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Potential of Solid Waste Compost and Spent Mushroom Substrate in Earthfill Quarry Topsoil Rehabilitation

Colleen E. Consuelo[1], Jan Britzmaine C. Meulio[1], Kenneth Raymund B. Garcia[1], Karen M. Pelaez[1], Clint Bernard C. Bulawan[1], Mary Louise N. Rapsing[1], Cezar Joshua T. Badiola[1], and Joseph Martin Q. Paet[2]*

[1]Bicol University, College of Engineering, Legazpi City, Albay, 4500, Philippines
[2]Bicol University, Research and Development Management Division,
Legazpi City, Albay, 4500, Philippines
*Corresponding Author: jmqpaet@bicol-u.edu.ph

Abstract

The increasing number of quarry activities in the Philippines has been causing extensive soil damage, altering its properties, and affecting the soil's post-mining productivity. This problem was established in this study where earthfill quarried topsoil (QT) in Gubat, Sorsogon, Philippines, showed diminished soil physicochemical characteristics compared to sampled nearby topsoil with undisturbed vegetation (NQT). This study further assessed the potential of two compost materials, i.e., solid waste compost (SWC), and spent mushroom substrate (SMS), in helping reestablish QT's quality. Fertility tests on both SWC and SMS showed relatively high levels of nutrients compared to other previously characterized materials and were employed as QT amendment to test its effects in growing IR64 rice. Central Composite Design (CCD) was used to determine compost-QT combinations (SWC or SMS added with peat moss and lime), if it would significantly affect rice's germination rate, survivability, and overall growth. CCD showed that SWC alone and SMS with lime significantly affected several rice response parameters ($p<0.05$). These results were validated to compare the performance of QT added with SWC at different percentages (10, 20, and 30%) and SMS (50%) with decreasing amounts of lime (10, 7.5, and 5%). Here we showed that adding compost to QT improved rice's rate of germination and development, shoot-root length ratio, and biomass but is more observable in SMS than SWC. In conclusion, the study provided preliminary evidence of the potential of locally produced SWC and SMS in improving quarried topsoil quality, whereby on-site trial and application must be considered.

Keywords: Soil Fertility, Central Composite Design, Rice Growth

Introduction

Quarrying is one of the types of surface mining known for extracting and processing raw materials such as rock, sand, and gravel to be used primarily in the construction sector. Despite being essential for the Philippine economy, this industry is regarded as one of the most destructive sectors that have created negative public perceptions (Catajan, 2021; Domingo, 1993). Mining is accelerated by urbanization and industrialization worldwide, which continue to impact natural ecosystems, leading to long-term physical, chemical, and biological damage, especially to soil quality as initially observed (Corbett et al., 1996; Obeng et al., 2019; J. Wang et al., 2011). In the Philippines, reports on illegal and excessive quarrying showed that people are becoming more conscious of the environmental impacts of mining activities, notably when natural calamities such as typhoons become exacerbated due to it (Conde, 2021; DENR, 2021; MGB-8, 2018; Miraflor, 2021; Ong, 2021). Hence, part of the call for the stringent implementation of Republic Act No. 7942 (1995), also known as the Philippine Mining Act of 1995, is to oblige mining companies to plan out the abandonment phase or mine closure process of mining projects to help mitigate environmental and societal impacts. With this, alternative and cost-efficient techniques in rehabilitating exploited areas started to turn towards the utilization of compost materials, such as municipal solid wastes and spent mushroom substrates, due to its economical, environment-friendly, and sustainable advantages as soil amendments (Ayilara et al., 2020; Harrison, 2008; Mortier et al., 2016; Roy et al., 2021).

In the Bicol Region, there are at least 800 quarry sites permitted to be operational for mineral extraction, equivalent to at least 85 thousand ha. of land; more than half of this is being excavated for non-metallic substances such as earthfill, the second most common mining commodity in the region (Mines and Geosciences Bureau RO V, 2020). Earthfill materials are a composite of silt, fine-grained gravel, clay, and sand, utilized for building and construction due to their strength, permeability, and compressibility (United States Department of Agriculture, 2015). Gubat, a second-class municipality in the province of Sorsogon, is among the areas in the region with ongoing earthfill quarry activities. While many are still expected to continue quarrying, as the extension of registration is permissible, and many more sites are being identified as mineral resource prospects, the same effort should be given to searching for technologies or approaches that will aid during the rehabilitation process of these mined sites.

Introduction of compost to mining-disturbed soils, according to Núñez (2013), improves soil quality via physical (with increased organic matter, soil porosity and water retention capacity increases while reducing erosion), chemical (attenuation of extreme pH values and increasing bioavailable nutrients, e.g., nitrogen and phosphorus while reducing toxic elements), and biological (reintroduction of microbial populations that aids in plant growth and reactivation of essential biogeochemical processes) aspects. Several attempts at compost application have been noted for the rehabilitation of disposal areas for bauxite residues (Di Carlo et al., 2019), pyritic mine sites (Masaka et al., 2017), metal-containing acid mine drainage (Molahid et al., 2019; Quicasán et al., 2017), opencast coal mining site (Haigh et al., 2019), and sulfidic mine wastes/tailings (Asemaninejad et al., 2021) among others. A long-term on-site study on the use of “recycled organics,” including composts, mulches, and soil conditioners, was also observed to improve tree growth and survivability as well as in moderating temperature and moisture in nutrient-poor and rainfall-deficient mining areas (Kelly, 2008). The addition of compost and other supplementary components is found to be variable, and site-dependent primarily since compost quality differs relative to the inputted waste material, preparation and processing, as well as time of composting (Mortier et al., 2016).

While the goal of soil conditioners in application to abandoned quarry sites is not to make them agriculturally productive, it sought to answer the most notable environmental impact of quarrying: erosion and loss of nutrients due to the removal of natural vegetation and the mineral extraction process. Without proper action, a positive feedback loop on the loss of nutrients, leading to lesser vegetation, more erosion, and more nutrients lost, is expected to happen; rehabilitation of quarried sites will become more problematic (Miller & Spoolman, 2016). Succession, nature’s natural capability to restore a disturbed environment in its attempt to recreate a stable ecosystem, favors opportunistic species such as grasses as the first occupants following perturbations. Efforts supporting vegetation growth during the early successional phase in a nutrient-deprived environment will be paramount, with the potential to end this cycle. The biological responses of rice were used as an indicator to assess the potential rehabilitation capabilities of compost materials since it is one of the most characterized model organisms for monocots, especially grasses (Borrill, 2020; Rensink & Buell, 2004).

