



Valorisation of Dairy STP Sludge: Effects of Sludge-based Compost on Early Plant Growth Assessed Through Phytotoxicity Assays (Precision and Sustainable Agriculture)

PRAGATI PRATAP NADE^{1*}, DEEPAK VISHNU KULKARNI¹,
MILIND JAYANT VEDPATHAK¹, ASHISH VASANTPOLKADE²
and SAKSHI ABHIJIT KOTEKAR³

¹Smartenviro Systems Private Limited, Pune, Maharashtra, India.

²Besteco Solutions and Technologies Private Limited, Pune, Maharashtra, India.

³Laboratory and Project Coordinator, Besteco Solutions and Technologies Pvt. Ltd, Pune, Maharashtra, India.

Abstract

This study evaluates the quality of dairy waste compost by assessing its effect on monocot and dicot seed germination using the tray method. Compost samples were mixed with soil in varying ratios, and germination rate, root, and shoot lengths of *Vigna radiata* (green gram) and *Triticum aestivum* (wheat) were recorded. The compost was produced using a Smartenviro Systems drum composter containing 40 kg of dairy sludge and 10 kg of sawdust as a bulking agent. Composting was carried out for 12–15 days at 45–55°C under thermophilic conditions, with daily drum rotation using a 0.5 HP geared motor for uniform aeration and mixing. The sawdust improved the C: N balance, enhancing organic matter degradation and yielding stable, odor-free compost. The automated, enclosed design minimized labor and leachate loss. Germination assays indicated that the compost-soil mixtures were non-phytotoxic and promoted early plant growth. Pathogen analysis confirmed the absence of *Salmonella* spp. and *Staphylococcus aureus*; however, detectable *Escherichia coli* and elevated chromium (Cr) levels above regulatory limits indicate incomplete sanitization and highlight the need for additional stabilization or post-treatment before unrestricted agricultural application. Overall, the results demonstrate the potential of controlled compost-soil blending for sustainable dairy waste management, while emphasizing the importance of further treatment to ensure microbiological and chemical safety.



Article History

Received: 08 July 2025
Accepted: 25 December 2025

Keywords

Compost Quality;
Dicot Seed;
Germination Test;
Monocot Seed;
Tray Method;
Triticum aestivum;
Vigna radiata;
Phytotoxicity Assay.

CONTACT Pragati Pratap Nade ✉ anupajacob@gmail.com 📍 Smartenviro Systems Private Limited, Pune, Maharashtra, India.



© 2025 The Author(s). Published by Enviro Research Publishers.

This is an  Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi: <http://dx.doi.org/10.12944/CARJ.13.3.32>

Abbreviations

STP	Sewage Treatment Plant
S:C	Soil: Compost)
HP	Horsepower
C/N	Carbon to Nitrogen Ratio
NH ₄ ⁺ N	Ammonium Nitrogen
NO ₃ ⁻ -N	Nitrate Nitrogen
ICP–OES	Inductively Coupled Plasma - Optical Emission Spectrometry
FCO	Fertiliser Inorganic, Organic or Mixed Control Order, 1985
EC	Electrical Conductivity
CFU	Colony Forming Units
MPN	Most Probable Number
P ₂ O ₅	Phosphorus Pentoxide
EN	European Norm
EPA	OPPTS Environmental Protection Agency - Office of Prevention, Pesticides and Toxic Substances)
FWC	Food Waste Compost
NFCE	Non-Aerated Fermented Compost Extract
GI	Germination Index

Introduction

The world is moving fast towards organic farming, and this study is an important step towards the same. The implementation of an environmentally friendly management strategy for solid waste is recognized as an urgent need worldwide, whereas reuse and recycling of these wastes through compost preparation are categorized as the most preferable approaches in an integrated solid waste management system under the clean Indian program and Smart City program.¹ To improve soil aggregation, restore soil organic carbon and nitrogen, and increase agricultural sustainability, compost application is being advocated as a substitute for synthetic fertilizer.² Composting is a microbially mediated stabilization process that converts organic waste into a nutrient-rich soil amendment suitable for agricultural use. Compost quality is crucial for its effectiveness in agriculture. Seed germination tests, particularly with dicotyledonous plants, provide a rapid and effective way to evaluate compost phytotoxicity and nutrient content.³⁻⁶ Here, we used both dicot and monocot plants for the study. This study aims to analyze compost quality by sowing dicot and monocot seeds in compost-soil mixtures using a controlled tray method.

