Effect of nitrogen amendments and inoculum on spent mushroom substrate composting for sustainable waste management

Rathnayake Mudiyanselage Ayesha Priyadarshani Rathnayake[1], Gallala Gamage Dasun Sandeepa Gamage[2], Sajeewani Rajika Amarasinghe[*2], Peliyagodage Chathura Dineth Perera[2]

[1]Grenfell Campus, Memorial University, Newfoundland and Labrador, A2H 5G5, Canada.
[2]Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya 81100, Sri Lanka.
Correspondence author e-mail: rajika@soil.ruh.ac.lk

Received: 19 November 2024 / Accepted: 7 January 2026

Abstract. Spent Mushroom Substrate (SMS) is the medium used in mushroom cultivation and is mostly dumped into the environment as waste. Composting SMS is identified as a sound method of reuse. However, lower N levels and reduced microorganism activity limit aerobic decomposition. Therefore, this experiment was conducted to evaluate the effects of amending different N sources to obtain good-quality SMS compost. Nitrogen sources were mixed to SMS separately based on the C/N ratio of each source, with and without the bio-dynamic inoculum to obtain ten SMS compost mixtures with Urea (T1), Urea + inoculum (T2), *Gliricidia sepium* leaves (T3), *G. sepium* leaves + inoculum (T4), *Tithonia diversifolia* leaves (T5), *T. diversifolia* leaves + inoculum (T6), *Pueraria phaseoloides* leaves (T7), *P. phaseoloides* leaves + inoculum (T8), SMS without inoculum (T9), and SMS with inoculum (T10). Treatments were arranged in a Completely Randomized Design (CRD) with four replicates and composted for 90 days. Final samples were analyzed for total organic matter (%), total N (%), C/N, total K (%), total P (%), pH and EC and data analysis was done using SAS software 9.1.3. According to the results, T7 and T8 have given a significantly higher level of N% (1.71 and 1.89, respectively). The C/N ratio of all treatments except T5, T9 and T10 reached an average of 20-30, and T8 recorded the lowest. In all treatments EC values were within the Sri Lankan Standards (<4 mS/cm), however, the pH values were higher (>8.5). Based on the results, it is concluded that treating SMS with *P. phaseoloides* leaves with the bio-dynamic inoculum could obtain good quality SMS compost resembling the given compost standards.

Keywords: compost; compost quality; green leaves; urea

1. Introduction

Mushrooms are a highly concentrated protein source with rich nutrient value and as a result, the demand for mushrooms and their value-added products have increased worldwide (Chakravarty, 2011). Statistical data indicate that the world mushroom production has reached a level of 25 million tons, and it plays a vital role in balancing the protein profile of vegetarian diets as well (Ashrafi *et al.*, 2014a). However, after obtaining the harvest, tons of the media used in mushroom cultivation are dumped without any alternative use. This is known as spent mushroom substrate (SMS), considered as waste. In mushroom cultivation, around 5 kg of SMS is released as waste in the process of 1kg of mushroom production and it was estimated that 70 million metric tons of SMS was generated around the world in 2007 (Ashrafi *et al.,* 2014a). This waste contains lignin-rich sawdust which decomposes slowly and ions such as Mg^{2+} and Ca^{2+}, which contribute to water hardening and pollution (Nepfumbada, 2021). Therefore, dumping of this SMS leads to surface runoff and leaching of these ions, which contaminates both surface water bodies and ground water. Consequently, it is important to find an eco-friendly and cost-effective method to reuse SMS.

Many researches have highlighted the potential of using SMS in compost production, which is considered as an environmentally acceptable method of disposing and utilizing organic waste (Zhang and Sun, 2015). Since SMS contains 45% moisture and bulky with 55% solids, it is within the range for compost production (De Jin *et al*., 2005; He *et al.,* 2001). Additionally, producing compost with SMS might be an extra income source for mushroom cultivators by allowing them to produce spent mushroom compost (SMSC) using naturally available nitrogen sources that thrive well in organic farming sector (Eudoxie *et al*., 2011). Hence, SMSC would be a beneficial amendment which improves soil water and nutrient holding capacity, soil water infiltration, permeability, aeration, and helps to improve the soil structure (Wiafe *et al.,* 2018; Fidanza *et al.,* 2010).