This research utilized locally produced compost materials within the Bicol region, sourcing them from; Legazpi Sustainable Compost Facility in Barangay Banquerohan, dubbed here as Solid Waste Compost (SWC) since it is produced from organic solid wastes from markets and households, and Spent Mushroom Substrate (SMS) from a local mushroom farm in Daraga, Albay which is initially a mixture of sawdust, rice bran, sugar, molasses, and lime for Oyster mushroom production which after harvest were stored for four months before use in this study. This work aims to provide baseline data on the physicochemical characteristics of an earthfill quarry site in Gubat, Sorsogon, and the effect of SWC and SMS addition on improving its quality to better support the early invasion of vegetation in this quarry-perturbed soil.

Materials and Methods

Study Site and Soil Sampling. Quarry Topsoil (QT) and Near Quarry Topsoil (NQT) samples were taken from Brgy. Carriedo, Gubat, Sorsogon (**Fig. 1**). The quarried area in this study was excavated and processed for at most 5 years until the present for earthfill materials. Three sampling locations were identified for QT collection, namely Quarry 1 (Q1), Quarry 2 (Q2), and Quarry 3 (Q3), where about a total of 25-30 kg of soil was collected, transported, homogenized, and air-dried before testing and experiment. About 10 kg of NQT sample was also collected from nearby vegetation, as pinned in **Figure 1**.

Compost Materials and Rice Seeds Preparation. Two sacks of solid waste compost (SWC) were requested from and provided by Legazpi Sustainable

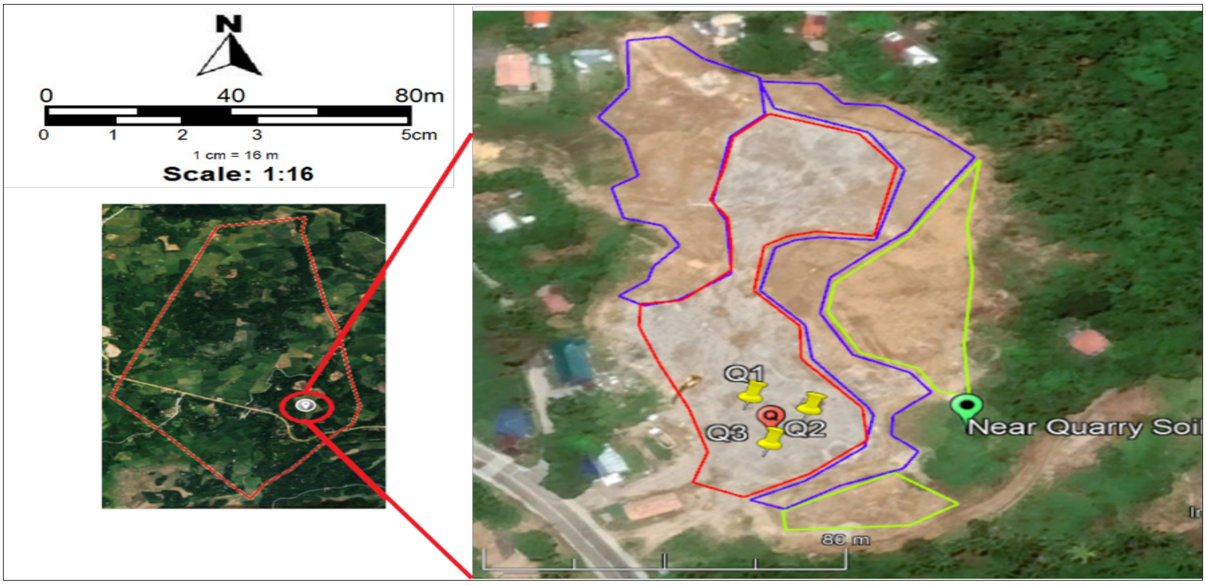

Figure 1 Satellite Map of Brgy. Carriedo Earthfill Quarry Site. The boundary of Brgy. Carriedo at Gubat, Sorsogon enclosed in red lines, and the encircled sampling site zoomed-in a scale of 1:16. Samples for QT were pooled from Q1 (12.940025, 124.096836), Q2 (12.939989, 124.096961), and Q3 (12.939878, 124.096883) which were pinned and labeled in yellow while NQT (12.939953, 124.097308) was tagged in green. The border in the sampling site drawn in red was the oldest quarry area, while those in violet and yellow-green are more recently excavated parts.

Composting Facility, and three sacks of spent mushroom substrate (SMS) were also purchased from a Mushroom Farm Facility in San Vicente, Daraga, Albay. Both SWC and SMS were homogenized and air-dried before testing and experiment. Meanwhile, *indica* rice cultivar (IR64) seeds were provided by the Genetics and Biotechnology Division, Plant Pathology Laboratory of the International Rice and Research Institute (IRRI) in Laguna, Philippines. The heat was used to break seed dormancy, and the surface was sterilized with 1% sodium hypochlorite before direct seeding.

Quarry Soil and Compost Physico-chemical Testing. QT and NQT samples were sent to the Regional Soils Laboratories (RSL) Region V in Naga City then tested for the following: electrical conductivity (conductometer), soil texture (bouyoucos hydrometer), water holding capacity (tapping), pH (potentiometric method), organic matter (Wackley and Black spectrophotometric method), estimated nitrogen content (%OM x 0.05), available phosphorus (Olsen's & Bray No. 1 method), and potassium (qualitative soil test kit). SWC and SMS samples were tested in RSL Region IV-A in Batangas for the following: moisture content (gravimetric method), pH (potentiometric method), total nitrogen (Kjeldahl method), total phosphorus (Vanadomolybdate method), and total potassium (atomic-emission spectroscopy).