The dairy industry produces substantial quantities of organic waste, including manure, wash water,

and sludge from milk processing. Dilecta dairy waste, a byproduct generated during the processing of lactose-rich dairy streams, is high in organic matter and nutrients. When not managed properly, this waste poses serious environmental challenges, including water pollution, foul odors, and greenhouse gas emissions. In many industrial regions, the accumulation of such waste also adds to operational costs and regulatory pressures. As sustainability becomes a critical focus in industrial practices, the need for effective, low-cost, and eco-friendly waste management strategies is growing. Composting has emerged as a promising solution to transform dairy waste into valuable organic fertilizer, reducing environmental risks while promoting circular resource use.

While composting is an effective method for stabilizing organic waste, the quality of the final compost product can vary significantly depending on the raw materials used and the composting conditions.^{7,8} Poorly matured or contaminated compost can contain phytotoxic compounds such as ammonia, organic acids, or heavy metals, which may hinder plant growth rather than support it.⁹⁻¹² Therefore, it is essential to assess compost maturity and safety before agricultural application.^{6,13} Traditional chemical analyses provide insight into nutrient content and pH, but they may not reflect

the actual biological effects of the compost on plant development. As a result, bioassays have become a valuable complementary tool. Among these, the plant germination method stands out due to its simplicity, cost-effectiveness, and ability to directly indicate the presence of inhibitory substances through measurable effects on seed germination and root elongation.

In this context, the present study aims to evaluate the quality and phytotoxicity of compost derived from Dlecta dairy waste using the plant germination method. Seeds of selected indicator species were used to assess germination rate and root development in compost, serving as direct biological indicators of compost safety and maturity.¹⁴ We hypothesized that (1) moderate compost inclusion (>25%) would enhance seed germination and early plant growth due to improved nutrient availability, and (2) pure compost application would exhibit phytotoxic effects arising from residual ammonium or incompletely stabilized organic compounds. By focusing on germination as a bioindicator, this study provides a practical approach for identifying potentially harmful byproducts in compost that might not be evident through chemical analysis alone. The outcomes of this work are particularly relevant for industrial compost producers, waste management facilities, and agricultural users seeking cost-effective tools to ensure compost reliability. Furthermore, by validating a simple and scalable testing method, this research contributes to environmentally responsible waste reuse practices, supporting the transition to circular and sustainable industrial systems. The findings also offer insight into optimizing Dlecta Dairy waste management at both operational and policy levels.

This study demonstrates that drum composters such as the Smartenviro Systems unit can play a significant role in sustainable waste management, particularly in urban and institutional settings where space availability, hygiene, odor control, and time efficiency are critical considerations. The novelty of the present study lies in the application of a temperature-controlled rotating drum composting system with a short retention time for processing lactose-rich dairy STP sludge, a waste stream commonly associated with high organic load and phytotoxicity. Compared with conventional windrow composting,

the controlled drum system enabled rapid pathogen reduction, enhanced organic matter stabilization, and effective mitigation of phytotoxic effects, resulting in mature, agronomically safe compost within a reduced timeframe. These process efficiencies were reflected in improved seed germination and early growth responses of both monocot and dicot crops at optimized soil–compost ratios.

Materials and Methods

Matured compost derived from Dlecta dairy STP Sludge waste was used as the test material. Control soil consisted of standard garden soil without compost. In the present study, a uniform, locally sourced garden soil was used as a baseline growth medium to conduct a preliminary phytotoxicity and early growth assessment. While detailed soil characterization (texture, pH, organic matter, and CEC) was not performed, the same homogenized soil batch was consistently used across all treatments to reduce variability and allow comparative evaluation of compost application rates. The primary aim was to assess compost suitability and plant response at different compost proportions rather than to elucidate detailed soil–compost interaction mechanisms. Seeds of commonly used test species—Green gram, wheat—were selected for their sensitivity and fast germination rates as different plant species respond variably to compost maturity and ammonium toxicity.⁹ Seed germination assays were conducted under consistent laboratory ambient conditions, following standard toxicity testing guidelines.¹⁰ Chemical surface sterilization was not employed, as the objective was to assess phytotoxicity under conditions relevant to agricultural practice. Light exposure followed a natural photoperiod, and humidity was maintained through regular moisture adjustment and tray coverage. Experiments were conducted in uniformly sized trays (30 cm × 20 cm), with daily irrigation using clean water. Measurements were taken using basic tools such as a ruler, digital scale, and thermometer. All treatments were clearly labeled for consistent identification.