However, the high carbon percentage of saw dust in SMS and depleted nutritional condition due to rapid utilization by the mushroom mycelium hinder the bio degradation of SMS into compost (Mallick *et al*., 2023). To enhance the composting process, the Carbon-to-Nitrogen (C/N) ratio needs to be maintained between 25:1 to 30:1 (Ashrafi *et al.,* 2014b). With the high carbon content of SMS, the C/N ratio rises to 70-80, necessitating the amending nitrogen source to lower the C/N ratio.

Urea is an excellent N source which can be integrated into the composting process (Wever *et al.,* 2004). However, rather than relying on inorganic fertilizers, using natural N sources in composting would be advantageous from both economic and environmental perspectives. High N containing plants such as *Gliricidia sepium, Tithonia diversifolia* and *Pueraria phaseoloides* have been proven to be good sources of N while *G. sepium* and *P. phaseoloides* host N-fixing symbiotic bacteria that colonize in their roots, where bacteria capable of fixing atmospheric nitrogen and transferring it to the plant in an available form (Omari *et al*., 2016; Quansah *et al*., 2001). Moreover, *T. diversifolia* accumulates high biomass nutrient density (N, P, K) from soil uptake (Jama *et al.* 2000; George *et al*., 2001). Therefore, use of these N sources in SMS composting will increase the N content and thereby reducing the C/N ratio facilitating the biological decomposition.

On the other hand, as SMS being a fungus-cultivated media, it lacks the diversity of microorganisms which help in biodegradation (Xu *et al.,* 2022). Inoculating SMS with a microbial inoculum could alter the microbiota structure of SMS (Xu *et al*., 2022) and enhance the biodegradation rate, thereby increasing the rate of compost process. For instance, *Bacillus* inoculation has been shown that kitchen waste can be composted rapidly by increasing bacterial diversity (Zhang *et al*., 2021). Therefore, the present study hypothesizes that adding N sources and microbial inoculum enhances the degradation and quality of produced compost using SMS. The objective was to characterize the chemical properties of the final compost samples treated with *G. sepium, T. diversifolia, P. phaseoloides*, Urea and bio-dynamic inoculum and to find the optimal compost mixtures which resemble the standard compost quality measures.

2.0 Methodology

Spent Mushroom Substrate (SMS) from oyster mushroom (*Pleurotus ostreatus*) cultivation was obtained from mushroom production unit of Faculty of Agriculture, University of Ruhuna, Sri Lanka. It was used as the bulking agent for compost production. Green leaves of *Pueraria phaseoloides*, *Gliricidia sepium*, and *Tithonia diversifolia* which were collected from the farm of Faculty of Agriculture, University of Ruhuna, Sri Lanka and commercially available urea were used as N sources for this experiment. The SMS was amended and mixed thoroughly with each of the above-mentioned N sources separately, according to the equation provided by Rynk *et al.* (1992).

2.1 Preparation of biodynamic formulation

The biodynamic formulation was prepared following the method by Kulkarni and Gargelwar., (2019). In a bucket, 500 g of cattle manure, and 250 ml of cattle urine, were mixed thoroughly with 10 L water. Then, 100 g of brown sugar and 100 g of mung bean flour were added and mixed well. Finally, a handful of topsoil was added to the mixture. The mixture was stirred twice a day to aerate and kept for 15 days. The optimal growth period for the microorganisms in this solution is noted to be 15 days.

2.2 Treatment preparation

Ten treatments were prepared: five mixtures without applying the inoculum and five mixtures with the inoculum (Table 1). The inoculum was applied at a rate of 5 ml per 1 kg of the substrate, accounting for the bulk density of the substrate (Amarasinghe and Jayaweera, 2022) which was 340 kgm^{-3}. Each mixture weighing 2 kg, was separately placed into a black polythene bag of gauge 150 and labelled accordingly. Each treatment was replicated three times. The bags were arranged under ambient temperature (~30°C) and relative humidity (~78%) conditions following a completely randomized design (CRD). Every compost mixture was mixed manually every other day for five minutes to speed the decomposition process. The moisture level was monitored and adjusted accordingly by field method, around 50-60% at the initial stage of composting and later it was kept for about 25-30% (SLS 1635, 2019). Mixtures were allowed for aerobic decomposition for 90 days.

Table 1: Treatments used for the experiment.