Central Composite Design for Quarry-Compost Combination. A response surface method using Central Composite Design (CCD) were employed using Design Expert ver.13 software. Variables initially considered were the percent addition of either SWC or SMS (20-50%), peat moss (PM; 5-10%), and lime (L; 5-10%). Forty-eight experimental runs for each compost were established by entering factorial points in triplicates, axial points in triplicates, and 6 central points. Compost-PM-L was added to QT to fill 300 g of soil for growing IR64 rice. Forty-eight seeds per seeding tray were sown to each SWC-PM-L and SMS-PM-L treatment combinations. The set-up was placed inside a 58 L plastic box, covered until 14 days post sowing (dps), then terminated after 21 days with daily temperature monitored at about 28±0.094°C. The following responses were measured: %Germination at 5dps (5GP), average rate of germination in days (ARG), survivability percentage (SP), individual biomass (IB; total dry weight per tray divided by plant per tray), biomass conversion (BC; total dry weight per tray divided by 300 g).

SWC and SMS Validation Experiment. Amendments to QT were identified using the CCD approach. For SWC, better responses were observed at lower amounts without adding PM or L, so the validation run included 10, 20, and 30% of SWC (designated as SWC1, SWC2, and SWC3, respectively). For SMS, better responses were observed when large amounts of compost were added with L, so the validation run included 50% SMS with decreasing amounts of lime (10, 7.5, and 5% designated as

SMS1, SMS2, and SMS3, respectively). Like the CCD approach, 48 seeds were sown on trays, placed inside a plastic box, then monitored for their temperature until termination at 21 dps. The setup included growing rice in untreated QT and NQT, and all treatments were done in triplicates. The following biological responses were then measured to compare the performance of the treated vs. untreated soil, i.e., 5GP, %Germination at 10 dps (10GP), stage of development (SD) following the guidelines set by Counce et al. (2000), SP, shoot-root ratio (S/R), IB, and BC.

Statistical Analysis. Numerical data were expressed as mean ± standard error mean. One or two population comparisons were done using independent sample t-test to determine mean differences. Meanwhile, multiple groups were compared using analysis of variance (ANOVA) or independent sample Kruskal Wallis test followed by post-hoc analysis. Test significance was set at $p < 0.05$, and statistical computations were run in *R* software ver. 4.1.2.

Results and Discussion

QT showed reduced soil quality compared to NQT

The laboratory analysis of selected physical properties of the soil samples showed that electrical conductivity (EC), % Sand, and %Clay significantly differed between QT and NQT (**Table 1**). NQT and QT samples were found to be non-saline, but the mean EC of the former was significantly higher. Regarding soil texture, NQT was classified as clay loam while QT was as sandy loam. The differences in texture can be attributed to the composition of each soil sample where the %Sand composition of QT is higher than NQT while the %Clay was significantly higher in NQT than in QT. Parameters related to soil fertility were also found to have significant differences between NQT and QT (**Table 1**). Water holding capacity (WHC) was higher in NQT than QT, similar to %OM. Soil pH of both NQT and QT was found to be acidic. Regarding nutrient composition, NQT had higher nitrogen content (N) but lower phosphorus content (P) than QT. Both soil samples were found deficient in potassium content (K).

It is generally observed that soils tend to have more available nutrients when EC value is higher than those with a lower EC value (Soil Survey Staff, 2014). Plant growth and microbial processes are not usually impeded at the observed EC in NQT and QT. However, when EC is less than 1, it was shown to reduce plant biomass production and leaf photosynthetic rate (Ding et al., 2018). The current EC value of NQT and QT will fail to support most plants especially those used in agricultural production (Abrol et al., 1998). Differences in EC can also be attributed to the differences in the composition of NQT and QT.

These results corroborated the standard observations between sandy soil and clay soil, where EC was found lower in the former than the latter (Soil Survey Staff, 2014). Additionally, the significant increase in %Sand composition in QT can pose a further risk of nutrient depletion where sulfur, nitrogen, and potassium can easily leach compared to soil with higher %Clay (Nathan, 2022). Soil texture was also found to affect plant growth and yield. For instance, rice yield, panicle and spikelet number, water productivity, chlorophyll content, and root and shoot biomass were to be higher in clay soil than in sandy loam soil (Arshad et al., 2021; Dou et al., 2016). Clay loam was also documented to increase drought tolerance and generally less prone to the spread of disease in plants (Arshad et al., 2021; Dou et al., 2016).

Table 1 Differences in physico-chemical parameters between NQT and QT

Parameters	NQT	QT	*P*-value
EC (Ms/cm)	0.038±0.001	0.032±0.000	0.001*
%Sand	43.133±0.667	63.800±0.000	<0.01*
%Silt	20.00±0.000	22.00±0.000	NC
%Clay	36.867±0.667	14.200±0.000	<0.01*
WHC	56.717±0.033	41.733± 0.214	<0.01*
pH	5.303± 0.003	5.887±0.003	<0.01*
%OM	0.373±0.015	0.063±0.007	<0.01*
%N†	0.019±0.001	0.003±0.000	<0.01*
P (ppm)	0.780±0.106	1.020±0.081	0.146
K	Deficient	Deficient	NC

Note: *Independent sample t-test is significant when $p < 0.05$ (n=3 per test); †Derived from %OM; Abbreviations: NC is not computed, EC is electrical conductivity, WHC is water holding capacity, OM is organic matter, N is nitrogen, P is phosphorus, and K is potassium.

WHC can be related to the soil texture of the samples, where clay soils are usually found to have higher WHC than sandy soil since it has a larger surface that allows the soil to hold more water (Ball, 2001). As average rainfall is expected to decrease following the global temperature increase, the WHC of quarry soils will be an important determinant of what vegetation will succeed in the area. Invasive grasses with traits better adapted to drought stress than most crops are observed to be more successful in this aspect (Chadha et al., 2018). Soil pH is another important determinant of plant growth and development since it affects the availability of nutrients and the biological functions of the soil (Neina, 2019). Both QT and NQT were acidic, which can be the optimum soil pH range for various plants, including vegetables, root crops, shrubs, and grasses (Ilagan et al., 2014; Nathan, 2022). However, N, P, and K become less bioavailable in soils with lower pH.