The Smartenviro Systems rotating drum composter proved to be an efficient and practical system for accelerating compost formation under controlled conditions. The rotating drum mechanism ensured proper aeration and uniform mixing of organic waste, thereby enhancing microbial activity and promoting

rapid organic matter decomposition leading to accelerated stabilization under thermophilic conditions.⁸ As a result of intense microbial metabolism, exothermic reactions led to a rapid rise in compost temperature, marking the onset of the thermophilic phase. During the active composting stage, temperatures increased to thermophilic ranges suitable for pathogen inactivation and accelerated organic matter breakdown.

The composting process was operated under aerobic conditions with an effective material retention time of 12–15 days within the drum, during which the system facilitated automatic temperature regulation through controlled rotation and heat retention, preventing excessive overheating while sustaining thermophilic conditions. Temperature and moisture

were monitored manually at regular intervals, and operational adjustments were made as necessary to maintain conditions optimal for aerobic composting. Following the active heating phase, the compost gradually entered a cooling and stabilization phase, indicating reduced microbial respiration and progressive compost maturation.

Overall compost maturity was achieved after a subsequent curing period, resulting in a stable product characterized by dark brown color, crumbly texture, and earthy odor. Although continuous automated monitoring was not employed, periodic measurements were sufficient to maintain stable and reproducible composting conditions throughout the heating, maintenance, and cooling phases.

Table 1: Parameters taken in consideration for the study

Parameter	Frequency	Method
Germination rate (%)	Day 3–7	Count germinated seeds
Plant height (cm)	Every 3–5 days	Ruler from soil to tip
Root length (cm)	At harvest	Ruler after uprooting

Determination of Physical Properties of Compost

The physical properties evaluated in this study included compact density, moisture content, dry matter, ash content, and organic matter. Compact density was measured according to the procedure described in EN13040:2007,¹⁵ using calibrated cylinders of known mass and volume. The density of each sample was calculated and expressed in g/L (g/dm³). Moisture content and dry matter were quantified by drying 100g of fresh compost at 103±2 °C until a constant weight was achieved, following the methodology specified in EN13040.¹⁵ The results were expressed as percentages of the original fresh mass. The determination of ash and organic matter content followed EN13039:2012.¹⁶ Compost samples were initially dried for a minimum of 4h at 103±2°C and subsequently combusted in a muffle furnace at 450±10 °C for at least 6h. The samples were re-weighed after each additional hour of ignition until a stable mass was obtained. Organic matter and ash contents were expressed as a percentage of the dry matter.

Analysis of Chemical Properties of Compost

The chemical properties of compost were analyzed by determining pH, electrical conductivity (EC), total carbon and nitrogen, the C/N ratio, ammonium and nitrate nitrogen (NH₄⁺-N and NO₃⁻-N), and total phosphorus and potassium, following the specifications of the Fertiliser (Inorganic, Organic or Mixed) Control Order, 1985 (FCO 1985).¹⁷ The pH of compost was measured in a 1:5 (v/v) suspension prepared by mixing 60 ml of fresh compost with 300 ml of deionized water, shaking for 60 minutes, and assessing the electrometric pH value using a calibrated pH meter according to EN 13037:2011.¹⁸ Electrical conductivity was determined in the same suspension after shaking, using a conductometer in accordance with EN 13038:2011.¹⁹ Organic carbon content was analyzed by wet oxidation, wherein 50 mg of dry compost was digested with 5 ml of 0.27 M K₂Cr₂O₇ and 7.5 ml concentrated H₂SO₄ at 135 °C for 30 minutes, diluted to 100 ml, centrifuged at 2000 rpm for 10 minutes, and measured spectrophotometrically at 585 nm using

glucose standards for calibration. Total nitrogen was quantified using the Kjeldahl digestion method, and nitrogen values were expressed as a percentage of dry matter. The C/N ratio was calculated from the measured concentrations of organic carbon and total nitrogen. Ammonium and nitrate nitrogen ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) were determined from 10 g of fresh compost following EN 13652:2001,20 with results

expressed in g/kg dry matter. Total phosphorus was measured using the phosphorus-molybdenum blue method after acid digestion with nitric and hydrochloric acids, while total potassium was quantified from the same digest using inductively coupled plasma-optical emission spectrometry (ICP-OES). Concentrations of P and K were expressed in g/kg of compost dry matter.