Treatment	Description	Abbreviation
T1	SMS + Urea	U
T2	SMS +Urea + Inoculum	UI
T3	SMS+ *Gliricidia sepium* leaves	G
T4	SMS+ *Gliricidia sepium* leaves + Inoculum	GI
T5	SMS + *Tithonia diversifolia* leaves	W
T6	SMS + *Tithonia diversifolia* leaves + Inoculum	WI
T7	SMS + *Pueraria phaseoloides* leaves	P
T8	SMS + *Pueraria phaseoloides* leaves + Inoculum	PI
T9	Only SMS	C
T10	SMS + Inoculum	CI

2.3 Data Collection and statistical analysis

The sampling was done after 90 days from each experimental unit and air dried. These were analyzed for pH, EC, total organic matter (%), total Nitrogen (N%) content, total Potassium content (K%) and total Phosphorus (P%) content. pH and EC were analyzed using pH and EC meter by following the standard method with 1:2.5 w/v and 1:5 w/v, respectively. At the end of composting, samples were collected and analyzed for the total organic matter %, N%, K% and P%. Total organic matter was analyzed using the loss on ignition method and N% was analyzed following the Kjeldahl method (Bremner, 1960). Both Total K% and total P were extracted using the wet ash method. Potassium (K%) was analyzed using a flame photometer (Page *et al.,* 1982) and P% was analyzed using a UV visible spectrophotometer (Self-Davis *et al.,* 2000). Total Organic C% was calculated using the conversion factor 1.724 (Amarasinghe *et al.,* 2024). Based on the results of organic C% and N%, C/N ratios of each compost sample were calculated. Normality of the data was tested using Shapiro-Wilk Test. Statistical analysis was done using ANOVA using SAS statistical software (Version 9.1.3) and post-hoc tests were done using Duncan's Multiple Range Test (DMRT).

3.0 Results and Discussion

The following results were obtained after analyzing the final compost samples. According to Table 2, the pooled results from the ANOVA for the chemical properties of the prepared compost samples: N%, C/N ratio, K%, P%, pH and EC were significant at $p \leq 0.05$.

Table 2: ANOVA Results for compost parameters

Parameter	Degrees of freedom	F Value	p Value
Organic C%	9	0.95	0.503
Organic Matter%	9	1.99	0.079
N%	9	125.31	**<0.0001**
C/N ratio	9	79.12	**<0.0001**
K%	9	25.60	**<0.0001**
P%	9	658.03	**<0.0001**
pH	9	14.21	**<0.0001**
EC	9	21.44	**<0.0001**

Statistically significant results at $p \leq 0.05$ are in bold.

