INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 25, No. 1, p. 86-93, 2024
http://www.innspub.net

RESEARCH PAPER

OPEN ACCESS

# Varying levels of spent mushroom substrate as soil conditioner for simultaneous production of Roselle

**Steve S. Serrano*, Ferdinand M. Navarro, Dianne Peralta, Rhodora S. Mortela**

*Don Mariano Marcos Memorial State University, South La Union Campus, College of Agriculture, Rosario, La Union, Philippines*

Article published on July 06, 2024

**Key words:** Alkalinity, Roselle, Soil conditioner, Soil pH, Soil reclamation, Spent mushroom substrate

**Abstract**

The use of spent mushroom substrate as a soil conditioner in roselle cultivation may provide economic rewards, but their potential to aid in soil reclamation and the development of technology related to roselle production in the Philippines must be carefully considered. The research was conducted on an approximate area of 127.5 m2 at the Don Mariano Marcos Memorial State University–College of Agriculture, Nagtagaan, Rosario, La Union. Using Randomized Complete Block Design, the area was split into three blocks. Five treatment combinations made up each block. The treatments were; T0 = 100% soil (control), T1 = 10% spent mushroom substrate + 90% soil, T2 = 20% spent mushroom substrate + 80% soil, T3 = 30% spent mushroom substrate + 70% soil, and T4 = 40% spent mushroom substrate + 60% soil. The application of 10% to 30% spent mushroom substrate to the soil positively affected growth and yield of roselle. A highly significant variation revealed on the mean stem diameter and mean number of fully developed primary branches while significant results were observed on the mean final plant height, mean number of fruits, mean fruit equatorial diameter, mean fresh fruit weight, mean fresh calyx weight, mean dried calyx weight and mean numbers of seeds. The performance of roselle is adversely affected by the level of alkalinity in T4, which measures 8.14. Soil treated with the increasing volume of spent mushroom substrate was observed physically and chemically improved except for phosphorus declined at the 10% level and soil pH stabilized at 30% level. The result testifies that by adding 10% to 40% amount of spent mushroom substrate could potentially treat deficient and acidic soils and serve as a useful soil conditioner for the concurrent production of roselle.

***Corresponding Author:** Steve S. Serrano ✉ stevesiendaserrano@gmail.com

**Introduction**

In the Philippines, roselle profile is indefinite however Filipinos have already known the calyx for its use in wines and other processed products marketed in some part of Metro Manila, Visayas, and Mindanao (Mahirang, 2017). In Ilocos region, the seeds are already been used as a coffee substitute, besides the leaves and calyces are also used as sourcing agent in 'sinigang' (Mahirang, 2017). Roselle is widely cultivated in other tropical countries valued for its leaves, seed, stem and especially for its calyx (Eslaminejad and Zakaria, 2011). The demand for the calyx in global trade market has stable rising at 15,000 tons every year where Sudan, Mexico, Thailand, China, Jamaica, Egypt, Senegal, and Mali are the top producers and exporters of Roselle while the top importers are Germany and USA (Maghirang, 2017). In the quantity of documented uses (food, drinks, medicine, animal feed and other industrial uses) and essential properties derived from Roselle, it is timely to promote its potential in the Philippines to put it into extensive production but the information on its agronomic production at present is still limited.

Roselle not requires high inputs for its cultivation hence it can be grown by simply applying organic fertilizers (Maghirang, 2017). Numerous studies have been published on Roselle that uses organic materials with the goal of improving its nutritional value, productivity, and soil reclamation in situations where most high-value crops cannot thrive. Norhayati *et al.* (2019) found that goat manure applied in BRIS soil at 160 mt/ha improves the growth and yield of Roselle. According to recent study of Liu *et al.* (2021), a mixture of biochar made of corn waste through the process of pyrolysis and composted corn waste were positively affect soil and quality of Roselle under saline soil. Furthermore, spent mushroom substrate has also shown potential in bioremediation. Wuana and Mbasugh (2013) discovered that Roselle can be a phytoextractor of Cu and Pb in soils and manures have these excessive heavy metal contaminations.