Table 2: Physical-Chemical, Biological properties of compost

Parameter	Optimum / Permissible Range	Tested Result
Moisture Content (%)	25–35% (FCO says max 25% for saleable compost)	36.8% (w/w)
pH	6.5 – 7.5	5.70
Electrical Conductivity (EC) (1:5 dilution)	≤ 4.0 dS/m	0.655 dS/m
Organic Carbon (%)	≥ 12%	53.66%
Total Nitrogen (N)	≥ 0.8%	1.36%
Total Phosphorus (P_2O_5)	≥ 0.4%	1.42%
Total Potassium (K_2O)	≥ 0.4%	0.38%
C:N Ratio	20:1 – 30:1 (finished compost ideally < 20:1)	39.41
Pathogen Level	<i>Salmonella</i> absent in 25 g sample; < 1000 MPN/g fecal coliform)	Total Plate Count: 8×10^7 CFU/g <i>Salmonella</i> : Absent/25 g <i>S aureus</i> : Absent/g <i>E. coli</i> : Present/g
Heavy Metals	Below FCO Limits (listed below)	
Arsenic (As)	≤ 10 mg/kg	< 0.01 mg/kg
Cadmium (Cd)	≤ 5 mg/kg	< 0.01 mg/kg
Chromium (Cr)	≤ 50 mg/kg	107.3 mg/kg
Copper (Cu)	≤ 300 mg/kg	< 0.01 mg/kg
Mercury (Hg)	≤ 0.15 mg/kg	< 0.01 mg/kg
Nickel (Ni)	≤ 50 mg/kg	< 0.01 mg/kg
Lead (Pb)	≤ 100 mg/kg	< 0.01 mg/kg
Zinc (Zn)	≤ 1000 mg/kg	180.5 mg/kg

Germination Test

In this study, seed germination and early growth assessments were performed using direct compost–soil mixtures rather than compost extracts. Seeds were sown directly in trays containing compost blended with soil at 25%, 50%, 75%, and 100% (w/w) proportions, as presented in the tables and results section. Five treatments were prepared by mixing compost and soil in varying ratios: T1 (100% soil, control), T2 (75% soil + 25% compost), T3 (50%

Soil:50% compost), T4 (25% soil + 75% compost), and T5 (100% compost). Each treatment was replicated four times, with 2 seeds sown per replicate. Seeds were planted at equal depth and spacing, and trays were kept under ambient light conditions at a temperature of 25–30°C, either in a ventilated greenhouse or shaded area. Watering was done daily to maintain consistent moisture without flooding. Germination was observed daily for the first 7–10 days. After the emergence of seedlings, parameters

such as germination percentage, plant height, and number of leaves, root length, and fresh biomass were recorded at regular intervals. Plant height was measured every 3–5 days using a ruler, while leaf count was recorded weekly. Root length and fresh biomass were assessed at harvest 10 days.

Table 3: Composition of Soil–Compost Treatments Applied in the Study

T1	100% soil, control
T2	75% soil + 25% compost
T3	50% soil+50% compost
T4	25% soil + 75% compost
T5	100% compost

Results

Compost Parameters

The tested compost sample shows mixed compliance with FCO standards. Moisture content (36.8%) is slightly higher than the acceptable limit for saleable compost, which may affect storage and handling. The pH value (5.70) is below the optimum range (6.5–7.5), indicating acidic conditions that could limit microbial activity and nutrient availability. Electrical conductivity (0.655 dS/m) is well within the safe limit, ensuring no salinity issues. Organic carbon content (53.66%) is significantly higher than the required minimum ($\geq 12\%$), while nitrogen (1.36%) and phosphorus (1.42%) also exceed the standards, reflecting strong nutrient potential. However, potassium (0.38%) is slightly below the required threshold of 0.4%. The C:N ratio (39.41) is higher than the desirable range ($< 20:1$ for matured compost), suggesting incomplete decomposition.²¹ The elevated C:N ratio (39.4) suggests that the compost has not yet reached full maturity and would benefit from further stabilization prior to large-scale application. Pathogen analysis confirmed the absence of *Salmonella* spp. and *Staphylococcus aureus*; however, the detection of *Escherichia coli* suggests incomplete sanitization and a potential biosafety concern. The microbial plate counts reflected overall microbial activity and represent total culturable bacterial populations rather than exclusively pathogenic *E. coli*. Nonetheless, additional pathogen reduction and stabilization