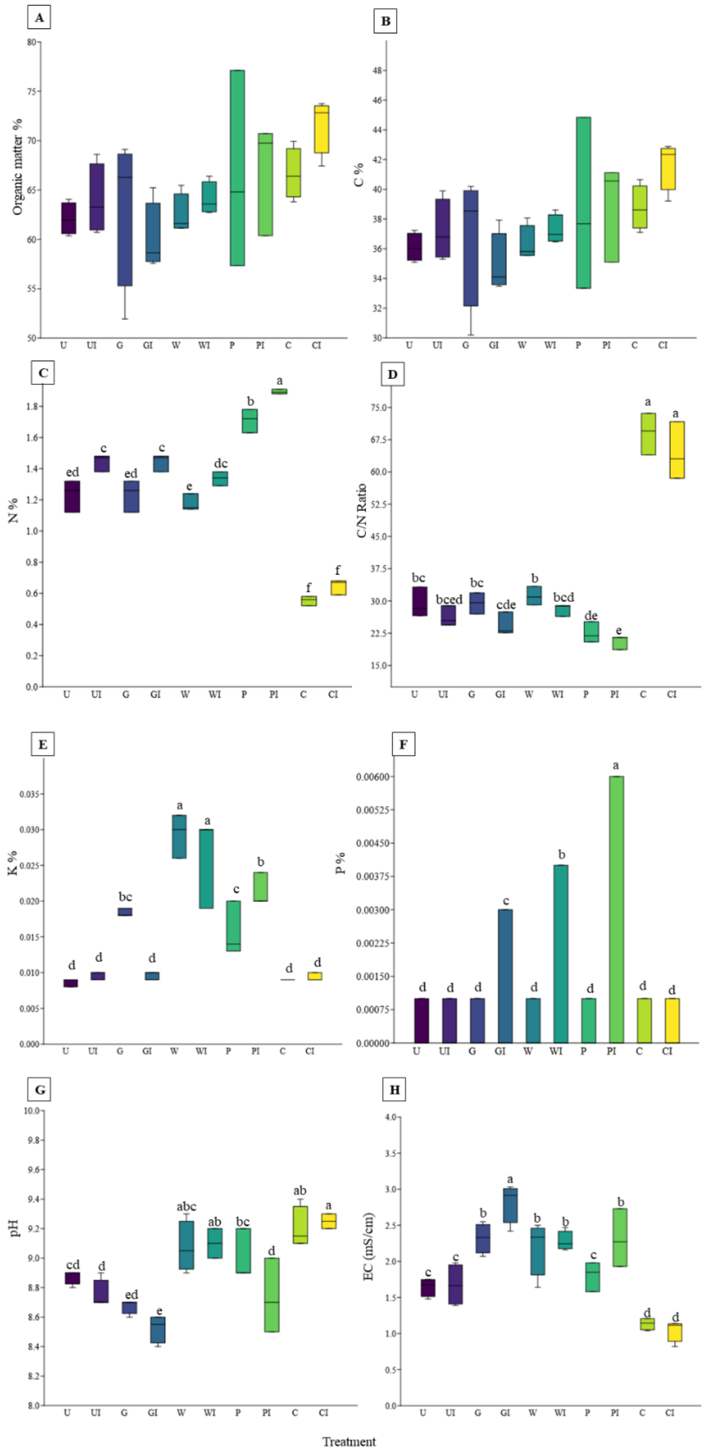

Figure 1. Analyzed chemical properties in the final sample of prepared compost. A- Total organic matter %, B: Total Organic Carbon%; C: N%; D: C/N ratio; D: K%; E: P%; F: pH; G: Electrical Conductivity (mS/cm) Values followed by the same letter are not significantly different as determined by the DMRT (p<0.05). Abbreviations are presented in Table 1.

3.1 Total Nitrogen (%)

Nitrogen, the outstanding major nutrient for crop growth and development, is essential to analyze when producing compost. The Carbon content (C%) of SMS was significantly high (58.33%) compared to its N level (0.76%), resulting in a C/N ratio of 76.78 which is not appropriate for efficient biodegradation. Therefore, amending the SMS with N sources is crucial to optimize the C:N ratio for rapid composting process (Table 3).

Table 03: Initial N% of the N sources used

N source	**N%**
Urea	46.00
G. sepium	8.81
P. phaseoloides	9.60
T. diversifolia	10.44

Compost samples collected at the end of composting were analyzed for N% (Figure 1C). Treatment 7 and 8 (SMS + *P. phasioloides* leaves with and without inoculum) showed significantly higher values compared to all the other treatments. However, T5 has shown only 1.17% N, despite having the highest initial N content in *T. diversifolia* leaves. This may happen due to the alkalinity developed when composting with *T. diversifolia*, which accelerates the N loss through ammonia volatilization (Rochette *et al*., 2013). When comparing the N content of the compost samples prepared with and without inoculum, treatments with the inoculum have resulted in higher N%. Cattle manure and urine contain diverse microbial communities including cellulotic bacteria, N-transforming bacteria, actinomycetes and fungi (Adegunloye *et al*., 2007; Li *et al*., 2020 and Nguyen & Nguyen, 2018). These microorganisms accelerate organic matter decomposition, enhance N mineralization and reduce N losses during composting, resulting in higher total N content in inoculated compost. In addition, cattle manure and cattle urine-based inoculum contains higher amount of N, which may contribute to the increment in N% (Nguyen & Nguyen, 2018 and Raj *et al*., 2014). Consequently, the present study found that inoculated SMS treatments (T2, T4, T6, T8 and T10) had higher N% than non-inoculated treatments.

Using *G. sepium*, *P. phaseoloides*, and *T. diversifolia* as green manures and nitrogen sources in organic agriculture can improve soil fertility, physical and chemical properties, as well as increase total soil nitrogen and NO_3-N (Setyowati *et. al.*, 2018). *G. sepium* is an effective soil nitrogen source, with studies showing that it enhances the activities of decomposing microflora and results in higher soil NO_3^- and NH_4^+ compared to other plant material treatments (Omari *et al*., 2016). *P. phaseoloides*, a common cover crop found in Sri Lanka, has also shown potential as a nitrogen source. Experiments have indicated that its compost result in higher levels of nitrogen and decomposition rate compared to other legumes (Quansah *et al.*, 2001). These findings confirm that these plant leaves effectively increased N% in compost production.