OM contributes to plant growth *via* physical, chemical, and biological alterations of the soil aiding in water uptake and increasing WHC, as it improves the soil structure by holding together particles in aggregates (Nathan, 2022). Higher OM also improves the soil's microflora and microfaunal activities, providing more nutrients to the plants (Funderburg, 2001). For instance, OM has been historically attributed to the release of nitrogen and is said to catalyze nutrient uptake by improving root development (King et al., 2020). Since %OM is significantly higher in NQT, it may promote better vegetative performance than QT. Soil nutrient compositions such as N, P, and K are also essential to plant growth and are integral in chlorophyll formation, root formation, sugar transport and efficient water use among others (Nathan, 2022). N is found to be significantly higher in NQT since it contains a lower %Sand and higher %OM (**Table 1**). While P and K are not significantly different between NQT and QT as per analysis (**Table 1**), soil texture may imply that P and K in QT may be lower than in NQT, especially since nutrients are easily leached in sandy soils.

SWC and SMS have varying fertility profile

Compost material quality differs significantly depending on how it was prepared, the substrate used, and the duration of composting, among others (Mortier et al., 2016). In almost all fertility parameters tested (pH, %MC, %N, %P, %K), SWC and SMS both exhibited significantly different profiles than previously established works as shown in **Table 2** (Beyer, 2011; Fidanza et al., 2010; Onwudiwe, et al., 2014; Tibu et al., 2019). Municipal solid waste composted in the works of Onwudiwe et al.(2014) and Tibu et al. (2019) varied significantly from the profile of SWC used in this study, most likely because of the different ratios of waste substrates used during the composting process and the processing in general. On the other hand, significantly different SMS fertility profile from this study compared to the reported values of Beyer (2011) and Fidanza et al. (2010) can be attributed to the type of mushroom used during cultivation (i.e., *Agaricus bisporus* in Fidanza *et al*. compared to *Pleuortus ostreatus* used in this study) and the duration of aging (i.e., 6 months in Beyer compared to 4 months in SMS). Knowing the fertility parameters of the compost to be used in quarry topsoil rehabilitation will help decide how much compost is to be added. While composts are generally applied in large amounts because of the limited bioavailable nutrients (Petruzzello, 2018), establishing the optimum ratio of amendment to be added in quarried topsoil will be able to promote better rehabilitation outcomes while still being economically sound.

Table 2 Compost fertility profile compared to literatures

Compost	pH	%N	%P	%K	%MC
SWC	8.880 ± 0. 061	1.511 ± 0.083	1.215 ± 0.046	1.113 ± 0.048	20.373 ± 4.548
A	8.3*	9.17*	0.05*	0.28*	ND
B	7.60*	0.87*	0.50*	0.12*	ND
SMS	7.063±0.05	0.616±0.033	1.140±0.027	0.660±0.006	40.693±1.958
C	7.1	2.72*	0.84*	0.43*	ND
D	6.62*	1.12*	0.29*	1.04*	57.33*

Note: *Values in SWC or SMS (n=3 per test) compost has significantly different mean using one sample *t*-test when $p < 0.05$; Abbreviations: SWC is solid waste compost used in this study; A values were from Onwudiwe et. al. (2014); B values were from Tibu (2019) using market waste data; SMS is spent mushroom substrate used in this study; C values were from Beyer (2011); D values were from Fidanza et al. (2010); ND means no data available for comparison.

SWC alone and SMS with Lime significantly affect rice growth response

Different biological responses of rice were measured to determine important components for QT rehabilitation, i.e., 5GP, ARG, SP, IB, and BC. **Table 3** summarizes the central composite design (CCD) report, where some combinations were significant. For SWC, CCD generated a significant linear model identifying the importance of SWC addition to QT in germination rate ($p<0.001$) and biomass ($p=0.022$). Similarly, the linear model from CCD identified the need for the addition of SMS to improve germination in QT ($p<0.001$). While the addition of lime together with SMS was found to have a significant model explaining its effect on the biomass of rice, the model lacks the necessary fit to explain these responses. Ideally, models generated from CCD can be used to optimize the compost-QT combinations. However, the predictive values of the models are weak to moderate ($R^2 < 3$), implying that about 70% or more can be attributed to intervening factors that were not included in the current experiment. Hence, the result of the CCD was only used to determine important factors and the concentration of treatments that will be used in the validation experiment. In this case, SWC at the lowest percent addition to QT (30 down to 20 and 10%) was used as per the CCD results showed that the best response was at low amounts of SWC.

Also, SMS was fixed to 50% since CCD identified response was highest at this concentration. Lastly, lime at decreasing concentrations (from 10 down to 7.5 and 5%) was still considered to validate its importance in QT rehabilitation.

Varying Effects of SWC and SMS on Rice Growth and Development

The rate of germination in SMS+L treated QT was statistically faster than the NQT and QT at 5dps but no longer significant at 10dps (**Fig. 2a** and **b**). Meanwhile, SW treatment did not change germination rate at 5dps and significantly slowed down at 10dps compared to both NQT and QT (**Fig. 2a** and **b**). Interestingly, both SMS+L and SWC significantly improved the proportion of the population of rice at an advanced stage of development, where 20% SWC showed the best result (**Fig. 2c**). Low germination in SWC also translated to a significantly lower number of surviving plants at 21dps while untreated quarry soil and SMS+L treated QT had statistically similar SP (**Fig. 2d**). Highest shoot-root length ratio was noted in SMS+L treated QT but 20 and 30% SWC also showed significantly improved S/R compared to both NQT and QT (**Fig. 2e**).

Table 3 Determination of important QT-compost combinations using CCD

Response	Model	P-value	Lack of Fit	R^2	Significant Component
SWC-5GP	2FI	0.243	0.097	0.169	-
SWC-ARG	Linear	< 0.001*	0.699	0.415	SWC
SWC-SP	Linear	0.229	0.840	0.093	-
SWC-IB	Quadratic	0.090	0.190	0.305	-
SWC-BC	Linear	0.022*	0.482	0.195	SWC
SMS-5GP	Linear	<0.001*	0.140	0.348	SMS
SMS-ARG	2FI	0.382	0.977	0.138	-
SMS-SP	2FI	0.367	0.725	0.141	-
SMS-IB	Quadratic	0.009*	0.012*	0.367	L
SMS-BC	Quadratic	0.019*	0.001*	0.381	L

Note: *Model and lack of fit test was significant when $p < 0.05$; Abbreviations: 5GP is 5-day germination; ARG is average rate of germination; SP is survivability percentage; IB is individual biomass; BC is biomass conversion; SWC is solid waste compost; SMS is spent mushroom substrate; L is lime; - cannot be determined since model was not significant.