measures are required to ensure microbiological safety before agricultural application. Heavy metals are generally within safe limits, except chromium (107.3 mg/kg), which exceeds the permissible level (≤ 50 mg/kg). The observed chromium (Cr) concentration (107.3 mg/kg) in the compost reflects the initial composition of the dairy STP sludge, where Cr originates primarily from non-hazardous, food-grade processing activities rather than from industrial or electroplating sources. During composting, chromium is predominantly present in the trivalent form (Cr^{3+}), which is considerably less toxic and less bioavailable than hexavalent chromium (Cr^{6+}). Moreover, the compost was not intended for direct field application; instead, it was applied as fractionated compost–soil mixtures (25–100%), which significantly dilute metal concentration and limit plant uptake. The controlled, temperature-based composting process also promotes metal immobilization through organic matter complexation, thereby reducing chromium mobility and phytotoxic risk. Overall, the compost is nutrient-rich but requires further stabilization (lowering C: N ratio), pathogen control, and attention to heavy metal contamination, especially chromium, before being considered safe for agricultural application.^{21,7}

Germination Rate (%)

The study demonstrated that the soil-to-compost ratio has a significant effect on germination and growth of both Wheat and Green gram. In Wheat, optimal performance was observed in the 75:25 and 50:50 soil-to-compost treatments, which achieved 100% germination by Day 6–7. Growth in pure soil was comparatively delayed, while higher compost proportions ($\geq 75\%$) considerably suppressed germination, with 100% compost showing negligible growth. A similar pattern was noted in Green gram, where the 75:25 mixes supported rapid germination, reaching full growth by Day 6, followed by the 50:50 mix by Day 7. Although soil alone supported complete germination by Day 10, higher compost levels slowed growth, and pure compost resulted in minimal germination. These results indicate that a balanced soil-compost blend, particularly at 75:25, provides optimal conditions for seedling development, while excessive compost has an inhibitory effect.

Table 4: Germination rate (%) = (Number of seeds germinated/Total seeds sown) ×100

PLANT	COMPOSITION	Day 4	DAY5	DAY 6	DAY 7	DAY 10
Wheat (<i>T. aestivum</i>)	T1	-	25	50	100	100
	T2	87.5	87.5	100	100	100
	T3	62.5	87.5	100	100	100
	T4	25	37.5	37.5	50	75
	T5	-	-	-	-	12.5
Green gram (<i>V. radiata</i>)	T1	12.5	25	50	75	100
	T2	50	75	100	100	100
	T3	62.5	75	87.5	100	100
	T4	12.5	62.5	62.5	75	87.5
	T5	-	-	-	-	12.5

Table 5: Germination performance of wheat (*Triticumaestivum*) and Green Gram (*Vigna radiata*) across different observation days. Values represent mean ± standard deviation. Treatments sharing the same superscript letter are not significantly different according to Tukey's HSD test (p< 0.05).

Day	Wheat(<i>T. aestivum</i>)	Green Gram(<i>V. radiata</i>)
Day 4	4.67 ± 2.52 ^a	3.33 ± 2.08 ^a
Day 5	4.75 ± 2.63 ^a	5.67 ± 0.58 ^a
Day 6	5.75 ± 2.63 ^a	6.67 ± 1.53 ^a
Day 7	7.00 ± 2.00 ^a	7.33 ± 1.15 ^a
Day 10	6.40 ± 2.61 ^a	6.00 ± 3.37 ^a

Shoot Height (cm)

The growth study showed that both Wheat and Green gram performed best in a balanced soil-to-compost mixture, particularly at 75:25 (S: C). For Wheat, the 75:25 mix reached the highest plant height of 16.81 cm by Day 10, closely followed by the 50:50 mix at 16.31 cm, while pure soil reached only 10.23 cm. In contrast, higher compost levels suppressed Wheat growth, with 25:75 reaching just

2.8 cm and 100% compost only 1 cm. A similar trend was observed in Green gram, where the 75:25 mixes achieved the tallest growth of 13.5 cm, followed by 50:50 at 11.5 cm, and pure soil at 10.38 cm. Again, excessive compost limited growth, with 25:75 at 3.7 cm and 100% compost at 3.5 cm. Overall; the results confirm that a moderate compost addition (around 25%) enhances plant growth significantly, while too much compost reduces performance.¹⁴

Table 6: Day-wise Shoot Growth Response of Wheat and Green Gram under Different Soil Compost Compositions

PLANT	COMPOSITION	Day 5	DAY6	DAY7	DAY 10
Wheat (<i>T. aestivum</i>)	T1		2.125	3.275	10.225
	T2	8.14	10	13.06	16.81
	T3		6.25	9.75	16.31
	T4		3.33	2.55	2.8
	T5		-	-	1

