seen during growth were not reflected in any biomass differences.

Several possible explanations are presented in relation to the above-mentioned discrepancy between vegetative growth dynamics and ultimate biomass production. Firstly, *I. reptans* has a relatively short life span, and, therefore, time for compost mineralization could be insufficient. Secondly, various levels of compost maturity could result in different times of releasing nutrients by each kind of compost. Finally, the number of replicates for each treatment was equal to three, limiting the sensitivity of results concerning moderate variations in biomass production. Application of compost affects plant growth through the modification of soil properties related to nutrient availability, root zone conditions, and physical properties of the soil (Sayara et al. 2020; Ho et al. 2022; Wang et al. 2022). However, obtained data on biomass production do not confirm significant increases in crop yields.

Therefore, the utilization of biomass is considered to be an indication trend rather than being used as proof of agronomic superiority from the various compost treatments or rates. In this study, the effects of the compost application rate were better shown through growth and post-harvest soil changes rather than through final biomass levels. Thus, further recommendation on compost application rates would not yet be made without conducting more experiments with better controls and measuring nutrient release.

SPAD response as an indirect physiological indicator

The SPAD variable proved to be more complicated compared to the growth morphology factors. In this respect, SPAD was influenced by the source and time factors, whereas the effect of dose alone was insignificant. Interactions between the three factors suggest that leaf color depended on the source of the compost and growth stage.

The SPAD index is typically linked to chlorophyll concentration and nitrogen content in the leaves, and it could be considered valuable supplemental data on plant physiological reactions (Kim and Kim 2024). But the SPAD index is a non-direct measure. It cannot prove nitrogen mineralization, nitrogen immobilization, or plant nitrogen absorption on its own. Thus, the SPAD index values obtained in the current study have to be treated as an indication of physiological responses rather than as a proof of nitrogen metabolism processes.

The findings indicate that the leaf greenness was impacted by changes over time in the growing medium. Organic matter can provide nutrients slowly and impact plants differently during different phases of their growth (Sogbohossou et al. 2018; Ho et al. 2022). Nevertheless, without measuring mineral nitrogen, salinity levels, and microbial activity, it cannot be known precisely how the change in SPAD occurred. Further studies must include SPAD analysis and the quantification of available nitrogen in the plant tissues.

Soil properties after compost application

There were statistically significant differences in SOC, TN, and C/N ratio among various compost levels and combinations of dosage types used after harvesting. This implies that application of compost in soils resulted in changes in their chemical composition. Differences in variables were not always proportional to the amount of compost applied, implying that there is an interaction effect of quantity and quality of compost.

The reason for non-linearity in the behavior of soils might be linked to differences in carbon stabilization, nitrogen concentration, and degree of decomposition among different types of compost used. Organic carbon-rich compost may help to enhance carbon input in soils, but the stabilization process and further transformation depend greatly on the nature of substrates and microbial action. Higher nitrogen concentration in soils does not necessarily mean that this component will be directly available to plants because inorganic nitrogen should first be transformed into plant-available nutrients. It was already proved that the use of compost contributes to the cycling of carbon in soils along with other elements, but the scale of the contribution depends on compost and soil properties (Bimantara et al. 2022; Wang et al. 2022; Guo et al. 2023).

It is also important to cautiously interpret the results obtained from soil analyses since the experiment was done under controlled conditions inside the greenhouse and there was not enough replication. Furthermore, only total soil organic carbon, total nitrogen, and C/N ratio were considered in this study and mineral nitrogen pools were not analyzed. Thus, soil analysis provides the evidence that compost altered soil chemical characteristics but no direct proof of nutrient mineralization and nitrogen availability was provided by this method.

Implications and limitations

The results of this paper reflect the site-specific differences in terms of the quality of composts from waste management facilities in Bali. It is possible to note that the compost that meets the quality criteria under the regulation will perform better, while non-conformable compost may alter the soil chemistry, although its impact on the plants is not consistent.

As regards to community-based compost application, there needs to be continuous quality control as emphasized by the current study. Such an approach requires assessing chemical parameters such as the C/N ratio, organic carbon, total nitrogen, pH, and moisture, as well as the physical parameters such as foreign materials and particle size. The reason is that this will assist in the integration of community-based composting within sustainable agriculture and the circular economy (Geissdoerfer et al. 2017; Waqas et al. 2023). The high quantity of foreign materials in PDU Denpasar indicates the need for additional source separation before using the compost in crops.

One of the major limitations of this study is the fact that the physiology behind the behavior of plants is based on quality factors of the compost as well as the outcomes of plant performance rather than actual measurements. Parameters such as mineral nitrogen, ammonium, nitrate levels, microbial biomass, respiration, salinity, phytotoxicity, and mineralization rates were not measured. Another limitation is that there are just three replicates per treatment combination. Thus, the conclusion made by the researcher should be viewed as lab data on compost rather than field recommendations.

Further research will require greater replication and longer study time, with additional measures taken to measure mineral N, ammonium, nitrate, microbial biomass, respiration, salinity, and phytotoxicity. Such measures will help distinguish between the effects of nutrient immobilization, phytotoxicity, osmotic effects, microbial competition, and other factors affecting plant responses to compost maturity in tropical environments.

In conclusion, there were variations in chemical and physical qualities of the compost derived from the community-based and municipal waste management systems in Bali. The four types of compost examined only had Padang Tegal compost that met all requirements specified in SNI 19-7030-2004, whereas the other compost samples were beyond certain standards, especially with regards to organic carbon content, organic matter, pH, C/N ratio, or foreign materials.

The Linear Mixed Model indicated that plant growth responses were strongly time-dependent. Compost dose affected plant height, number of leaves, and stem diameter, whereas SPAD response was more closely related to compost source and its interactions with dose and observation time. However, final fresh and dry biomass were not significantly affected by compost source, dose, or their interaction. This indicates that temporal growth responses did not consistently result in significant harvest biomass differences under the present experimental conditions.

The early growth response observed in some compost-amended treatments may be associated with compost maturity and temporary changes in nutrient availability. However, because mineral nitrogen dynamics, microbial activity, salinity, phytotoxicity, and respiration were not measured, the underlying mechanisms remain inferential. Therefore, nitrogen immobilization should be interpreted only as one possible explanation rather than a confirmed mechanism.

Overall, this study provides location-specific greenhouse evidence on the quality variation and plant response associated with composts from local waste management facilities in Bali. The findings emphasize the need for controlling the quality of composts, enhancing the efficiency of source separation, and conducting more research with increased replications and direct analysis of the dynamics of nutrients.

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