3.2 Total Organic Carbon

Soil organic carbon is a major factor prompting plant growth and development. The highest C% was recorded in samples without nitrogen sources (Figure 1B). However, compared to the initial high C% of SMS (58.33%) final SMS compost (SMSC) amended with N sources showed a reduction in C% during the composting process. During the process of composting, microbes start decomposing the organic material utilizing C as the energy source and N for the protein synthesis (Insam *et al*., 2023). Thus, effective decomposition needs a balance between the C and N. With low N content, microbes may immobilize any available N from inoculum into their biomass to meet their needs, rather than building enzymes that degrade carbon compounds (Ayilara *et al*., 2020 and Nguyen & Nguyen, 2018). Therefore, total N required to sustain robust decomposition of SMS is insufficient and overall carbon breakdown remains limited increasing the total C content. The study conducted by Zeng *et al.* (2022) showed that the total organic C of the initial SMS was 44.89%.

3.3 C/N Ratio

When comparing the C/N ratio of all treatments, the optimum C/N ratio (10-25) according to the SLS 1635:2019 was observed in T8 (*P. phaseoloides* and inoculum incorporated) and T7 (without inoculum) (Figure 1D). The control (T9) has a significantly higher value for the C/N ratio which did not achieve the standards of compost. SMS is rich in C and lacks in N because of developing fungi mycelium has utilized most of the N in the substrate during mushroom production.

As mentioned by Owaid *et al*. (2017), C/N ratio plays a very important role in crop growth and development. The quality assessment done by Ashrafi *et al.* (2014b) compost made of SMS revealed that the initial N level of SMS was very low N (0.78%), and it reached a level of 1.11% at the end of 12 weeks of composting. Further, according to the above study, the organic carbon level of the SMS has reduced from 32.9% to 25.3% at the end of 12^{th} week. Thereby, they observed a C/N ratio of 23 at the end of the composting process. A research study showed that the SMS amended with cattle manure is rich in TOC % whereas low in TN and the C:N ratio was changed from 29 to 19 after composting (Zeng *et al.*, 2022). In the present study, the initial organic carbon level of SMS was 58.33% and N was 0.76%, with initial C/N ratio as 76. However, with the application of the treatments, the N level of the final samples have increased to a level of 1.2% - 1.8%, reducing the C/N ratio of the final compost samples.

3.4 Total Potassium (%)

Potassium is an important nutrient in demining compost quality which should meet a minimum of 1% in compost according to the SLS (1635:2019). However, all the treatments showed K%

lower than the standard level (Figure 1E). The K% of T5 and T6 were significantly higher than the other samples.

The higher K content in compost treatments containing *Tithonia diversifolia* can be attributed to the inherent high K content of the *Tithonia* biomass (Kaboneka *et al*., 2021). These leaves typically contain 3.4% – 4.1% of K on dry weight basis where reported K% of *Gliricidia* and *Pueraria* is around 1.3% – 2.7% on dry weight basis (Gabhane *et al*., 2023; Zurhalena *et al*., 2023). Unlike N, K in plant tissues is mostly in readily mineralizable forms and is nonvolatile during decomposition, input of *Tithonia* biomass can result in greater K pool that persist through the composting process to the final product.

3.5 Total Phosphorus (%)

All the treatments showed very low P% in final compost, which did not meet the minimum requirement of 0.5% P according to the SLS 1635: 2019. However, according to the results obtained, the P% of treatments T4, T6 and T8 were significantly higher than the other treatments (Figure 1F). SMS, used as the common substrate in all treatments inherently contain notable P residues which have a possibility to be bound with other amendments in initial mushroom mixture such as $CaCO_3$ and $MgSO_4.7H_2O$ as calcium and magnesium phosphates (Aiduang *et al*., 2025; Matar *et al.*, 1992). When SMS is amended with *Gliricidia*, *Pueraria* and *Tithonia*, total P inputs are increased due to the higher P content in these species (Gabhane *et al*., 2023 and Kaboneka *et al*., 2021). The addition of inoculum likely stimulated microbial activity and phosphatase-mediate P mineralization, increasing available P in mature compost (Nguyen & Nguyen, 2018). As the P is not viable for volatilization losses, final compost product can result in increased P contents than non-amended treatments.

3.6 pH and Electrical Conductivity (EC)

Measured values of pH in final samples (Figure IG) had an average pH range from 8.5 – 9.5. According to the compost standards by SLS 1635: 2019, an ideal compost sample should have a pH of 6.5 – 8.5. The higher pH values observed in the present study may be due to the residual Ca^{2+} ions which were added as lime ($CaCO_3$) and Epsom salt ($MgSO_4.7H_2O$) utilized during the mushroom production process. Based on the results, the lowest pH was recorded in T4 (8.5) while the highest was in T10 (9.25).