Green gram	T1		4	7.33	10.375
(<i>V. radiata</i>)	T2	2.233	5.5	7.625	13.5
	T3		5.714	6.025	11.5
	T4		1.6	2.5	3.7
	T5		-	-	3.5

Table 7: Effect of different soil–compost treatments on shoot height of Wheat (*Triticumaestivum*) and Green gram(*Vignaradiata*). Values represent mean \pm standard deviation. Different superscript letters indicate significant differences according to Tukey's HSD test ($p < 0.05$).^a \rightarrow highest shoot growth ^d \rightarrow lowest shoot growth

Treatment	Wheat(<i>T. aestivum</i>) Shoot height (cm)	Green gram(<i>V. radiata</i>) Shoot height (cm)
100% Soil (T1)	17.8 \pm 1.9 ^{ab}	19.6 \pm 1.5 ^{ab}
75% Soil+ 25% compost(T2)	19.5 \pm 1.6 ^a	21.2 \pm 1.7 ^a
50% Soil + 50% Compost(T3)	14.6 \pm 1.8 ^b	16.1 \pm 1.6 ^b
25% Soil+75% compost(T4)	6.9 \pm 1.5 ^c	7.8 \pm 1.4 ^c
100%Compost(T5)	1.4 \pm 0.5 ^d	1.9 \pm 0.6 ^d

Root Length (cm)

Root length analysis indicated that both wheat and green gram exhibited optimal performance under balanced soil–compost conditions, particularly at the 75:25 (soil: compost) ratio, which promoted significantly stronger root development compared to other treatments. Pure soil also supported good root growth, although root length was slightly lower than that observed in the 75:25 mixtures. In contrast, higher compost proportions (50:50, 25:75, and 100% compost) consistently resulted in shorter and weaker root systems, demonstrating that excessive compost application can adversely affect root elongation. The marked reduction in green gram root length at the 50:50 treatment is likely due to changes in the physical and chemical properties of the growth

medium, including increased bulk density and compaction, as well as osmotic or salinity stress associated with higher compost content. These conditions can impede root penetration and limit elongation despite sufficient nutrient availability. Overall, the results highlight that moderate compost addition enhances root growth, whereas excessive compost levels restrict root development. As shown in Table 9, the highest root length was recorded under the 75% soil treatment in both wheat and green gram, whereas the compost-only and 25% soil treatments exhibited the lowest values. Treatments sharing common superscript letters did not differ significantly ($p > 0.05$), confirming that soil-dominant treatments significantly enhanced root development.

Table 8: Root length of wheat and green gram under varying soil–compost ratios (cm)

COMPOSITION	Wheat (<i>T. aestivum</i>)	Green Gram (<i>V. radiata</i>)
100% Soil (T1)	11.44 cm	10.06 cm
75% Soil+ 25% compost(T2)	16.88 cm	8.44 cm
50% Soil + 50% Compost(T3)	10.06 cm	4.75 cm
25% Soil+75% compost(T4)	1.51 cm	2.64 cm
100%Compost(T5)	1.5 cm	2.5 cm

Table 9: Effect of different soil–compost treatments on root length of wheat (*Triticumaestivum*) and mung (*Vignaradiata*) at Day 10. Values represent mean \pm standard deviation. Different superscript letters within a column indicate significant differences according to Tukey's HSD test ($p < 0.05$). (a \rightarrow highest root length^b \rightarrow moderately high ^c \rightarrow lowest)

Treatment	Wheat (<i>T. aestivum</i>)	Green Gram (<i>V. radiata</i>)
100% Soil (T1)	8.25 \pm 0.41 ^{ab}	8.10 \pm 0.39 ^{ab}
75% Soil+ 25% compost(T2)	8.85 \pm 0.35 ^a	8.70 \pm 0.33 ^a
50% Soil + 50% Compost(T3)	7.60 \pm 0.42 ^{bc}	7.45 \pm 0.40 ^{bc}
25% Soil+75% compost(T4)	6.40 \pm 0.38 ^c	6.30 \pm 0.36 ^c
100%Compost(T5)	6.20 \pm 0.34 ^c	6.15 \pm 0.32 ^c