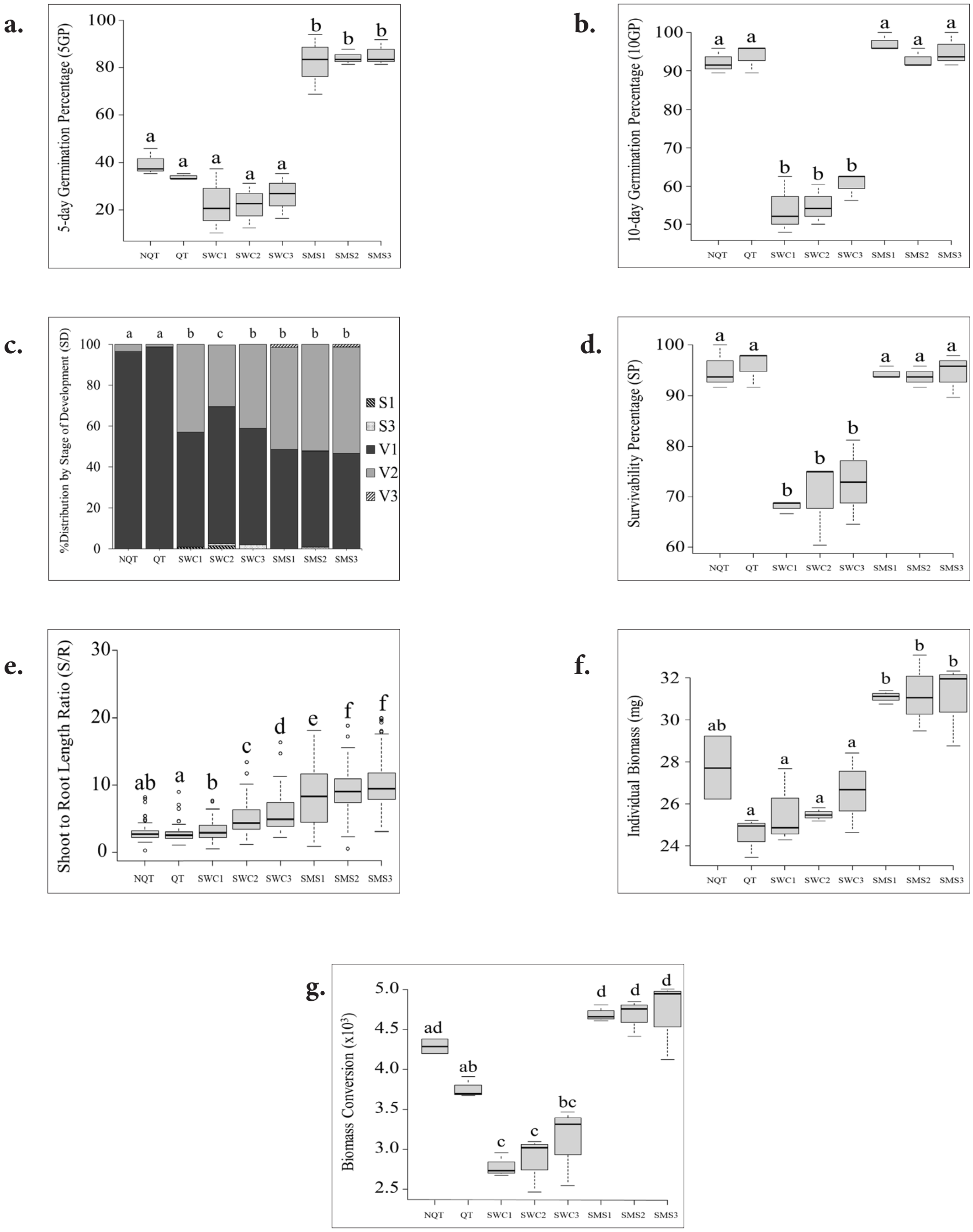

Figure 2 Effects of SWC and SMS+L Treatments to Rice's Biological Responses

Change in QT quality upon SWC and SMS+L treatment on the rate of germination (**a** and **b**), stage of development (**c**), survivability (**d**), growth (**e**), and biomass (**f** and **g**) of rice (n=48 per replicate in triplicates). Statistical significance was computed using ANOVA (**a**, **b**, **d**, **f**, and **g**) and Kruskal-Wallis Test (**c** and **e**) with post-hoc or pair-wise analysis results indicated by letters (a-d) with different letters indicating significantly different mean or median at $p < 0.05$. Abbreviations: NQT is near quarry topsoil; QT is quarry topsoil; SWC is solid waste compost at 10% (1), 20% (2), and 30% (3); SMS is 50% spent mushroom substrate with 10% (1), 7.5% (2), and 5% (3) lime.

Lastly, SMS+L showed significantly higher IB and BC compared to untreated soil while the addition of SWC showed the poorest biomass as affected by low SP (**Fig. 2f** and **g**).

Temperature, water, chemical environment, and substrate can influence a high percentage of seed germination and better growth and development. While temperature is the same in all set-ups, the addition of SWC and SMS in soil may have increased the WHC of the QT, leading to more water available during seed imbibition to initiate germination and use for growth. Higher available water favors growing and developing rice since it promotes better plant physiological response, while some species or communities of grasses have been documented to tolerate drought (Cardoso et al., 2015; Cyriac et al., 2018; Shi et al., 2012). Composts are also known to contain abundant microbes, which were previously shown to be more favorable for plant growth and development as compared to microbial population present in quarry-disturbed soil (Abakumov et al., 2020; Harrison, 2008; Ortíz-Castro et al., 2009; Petruzzello, 2018). On the other hand, SWC treatment showed an unusual response in some parameters, including the rate of germination and survivability, which showed that the determination of the optimum concentration of compost amendments is still necessary to achieve the best response.