Since mushroom cultivation is a growing agribusiness in the Philippines yet the disposal of mushroom waste after production is not giving much attention. After mushroom is fully harvested, the remains substrate disposed as "spent mushroom substrate" (SMS) (Ribas *et al.*, 2009). In other countries the disposal management of SMS is also a major problem (Phan and Sabaratnam, 2012). This trouble rouses the attention of research for the possible applications of SMS into different fields. According to reviews of Mahari *et al.* (2020) and Paula *et al.* (2020), SMS has been documented its positive contributions in agriculture for both crop production and soil remediation. A recent study by Muchena *et al.* (2021) stated that SMS is a potential fertilizer for baby spinach. According to the latest findings of Yu *et al.* (2021), the combined application of SMS from *Pleurotus eryngii* and SMS from *Agaricus bisporus* have potential for remediation of Cd-contaminated paddy soil. Wang *et al.* (2020) suggested that the application of SMS chiefly from *Flammulina velutipes* substrate can treat cucumber *Fusarium* wilt and decrease the population of *Fusarium oxysporum* f. sp. *cucumerinum* (FOC). Ngan and Riddech (2020) suggested that using SMS as biofertilizer carrier is a good alternative for enriching soil moreover SMS based inoculant significantly promoted the biomass and chlorophyll content of Roselle.

Cultivation of roselle with the use of spent mushroom substrate as soil conditioner may offer economic incentives yet it needs to evaluate their potentials in depth that may contribute in soil reclamation and the development of technology to use for Roselle production in the Philippines.

**Material and methods**

*Research design*

The study was conducted in an area measuring approximately 127.5 m2 at the Don Mariano Marcos Memorial State University – South La Union Campus - College of Agriculture, Nagtagaan, Rosario, La Union. The land was laid out using a randomized complete block design replicated three times. There are five plots in each block where the treatments are distributed. The treatments are as follows: T0 – 100% soil (control); T1 – 10% spent mushroom substrate +

90% soil; T2 – 20% spent mushroom substrate + 80% soil; T3 – 30% spent mushroom substrate + 70% soil; T4 – 40% spent mushroom substrate + 60% soil.

*Materials*

The soil was gathered from the Greenhouse of the College of Agriculture, and the spent mushroom substrate (SMS) was sourced out from one mushroom grower in Bangar, Rosario, La Union. Based on the actual interview to the farmer, his own substrate formulation to produce mushroom (*Pleurotus florida*) consists of 40% sawdust, 40% rice straw, 18% rice bran, 1% molasses, and 1% agricultural lime. Roselle seeds were purchased online. Other supplies used in the study were purchased from agricultural shops in Rosario, La Union.

*Procedures*

The study was carried out using pot experiment method. The soil and the spent mushroom substrate were pulverized and each material was mixed thoroughly to ensure the uniformity of the media. Afterwards, the amount of soil and spent mushroom substrate (SMS) were measured individually by volume using a pail and mixed them in accordance to the different treatment ratios. Each treatment was taken a kilogram of a sample subjected for physical and chemical analysis. Then each treatment was bagged and weighed at 15 kg per pot. Before arranging the plastic pots on the experimental area, plastic mulch was laid down first on the ground and secured using bamboo clips. This was used to prevent root penetration in the soil and to supress weeds. The following cultural management practices were applied to the test plants irrespective for the treatments:

*Cultural management*

*Seedling production*

Seeds were sown in seedling trays (104 holes) filled with 1:1:1 mixture of vermicompost, carbonized rice hull and garden soil at one seed per cell. Seedlings were nourished in seedling nursery until they are ready to transplant.

*Transplanting*

This was done late in the afternoon. Roselle seedlings are ready to transplant 30 days after sowing. Seedlings with roughly equal in heights were selected and transplanted at 1 seedling per pot.

*Watering*

Watering in plants depends on weather and soil conditions. Soil moisture was being monitored regularly. Watering was done when it was required.

*Weeding*

All emerging weeds all over the experimental area were removed by hand pulling and mowing.