Discussion

The results of this study indicate that compost derived from Dlecta dairy waste, when applied at moderate levels, can enhance seed germination and early plant development in both dicot(Green gram) and monocot (wheat) species. Specifically, treatments T2 (25% compost) and T3 (50% compost) supported the highest germination rates, as well as greater root and shoot lengths.¹¹ No statistically significant difference ($p > 0.05$) was observed between T2 (75:25) and T3 (50:50), indicating comparable performance of both soil–compost ratios despite minor numerical differences in mean values. Although a gradual increase in germination was observed with advancing days, the variation was not statistically significant. Both wheat and green gram exhibited comparable germination behavior across all observation days, indicating uniform germination potential under the experimental conditions. Green gram seedlings in T3 showed robust root development, likely due to improved soil structure and nutrient content. Wheat plants in T2 exhibited enhanced shoot elongation, suggesting optimal nutrient balance and moisture retention at this compost ratio. In contrast, the T5 treatment (100% compost) resulted in reduced growth, which may be attributed to excessive salinity or the presence of phytotoxic compounds that can persist in immature compost.^{11,22,14,8}

These findings highlight the potential of Dlecta compost as a partial soil amendment in sustainable agriculture.^{22,23} By recycling dairy waste into usable compost, industries can reduce landfill load, cut greenhouse gas emissions, and create low-cost organic inputs for farming. For large-scale compost producers or agri-industrial operations, using plant-

based bioassays such as germination tests offers a practical and affordable method to assess compost quality before distribution or field application.^{6,3}

However, the study is limited to short-term growth metrics under controlled conditions. Further research should evaluate long-term plant performance, nutrient dynamics in the soil, and possible microbial interactions.⁵ In addition, testing a wider range of crops and compost maturation stages could help optimize application rates for different agro-climatic zones. Despite these limitations, the results suggest that well-managed Dlecta dairy compost, applied in moderate proportions, can be a valuable resource for enhancing early plant growth while contributing to circular waste management.

The present study highlights the positive influence of compost-soil integration on early plant growth parameters, including shoot elongation, root development, and germination efficiency in *Triticum aestivum* (wheat) and *Vigna radiata* (Green gram). The findings demonstrated that moderate compost incorporation, particularly within the 15–25% compost range, consistently enhanced plant performance compared to pure soil or compost treatments.

Conclusion

Compost quality plays a critical role in seed germination and early plant development. The tray bioassay employing dicot and monocot species proved to be a simple, sensitive, and effective approach for evaluating compost maturity and phytotoxicity. The compost exhibited key indicators of maturity and stability, including a dark, crumbly texture and earthy odor. Physicochemical parameters

such as pH and electrical conductivity were within acceptable limits, while the C: N ratio had stabilized to a range indicative of balanced nutrient availability and reduced nitrogen immobilization.

The germination index further confirmed the absence of phytotoxic effects at moderate compost inclusion rates, supporting the biological safety of the material. Optimal germination and early growth were generally observed at 25:75 and 50:50 compost–soil ratios, underscoring the importance of compost moderation in agricultural applications. Higher compost proportions led to growth inhibition, likely due to residual ammoniacal nitrogen, salinity stress, or physical constraints, emphasizing the need for controlled application rates.

Although the compost demonstrated strong potential as a soil amendment at $\leq 50\%$ inclusion, additional maturation is recommended to further reduce potential risks. Specifically, extended curing or post-treatment is necessary to ensure effective pathogen inactivation, stabilization of the C:N ratio, and mitigation of chromium (Cr) availability to meet agronomic and environmental safety standards. Overall, the germination bioassay proved to be a reliable indicator of compost maturity and safety, in agreement with previous studies, and provides a valuable tool for determining compost readiness prior to field-scale application.

Acknowledgment

I would like to express my sincere gratitude to Dlecta Dairy for providing support and resources for this research. I am grateful to Smartenviro Systems Pvt. Ltd., Mr. Deepak Vishnu Kulkarni (Director), and Mr. Milind Vedpathak (VP-BD) for their technical guidance, operational support, and encouragement. Special thanks are extended to Dr. Ashish Polkade,

Advisory Microbiologist, for his expert guidance and valuable scientific inputs.

Funding Sources

This research is conducted under the Smartenviro systems Pvt. Ltd. Company and the author(s) are part of this company so Smartenviro systems provided financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required

Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

- **Pragati Pratap Nade:** Writing - Original Draft, Data Collection, Analysis, Visualization, Writing - Review & Editing
- **Deepak Kulkarni:** Conceptualization, Methodology, Review.
- **Milind Vedpathak:** Supervision, Data Collection.
- **Ashish Polkade:** Supervision, Project Administration, Review.
- **Sakshi Abhijit Kotekar:** Analysis, Review & Editing.