Shoot-to-root ratio (S/R) is another important overall indicator in assessing the health of a plant where an increase in the S/R is almost always in response to more favorable growing conditions, while a reduction in the S/R would indicate that a plant is most likely growing under less favorable conditions (Agathokleous et al., 2019). The increase in roots is believed to be in response to plants having to compete more effectively for soil nutrients than those with a higher proportion of shoots primarily for collecting more light energy (Mašková & Herben, 2018). In this case, NQT and QT did not provide as much conducive conditions for growth, which is apparent in their fertility profile, as SWC and SMS+L treated soil did of the quarry soils. This improvement in S/R *via* the addition of compost will be advantageous during early vegetation succession, as previously described (Antos & Halpern, 1997). The potential of SMS+L treatment was further supported by the biomass data showing that the plant gained more access to nutrients they need to grow than the quarry soil. Similar works also highlighted the impact of SMS addition to biomass, where up to 300% grass biomass yield was observed by Paula et al. (2017) as well as in other works (Collela et al., 2019; Elsakhawy & Tawfik, 2019; S. H.-L. Wang et al., 1984). For SWC, an increasing trend in both IB and BC upon an increase in concentration was also apparent, albeit not significant. Initially hypothesized non-optimum addition of SWC to QT may have also contributed to the low biomass observed, which is one of the challenges identified in the review article of Ayilara et al. (2020). Similarly, other works also opted to establish baseline data or experimentally optimize municipal solid waste as a soil amendment (Moldes et al., 2007; Weerasinghe & De, 2017). More work should also be done on the characterization of SWC quality as it was identified as another limiting factor in the immediate use and recommendation of compost material as a soil amendment (Roy et al., 2021). Generally, improvement in plant growth performance upon applying compost could be attributed to higher nutrient availability, improved soil structure and quality, and possibly the slow release of nutrients.

Conclusion and Recommendations

The quarry industry serves a vital role in the ongoing infrastructure development in the Philippines as the requirement for construction materials increased. This study established that topsoil from an earthfill quarry in Sorsogon province, Philippines, had diminished soil physico-chemical characteristics compared to topsoil from a nearby site with undisturbed vegetation. This aspect demands the need for topsoil rehabilitation, which will be critical in re-establishing the ability of the soil to support life and avoid further loss of nutrients if left completely abandoned. As such, the current work showed the potential of compost materials including solid waste compost and spent mushroom substrate on improving quarried topsoil quality by primarily supplying needed nutrients to promote plant growth. Rice grown on compost-treated quarry topsoil also performed better in germination, growth, and development, simulating success of possible early succession of vegetation in quarry sites. However, more studies are needed to optimize compost addition as a means to rehabilitate disturbed quarry soils due to their varying fertility profiles, especially on solid waste compost where quality was not yet fully characterized. Taken together, mining companies are encouraged to consider the use of composted materials within the region, such as solid waste composts and spent mushroom substrate, for on-site trials as well as for feasibility and sustainability studies.

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References

Abakumov, E., Zverev, A., Suleymanov, A., & Suleymanov, R. (2020). Microbiome of post-technogenic soils of quarries in the Republic of Bashkortostan (Russia). Open Agriculture, 5(1), 529–538. https://doi.org/10.1515/opag-2020-0053

Abrol, I. P., Yadav, J. S. P., & Massoud, F. I. (1998). SALINE SOILS AND THEIR MANAGEMENT. In Salt-affected soil and their management. Food and Agriculture Organization.https://www.fao.org/3/x5871e/x5871e00.htm#Contents

Agathokleous, E., Belz, R. G., Kitao, M., Koike, T., & Calabrese, E. J. (2019). Does the root to shoot ratio show a hormetic response to stress? An ecological and environmental perspective. Journal of Forestry Research, 30(5), 1569–1580. https://doi.org/10.1007/s11676-018-0863-7

Antos, J. A., & Halpern, C. B. (1997). Root system differences among species: Implications for early successional changes in forests of Western Oregon. American Midland Naturalist, 138(1), 97–108. https://doi.org/10.2307/2426658

Arshad, M., Nisar, S., Gul, I., Nawaz, U., Irum, S., Ahmad, S., Sadat, H., Mian, I. A., Ali, S., Rizwan, M., Alsahli, A. A., & Alyemeni, M. N. (2021). Multi-element uptake and growth responses of Rice (Oryza sativa L.) to TiO2 nanoparticles applied in different textured soils. Ecotoxicology and Environmental Safety, 215, 112149. https://doi.org/10.1016/j.ecoenv.2021.112149

Asemaninejad, A., Langley, S., Mackinnon, T., Spiers, G., Beckett, P., Mykytczuk, N., & Basiliko, N. (2021). Blended municipal compost and biosolids materials for mine reclamation: Long-term field studies to explore metal mobility, soil fertility and microbial communities. Science of the Total Environment, 760, 143393. https://doi.org/10.1016/j.scitotenv.2020.143393

Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O., & Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. Sustainability (Switzerland), 12(11), 1–23. https://doi.org/10.3390/su12114456

Ball, J. (2001). Soil and Water Relationships. Noble Research Institute. https://www.noble.org/news/publications/ag-news-and-views/2001/september/soil-and-water-relationships/

Beyer, D. M. (2011). Spent Mushroom Substrate. PennState Extension. https://extension.psu.edu/spentmushroom-substrate

Borrill, P. (2020). Blurring the boundaries between cereal crops and model plants. New Phytologist, 228(6), 1721–1727. https://doi.org/10.1111/nph.16229

Cardoso, J. A., Pineda, M., Jiménez, J. de la C., Vergara, M. F., & Rao, I. M. (2015). Contrasting strategies to cope with drought conditions by two tropical forage C 4 grasses. AoB Plants, 7, plv107. https://doi.org/10.1093/aobpla/plv107

Catajan, M. E. (2021, January 31). Philippine mines continue unhampered 4 years after Gina Lopez shutdown order. Philippine Center for Investigative Journalism. https://www.rappler.com/business/philippine-mines-continue-unhampered-4-years-after-gina-lopez-shutdown-order/

Chadha, A., Florentine, S. K., Chauhan, B. S., Long, B., & Jayasundera, M. (2018). Influence of soil moisture regimes on growth, photosynthetic capacity, leaf biochemistry and reproductive capabilities of the invasive agronomic weed; Lactuca serriola. PLoS ONE, 14(6), 1–17. https://doi.org/10.1371/journal.pone.0218191

Collela, C. F., Soares Costa, L. M. A., De Moraes, T. S. J., Zied, D. C., Rinker, D. L., & Dias, E. S. (2019). Potential utilization of spent agaricus bisporus mushroom substrate for seedling production and organic fertilizer in tomato cultivation. Ciencia e Agrotecnologia, 43. https://doi.org/10.1590/1413-7054201943017119