In Contrast to the pH results, the EC of T10 (1.05 mS/cm) was the lowest, T4 had the highest EC (2.82 mS/cm) (Figure 1F). According to SLS 1635 (2019), an ideal compost sample should have EC <4 mS/cm. Thus, within a specific range, EC would indicate good nutrient availability for plants, with the low end indicating nutrient poor soil that is structurally unstable and disperses readily and the high-end salinity problems (Smith *et al.*, 1997). Accordingly, all the SMSC were within the acceptable range for the EC, showing less salinity in final compost mixtures.

EC of compost is mainly determined by the cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and NH_4^{+}) and the anions (SO_4^{2-}, Cl^{-}, NO_3^{-} and HCO_3^{-}) (Bhardwaj *et al.*, 2021). The EC of all the treatments amended with N sources increased compared to the non-amended SMS which may be due to the increment in NO_3^{-} and NH_4^{+} compared to the control treatment. Further, SMS pre-treated with lime and Epsom salt has a higher affinity for Ca^{2+} and Mg^{2+} ions which can result for higher EC. Over time, decomposition by microorganisms accelerates the extraction of ions from organic matter (Zeng *et al.*, 2022). Khater (2015) has highlighted that an average EC of 2.0 – 4.0 mS/cm as the optimum EC level for the plant growing media.

4.0 Conclusions

Based on the results obtained, it is concluded that SMS compost which is incorporated with *Pueraria phaseoloides* leaves and bio-dynamic inoculum is more suitable for compost production compared to other utilized nitrogen sources, when considering the SL standard for quality measurements of compost. It revealed that incorporating N sources and inoculum have led to higher N and appropriate C/N ratios than utilizing SMS directly as a soil amendment or compost. The addition of the inoculum acted as a beneficial microbial enhancer to accelerate the composting process and significantly increases the N level of the final compost. This shows that microbial inoculum can be an effective strategy to upgrade the compost by adding N and expedite the compost process.

However, in this study the P and K levels in final composts were below the standard levels. Therefore, supplementation of P and K sources in SMS should be considered in future research to meet the compost quality.

References

Adegunloye, D.V., Adetuyi, F.C., Akinyosoye, F.A. & Doyeni, M.O., 2007, Microbial analysis of compost using cowdung as booster. Pakistan journal of nutrition 6(5): 506-510.

Aiduang, W., Jatuwong, K., Kiatsiriroat, T., Kamopas, W., Tiyayon, P., Jawana, R., Xayyavong, O. & Lumyong, S., 2025, Spent mushroom substrate-derived biochar and its applications in modern agricultural systems: An extensive overview. Life 15(2): 317.

Akande M.O., Oluwatoyinbo F.I., Makinde E.A., Adepoju A.S. & Adepoju I.S., 2010, Response of okra to organic and inorganic fertilization. Nature and Science 8(11): 261-266.

Amarasinghe S.R. & Jayaweera W.M.C.S., 2022, Evaluation of phytotoxicity of composts produced from mushroom substrate using seed germination bioassay of *Raphunus sativus* L. Tropical Agricultural Research and Extension 25(4): 355-368.

Amarasinghe S.R., Premanath K.P.S.D. & Wanniarachchi S.D., 2024, Impact of different soil amendments on carbon and nitrogen mineralization in ultisols. Tropical Agricultural Research and Extension 27(3): 145-156.

Ashrafi R., Mian M.H., Rahman M.M. & Jahiruddin M., 2014a, Recycling of spent mushroom substrate for the production of oyster mushroom. Research in Biotechnology 5(2).

Ashrafi R., Rahman M.M., Jahiruddin M. & Mian M.H., 2014b, Quality assessment of compost prepared from spent mushroom substrate. Progressive Agriculture 25: 1-8.

Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O. & Odeyemi, O., 2020, Waste management through composting: Challenges and potentials. Sustainability 12(11): 4456.

Bhardwaj A.K., Rajwar D. & Nagaraja M.S., 2021, Soil fertility problems and management. Managing Salt-Affected Soils for Sustainable Agriculture: 386-407.

Bremner J.M., 1960, Kjeldahl method for nitrogen determination. Journal of Agricultural Science 55: 11-33.