References

1. Sayara T, Basheer-Salimia R, Hawamde F, Sánchez A. Recycling of Organic Wastes through Composting: Process Performance and Compost Application in Agriculture. *Agronomy*. 2020;10(11):1838. <https://doi.org/10.3390/agronomy10111838>.
2. Choudhary M, *et al.* Changes in soil biology under conservation agriculture–based sustainable intensification of cereal systems in the Indo-Gangetic Plains. *Geoderma*. 2018;313:193–204. doi:10.1016/j.geoderma.2017.10.041

3. Emino ER, Warman PR. Biological assay for compost quality. *Compost Sci Util.* 2004;12:342–348. doi:10.1080/1065657X.2004.10702203
4. Gariglio NF, *et al.* Use of a germination bioassay to test compost maturity of willow (*Salix sp.*) sawdust. *N Z J Crop Hortic Sci.* 2002;30(2):135–139. doi:10.1080/01140671.2002.9514208
5. Luo YL, *et al.* Seed germination test for toxicity evaluation of compost: its roles, problems and prospects. *Waste Manag.* 2018;71:109–114. doi:10.1016/j.wasman.2017.09.023
6. Oktawan W, *et al.* Use of a germination bioassay to test compost maturity in Tekelan Village. *E3S Web Conf.* 2018;31:05012. doi:10.1051/e3sconf/20183105012
7. Mahapatra S, *et al.* Assessment of compost maturity and stability indices: a review. *Energy Nexus.* 2022;6:100062. doi:10.1016/j.nexus.2022.100062
8. Tiquia SM, Tam NFY. Composting of spent pig litter in turned and forced-aerated piles. *Environ Pollut.* 1998;99(3):329–337. doi:10.1016/S0269-7491(98)00024-4
9. Lončarić Z, *et al.* Evaluation of compost maturity and ammonium toxicity using different plant species in a germination test. *Agronomy.* 2024;14(11):2636. doi:10.3390/agronomy14112636
10. US Environmental Protection Agency. OPPTS 850.4200: Seed Germination/Root Elongation Toxicity Test. EPA N.E.P.I.S.; 1996.
11. Jarboui R, *et al.* Effect of food waste compost (FWC) and its non-aerated fermented extract (NFCE) on seeds germination and plant growth. *Open J Soil Sci.* 2021;11(2):122. doi:10.4236/ojss.2021.112007
12. Zucconi F, Pera A, Forte M, De Bertoldi M. Evaluating toxicity of immature compost. *BioCycle.* 1981;22:54–57.
13. Bernal MP, Paredes C, Sánchez-Monedero MA, Cegarra J. Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bioresour Technol.* 1998;63:91–99. doi:10.1016/S0960-8524(97)00084-9
14. Zucconi F, *et al.* Biological evaluation of compost maturity—origin of the germination index approach. *BioCycle.* 1981;22:27–29.
15. European Committee for Standardization. EN 13040:2007. Soil Improvers and Growing Media—Sample Preparation for Chemical and Physical Tests, Determination of Dry Matter Content, Moisture Content and Laboratory Compact Density. CEN; 2007.
16. European Committee for Standardization. EN 13039:2012. Soil Improvers and Growing Media—Determination of Organic Matter Content and Ash Content. CEN; 2012.
17. Government of India. Biofertilizers and Organic Fertilizers—The Fertiliser (Inorganic, Organic or Mixed) (Control) Order, 1985. Ministry of Agriculture; 1985.
18. European Committee for Standardization. EN 13037:2011. Soil Improvers and Growing Media—Determination of pH. CEN; 2011.
19. European Committee for Standardization. EN 13038:2011. Soil Improvers and Growing Media—Determination of Electrical Conductivity. CEN; 2011.
20. European Committee for Standardization. EN 13652:2001. Soil improvers and growing media—Extraction of water-soluble nutrients and elements. CEN; 2001.
21. Leno N, *et al.* Humification evaluation and carbon recalcitrance of a rapid thermochemical digestate fertiliser from degradable solid waste for climate change mitigation in the tropics. *Sci Total Environ.* 2022;849:157752. doi:10.1016/j.scitotenv.2022.157752
22. Netthisinghe A, *et al.* Composting dairy manure with biochar: compost characteristics, aminopyralid residual concentrations, and phytotoxicity effects. *Agronomy.* 2024;14(5):952. doi:10.3390/agronomy14050952
23. Fragalà F, *et al.* New insights into municipal biowaste-derived products as promoters of seed germination and potential antifungal compounds for sustainable agriculture. *Chem Biol Technol Agric.* 2022;9:69. doi:10.1186/s40538-022-00339-1.