Conde, M. (2021, February 19). Philippine quarries under scrutiny after deadly mudflow buries homes. Mongabay. https://news.mongabay.com/2021/02/philippine-quarries-under-scrutiny-after-deadly-mudflow-buries-homes/

Corbett, E. A., Anderson, R. C., & Rodgers, C. S. (1996). Prairie revegetation of a strip mine in Illinois: Fifteen years after establishment. In Restoration Ecology (Vol. 4, Issue 4, pp. 346–354). https://doi.org/10.1111/j.1526-100X.1996.tb00187.x

Counce, P. A., Keisling, T. C., & Mitchell, A. J. (2000). A uniform, objectives, and adaptive system for expressing rice development. Crop Science, 40(2), 436–443. https://doi.org/10.2135/cropsci2000.402436x

Cyriac, D., Hofmann, R. W., Stewart, A., Sathish, P., Winefield, C. S., & Moot, D. J. (2018). Intraspecific differences in long-term drought tolerance in perennial ryegrass. PLoS ONE, 13(4), 1–17. https://doi.org/10.1371/journal.pone.0194977

DENR. (2021). DENR STOPS ILLEGAL QUARRYING ACTIVITIES IN LIAN, BATANGAS. https://www.denr.gov.ph/index.php/news-events/press-releases/2943-denr-stops-illegal-quarrying-activities-in-lian-batangas

Di Carlo, E., Chen, C. R., Haynes, R. J., Phillips, I. R., & Courtney, R. (2019). Soil quality and vegetation performance indicators for sustainable rehabilitation of bauxite residue disposal areas: A review. Soil

Research, 57(5), 419–446. https://doi.org/10.1071/SR18348

Ding, X., Jiang, Y., Zhao, H., Guo, D., He, L., Liu, F., Zhou, Q., Nandwani, D., Hui, D., & Yu, J. (2018). Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (Brassica campestris L. Ssp. Chinensis) in a hydroponic system. PLoS ONE, 13(8), 1–15. https://doi.org/10.1371/journal.pone.0202090

Domingo, E. G. (1993). The Philippine mining industry: status and trends in mineral resources development. Journal of Southeast Asian Earth Sciences, 8(1–4), 25–36. https://doi.org/10.1016/0743-9547(93)90004-9

Dou, F., Soriano, J., Tabien, R. E., & Chen, K. (2016). Soil Texture and Cultivar Effects on Rice (Oryza sativa, L.) Grain Yield, Yield Components and Water Productivity in Three Water Regimes. PLoS ONE, 11(3), 1–12. https://doi.org/10.1371/journal.pone.0150549

Elsakhawy, T., & tawfik, wael. (2019). Evaluation of Spent Mushroom Substrate extract as biofertilizer for growth improvement of Rice (Oriza sativa). Egyptian Journal of Soil Science, 0(0), 0–0. https://doi.org/10.21608/ejss.2019.18835.1320

Fidanza, M. A., Sanford, D. L., Beyer, D. M., & Aurentz, D. J. (2010). Analysis of fresh mushroom compost. HortTechnology, 20(2), 449–453. https://doiorg/10.21273/horttech.20.2.449

Funderburg, E. (2001). What Does Organic Matter Do In Soil? Noble Research Institute. https://www.noble.org/news/publications/ag-news-and-views/2001/august/what-does-organic-matter-do-in-soil/

Haigh, M., Desai, M., Cullis, M., D'Aucourt, M., Sansom, B., Wilding, G., Alun, E., Garate, S., Hatton, L., Kilmartin, M., Panhuis, W., & Jenkins, R. (2019). Composted Municipal Green Waste Enhances Tree Success in Opencast Coal Land Reclamation in Wales. Air, Soil and Water Research, 12. https://doi.org/10.1177/1178622119877837

Harrison, R. B. (2008). Composting and Formation of Humic Substances. Encyclopedia of Ecology, Five-Volume Set, 713–719. https://doi.org/10.1016/B978-008045405-4.00262-7

Ilagan, L. A., Tablizo, R. P., Jr, R. B. B., & Marquez, N. A. (2014). Soil Fertility Evaluation For Rice Production In Catanduanes Province, Philippines. International Journal of Scientific & Technology Research, 3(12), 81–87.

Kelly, G. (2008). Application of recycled organics in mine site rehabilitation. In Department of Environment and Climate Change NSW. www.environment.nsw.gov.au

King, A. E., Ali, G. A., Gillespie, A. W., & Wagner-Riddle, C. (2020). Soil Organic Matter as Catalyst of Crop Resource Capture. Frontiers in Environmental Science, 8(May), 1–8. https://doi.org/10.3389/fenvs.2020.00050

Masaka, J., Mutambu, M., Mhindu, R., & Muringaniza, K. (2017). Pyritic metals sequestration on mine dumps treated with oyster mushroom (Pleurotus ostreatus, Jacq.et Fr.). Chemical and Biological Technologies in Agriculture, 4(1), 1–14. https://doi.org/10.1186/s40538-017-0108-6

Mašková, T., & Herben, T. (2018). Root:shoot ratio in developing seedlings: How seedlings change their allocation in response to seed mass and ambient nutrient supply. Ecology and Evolution, 8(14), 7143–7150. https://doi.org/10.1002/ece3.4238

MGB-8. (2018). MGB-08 INVESTIGATES QUARRYING COMPLAINT. Mines and Geosciences Bureau Regional Office 8. https://region8.mgbgov.ph/en/featured-news/news-articles/265-mgb-08-investigates-quarrying-complaint.html

Miller, G. T., & Spoolman, S. E. (2016). Environmental Science (Fifteenth). Cengage Learning.