Chakravarty B., 2011, Trends in mushroom cultivation and breeding. Australian Journal of Agricultural Engineering 2(4): 102-109.

De Jin R., Suh J.W., Park R.D., Kim Y.W., Krishnan H.B. & Kim K.Y., 2005, Effect of chitin compost and broth on biological control of *Meloidogyne incognita* on tomato (*Lycopersicon esculentum* Mill.). Nematology 7(1): 125-132.

Eudoxie, G.D. & Alexander, I.A., 2011, Spent mushroom substrate as a transplant media replacement for commercial peat in tomato seedling production. Journal of Agricultural Science 3(4): 41.

Fidanza M.A., Sanford D.L., Beyer D.M. & Aurentz D.J., 2010, Analysis of fresh mushroom compost. HortTechnology 20(2): 449-453.

Gabhane, V.V., Satpute, U., Jadhao, S.D., Patode, R.S. & Ramteke, P., 2023, Managing soil potassium through green manuring with gliricidia for improving cotton yield and quality of shrink-swell soils of Central India. Journal of Plant Nutrition 46(14): 3499-3518.

Griessel W., 2002, Anaerobic bioconversion of the organic fraction from the fruit processing industry. Doctoral dissertation - Stellenbosch University.

He Z., Yang X., Kahn B.A., Stoffella P.J. & Calvert D.V., 2001, Plant nutrition benefits of phosphorus, potassium, calcium, magnesium, and micronutrients from compost utilization. Compost Utilization in Horticultural Cropping Systems: 307-320.

Insam, H., Klammsteiner, T. & Gómez-Brandòn, M., 2023, Biology of compost. Encyclopedia of Soils in the Environment: 522-532.

Kaboneka, S., Kwizera, C., Nijimbere, S., Irakoze, W., Nsengiyumva, P., Ndihokubwayo, S. & Habonimana, B., 2021, Direct and residual fertilizer values of maize (*Zea mays* L.) stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure. International Journal of Advances in Scientific Research and Engineering 7(7).

Khater E.S.G., 2015, Some physical and chemical properties of compost. International Journal of Waste Resources 5(1): 72-79.

Kulkarni, S.S. & Gargelwar, A.P., 2019, Production and microbial analysis of Jeevamrutham for nitrogen fixers and phosphate solubilizers in the rural area from Maharashtra. IOSR Journal of Agriculture and Veterinary Science 12: 85-92.

Li J., 2021, Inoculation of phosphate-solubilizing bacteria (*Bacillus*) regulates microbial interaction to improve phosphorus fractions mobilization during kitchen waste composting. Bioresource Technology 340: 125714.

Li, H., Yang, Z., Zhang, C., Shang, W., Zhang, T., Chang, X., Wu, Z. & He, Y., 2024, Effect of microbial inoculum on composting efficiency in the composting process of spent mushroom substrate and chicken manure. Journal of Environmental Management 353: 120145.

Li, J., Wang, X., Cong, C., Wan, L., Xu, Y., Li, X., Hou, F., Wu, Y. & Wang, L., 2020, Inoculation of cattle manure with microbial agents increases efficiency and promotes maturity in composting. 3 Biotech 10(3): 128.

Mallick M.A.I., Nath R., Ghorai N., Mishra S., Saha A. & Sanyal S.M., 2023, Unlocking the potential: A comprehensive review of environmentally sustainable applications for agro-based spent mushroom substrate (SMS). A Basic Overview of Environment and Sustainable Development: 434.

Matar, A., Torrent, J. & Ryan, J., 1992, Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. Advances in Soil Science 18: 81-146.

Nepfumbada C., 2021, The synthesis of calcium phosphate from municipal wastewater and its application for the removal of metals from acidic effluents. Doctoral dissertation - Stellenbosch University.

Nguyen, T.P. & Nguyen, T.N.Q., 2018, Composting of cow manure and rice straw with cow urine and its influence on compost quality. Journal of Vietnamese Environment 9(2): 61-66.

Omari R.A., Aung H.P., Mudan H.O., Yokoyama T., Onwona-Agyeman S., Oikawa Y., Fujii Y. & Bellingrath-Kimura S.D., 2016, Influence of different plant materials in combination with chicken manure on soil carbon and nitrogen contents and vegetable yield. Pedosphere 26(4): 510-521.

Owaid M.N., Abed I.A. & Al-Saeedi S.S., 2017, Applicable properties of the bio-fertilizer spent mushroom substrate in organic systems as a byproduct from the cultivation of *Pleurotus* spp. Information Processing in Agriculture 4(1): 78-82.

Page A.L., 1982, Methods of soil analysis: chemical and microbiological properties. American Society of Agronomy.

Quansah C., Fening J.O., Ampontuah E.O., Afreh D. & Amin A., 2001, Potential of *Chromolaena odorata*, *Panicum maximum*, and *Pueraria phaseoloides* as nutrient sources and organic matter amendments for soil fertility maintenance in Ghana. Biological Agriculture & Horticulture 19(2): 101-113.

Raj A., Jhariya M.K. & Toppo P., 2014, Cow dung for eco-friendly and sustainable productive farming. Environmental Science 3(10): 201-202.

Rochette P., Angers D.A., Chantigny M.H., Gasser M.O., MacDonald J.D., Pelster D.E. & Bertrand N., 2013, NH_3 volatilization, soil concentration, and soil pH following subsurface banding of urea at increasing rates. Canadian Journal of Soil Science 93(2): 261-268.

Rynk R., Van de Kamp M., Willson G.B., Singley M.E., Richard T.L., Kolega J.J., Gouin F.R., Laliberty L., Kay D., Murphy D. & Hoitink H.A., 1992, On-farm composting handbook (NRAES 54). Northeast Regional Agricultural Engineering Service (NRAES).

Self-Davis, M.L., Moore Jr, P.A. & Joern, B.C., 2000. Determination of water-and/or dilute salt-extractable phosphorus. Methods of phosphorus analysis for soils, sediments, residuals, and waters: 24-26.

Smith J.L. & Doran J.W., 1997, Measurement and use of pH and electrical conductivity for soil quality analysis. Methods for Assessing Soil Quality 49: 169-185.

Sri Lanka Standards Institution (SLSI)., 2019, Specification for compost made from raw materials of agricultural origin.

The Organic Recycling Authority., 2022, Composting. https://www.biocycle.net/category/composting/, Accessed 20 Dec 2023.

Viégas, I.D.J.M., Costa, M.G., Ferreira, E.D.O., Peréz, N.L.P., Barata, H.S., Galvão, J.R., Conceição, H.E.O. & Santo, S.D.E., 2021, Contribution of *Pueraria phaseoloides* L. in the cycling of macronutrients in oil palm plantations. Journal of Agricultural studies 9(3): 1-13.

Wever G., Van Der Burg A.M. & Straatsma G., 2004, Potential of adapted mushroom compost as a growing medium in horticulture. International Symposium on Soilless Culture and Hydroponics 697: 171-177.

Wiafe-Kwagyan M. & Odamtten G.T., 2018, Use of *Pleurotuseous* strain P-31 spent mushroom compost (SMC) as soil conditioner on the growth and yield performance of *Capsicum annuum L.* and *Solanum lycopersicon L.* seedlings under greenhouse conditions in Ghana. Tropical Life Sciences Research 29(1): 173.

Xu S.-Y., Wei J.-K., Xue F.-Y., Li W.-C., Guan T.-K., Hu B.-Y., Chen Q.-J., Han Y.-Y., Liu C.-J. & Zhang G.-Q., 2022, Microbial inoculation influences microbial communities and physicochemical properties during lettuce seedling using composted spent mushroom substrate. Applied Soil Ecology 174: 104418.

Zeng, G., Liu, Z., Guo, Z., He, J., Ye, Y., Xu, H. & Hu, T., 2022, Compost with spent mushroom substrate and chicken manure enhances rice seedling quality and reduces soil-borne pathogens. Environmental Science and Pollution Research 30(31): 77743-77756.

Zhang X., Zhan Y., Zhang H., Wang R., Tao X., Zhang L., Zuo Y., Zhang L., Wei Y. & Li J., 2021, Inoculation of phosphate-solubilizing bacteria (*Bacillus*) regulates microbial interaction to improve phosphorus fractions mobilization during kitchen waste composting. Bioresource Technology 340: 125714.

Zhang, L. & Sun, X., 2015, Effects of earthworm casts and zeolite on the two-stage composting of green waste. Waste management 39: 119-129.

Zurhalena, Z., Endriani, E., Farni, Y. & Fuadi, N.A., 2023, Application of cow manure and *Gliricidia sepium* pruning compost to improve physical properties of ultisols and soybean yield. Journal of Degraded and Mining Lands Management 10(3): 4527-4535.