Mines and Geosciences Bureau RO V. (2020). Directory of Mines and Quarries CY 2019. https://region5.mgb.gov.ph/attachments/category/27/Directory-of-Mines-and-Quarries-2019.pdf

Miraflor, M. B. (2021, October 15). La Union shuts down "illegal" quarry operations. Manila Bulletin. https://mb.com.ph/2021/10/15/la-union-shuts-down-illegal-quarry-operations/

Molahid, V. L. M., Mohd Kusin, F., & Madzin, Z. (2019). Role of multiple substrates (spent mushroom compost, ochre, steel slag, and limestone) in passive remediation of metal-containing acid mine drainage. Environmental Technology (United Kingdom), 40(10), 1323–1336. https://doi.org/10.1080/09593330.2017.1422546

Moldes, A., Cendón, Y., & Barral, M. T. (2007). Evaluation of municipal solid waste compost as a plant growing media component, by applying mixture design. Bioresource Technology, 98(16), 3069–3075. https://doi.org/10.1016/j.biortech.2006.10.021

Mortier, N., Velghe, F., & Verstichel, S. (2016). Organic Recycling of Agricultural Waste Today: Composting and Anaerobic Digestion. In Biotransformation of Agricultural Waste and By-Products: The Food, Feed, Fibre, Fuel (4F) Economy. Elsevier Inc. https://doi.org/10.1016/B978-0-12-803622-8.00004-5

Nathan, M. V. (2022). Soils, Plant Nutrition and Nutrient Management. University of Missouri Extension. https://extension.missouri.edu/publications/mg4?fbclid=IwAR2xUssHyAfSyK6zb5L7-S59bmy2SnliCzrMshCmm2bTaw27fUwFSesKrcU

Neina, D. (2019). The Role of Soil pH in Plant Nutrition and Soil Remediation. Applied and Environmental Soil Science, 2019(3). https://doi.org/10.1155/2019/5794869

Núñez, R. P. (2013). Use of composted materials in the potential rehabilitation of spaces affected by mining waste and mine soils. Geological and Mining Bulletin, 124(3), 405–419.

Obeng, E. A., Oduro, K. A., Obiri, B. D., Abukari, H., Guuroh, R. T., Djagbletey, G. D., Appiah-Korang, J., & Appiah, M. (2019). Impact of illegal mining activities on forest ecosystem services: local communities' attitudes and willingness to participate in restoration activities in Ghana. Heliyon, 5(10), e02617. https://doi.org/10.1016/j.heliyon.2019.e02617

Ong, G. (2021, October 24). 12 nabbed for illegal quarrying in Rizal. The Philippine Star. https://www.philstar.com/nation/2021/10/24/2136250/12-nabbed-illegal-quarrying-rizal

Onwudiwe, N., Benedict, O. U., Ogbonna, P. E., & Ejiofor, E. E. (2014). Municipal solid waste and NPK fertilizer effects on soil physical properties and maize performance in Nsukka, Southeast Nigeria. African Journal of Biotechnology, 13(1), 68–75. https://doi.org/10.5897/ajb2013.13352

Ortíz-Castro, R., Contreras-Cornejo, H. A., Macías-Rodríguez, L., & López-Bucio, J. (2009). The role of microbial signals in plant growth and development. Plant Signaling and Behavior, 4(8), 701–712. https://doi.org/10.4161/psb.4.8.9047

Paula, F. S., Tatti, E., Abram, F., Wilson, J., & O'Flaherty, V. (2017). Stabilisation of spent mushroom substrate for application as a plant growth-promoting organic amendment. Journal of Environmental Management, 196, 476–486. https://doi.org/10.1016/j.jenvman.2017.03.038

Petruzzello, M. (2018). Compost. Britanica. https://www.britannica.com/topic/food

Philippine Mining Act of 1995. (1995). Republic Act No. 7942. Philippines.

Quicasán, D. F., Forero, N. F., & Vasquez, O. Y. (2017). Prevención de drenajes ácidos de mina utilizando compost de champiñón como enmienda orgánica. Revista Colombiana de Biotecnología, 19(1), 92–100. https://doi.org/10.15446/rev.colomb.biote.v19n1.58904

Rensink, W. A., & Buell, C. R. (2004). Arabidopsis to rice. Applying knowledge from a weed to enhance our understanding of a crop species. Plant Physiology, 135(2), 622–629. https://doi.org/10.1104/pp.104.040170

Roy, E. D., Esham, M., Jayathilake, N., Otoo, M., Koliba, C., Wijethunga, I. B., & Fein-Cole, M. J. (2021). Compost Quality and Markets Are Pivotal for Sustainability in Circular Food-Nutrient Systems: A Case Study of Sri Lanka. Frontiers in Sustainable Food Systems, 5(November), 1–15. https://doi.org/10.3389/fsufs.2021.748391

Shi, H., Wang, Y., Cheng, Z., Ye, T., & Chan, Z. (2012). Analysis of Natural Variation in Bermudagrass (Cynodon dactylon) Reveals Physiological Responses Underlying Drought Tolerance. PLoS ONE, 7(12). https://doi.org/10.1371/journal.pone.0053422

Soil Survey Staff. (2014). Soil Survey Field and Laboratory Methods Manual. In United States Department of Agriculture, Natural Resources Conservation Service (Issue Soil Survey Investigations Report No. 51, Version 2.0). https://www.nrcsusdagov/wps/PA_NRCS Consumption/download?cid=stelprdb1244466&ext=pdf

Tibu, C., Annang, T. Y., Solomon, N., & Yirenya-Tawiah, D. (2019). Effect of the composting process on physicochemical properties and concentration of heavy metals in market waste with additive materials in the Ga West Municipality, Ghana. International Journal of Recycling of Organic Waste in Agriculture, 8(4), 393–403. https://doi.org/10.1007/s40093-019-0266-6

United States Department of Agriculture. (2015). Chapter 8: Earthfill and Rockfill. In National Engineering Handbook (Issue October).

Wang, J., Li, Z., Hu, X., Wang, J., Wang, D., & Qin, P. (2011). The ecological potential of a restored abandoned quarry ecosystem in Mt. Mufu, Nanjing, China. Ecological Engineering, 37(6), 833–841. https://doi.org/10.1016/j.ecoleng.2010.12.026

Wang, S. H.-L., Lohr, V. I., & Coffey, D. L. (1984). Growth response of selected vegetable crops to spent mushroom compost application in a controlled environment. Plant and Soil, 82(1), 31–40. https://doi.org/10.1007/BF02220767

Weerasinghe, T. K., & De, S. I. H. W. K. (2017). Effect of applying different ratios of compost made of municipal solid waste on the growth of Zea mays L. (Corn). Journal of Soil Science and Environmental Management, 8(3), 52–60. https://doi.org/10.5897/jssem2016.0609

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