*Insect pest and disease management*

Daily monitoring was initiated to check the earliest signs of disease and insect pest's damage. The identified pests were managed through integrated pest management.

*Harvesting*

The criterion used in harvesting Roselle calyx is when the seed pod's color changes from green to brown while the calyx is still fresh. Harvesting was done through cutting the fruit pedicel using pruning shear.

*Decoring*

The seed pod was removed by using a sharpen stainless steel tube with a 15 mm diameter by piercing the pedicel under the fruit and gently push out the seedpod.

*Drying of seed pod and calyces*

The multipurpose commodity solar tunnel dryer (MCSTD) was used to dry the calyces and seedpods of Roselle for five days after they were decored.

*Data gathered*

Soil physical and chemical properties (before and after production of roselle) – This was obtained by analyzing the different soil media formulations including the control treatment before and after the production of roselle. Every treatment is collected a kilogram of soil sample before and after the production of roselle and brought to the Department of Agriculture - Soils Laboratory for analysis.

*Growth parameters*

Mean initial and final plant height (cm). This was measured starting from the base of the plant up to the tip of the longest part of the plant using a meter stick.

*Mean stem diameter (mm)*

This was determined by measuring the stem diameter of roselle at 1 inch above the ground using a digital vernier caliper after the last harvesting.

*Mean number of fully developed primary branches*

This was obtained by counting the fully developed primary branches having with the growth of 1-foot length and above.

*Mean number of primary branches*

This was taken by counting all emerged lateral branches on the main stem.

*Yield parameters*

Mean number of fruits. This was determined by counting all harvested fruits. Mean fruit equatorial diameter (mm). This was measured using a digital vernier caliper at the center part of the fruit.

*Mean fresh fruit weight (g)*

This was taken by weighing the fruits right after harvesting using digital weighing scale.

*Mean fresh calyx weight (g)*

This was obtained by weighing fresh calyces using a digital weighing scale right after decoring.

*Mean dried calyx weight (g)*

This was determined by weighing all calyces per sample plant after drying using a digital weighing scale.

*Mean total number of seeds*

This was taken by counting all the seeds that was harvested.

*Mean dried weight of seeds (g)*

This was determined by weighing the seeds after drying using a digital weighing scale.

*Analysis of data*

Data were analysed using Analysis of Variance (ANOVA) for single factor experiment in Randomized Complete Block Design (RCBD) and run using the statistical software "Statistical Tool for Agricultural Research (STAR) 2.0.1, 2013". Comparison among treatment means were tested using Tukey's Honest Significance Difference.

**Results**

Table 1 presents the growth parameters of roselle as affected by varying levels of spent mushroom substrate used as soil conditioner. Analysis of variance disclosed highly significant variations on the mean stem diameter and mean number of fully developed primary branches. T3 had the largest stem diameter (14.63 mm), but it is comparable to T2 (14.58 mm). T1 ranked third with 13.47 mm followed by T4 with 11.94 mm and lastly T0 with 10.25 mm. In terms of the number of fully developed primary branches, T3 led with 6, but it was comparable to T1 and T2 with both 5; meanwhile, T4 and T0 are comparable produced 3 and 1 respectively.

There was a significant variation observed in the mean final plant height. T1 had the tallest final plant height with 93.17 cm, which is comparable to T3 and T2 with 88.37 cm and 87.58 cm respectively, while T0 came in fourth place with 72.71 cm, which is comparable to T4 with 71.23cm.

Table 2 shows the yield parameters of Roselle as affected by varying levels of spent mushroom substrate as soil conditioner. Significant differences were observed on the mean number of fruits, mean fruit equatorial diameter, mean fresh fruit weight, mean fresh calyx weight, mean dried calyx weight and mean numbers of seeds meanwhile a not significant variation was revealed on the mean dried weight of seeds.

**Table 1.** Growth parameters of roselle as affected by varying levels of spent mushroom substrate mixed to soil as soil conditioner

| Treatments | Mean initial plant height at transplanting (cm) | Mean final plant height after harvesting(cm) | Mean stem diameter (mm) | Mean no. Of fully developed primary Branches | Mean no. of primary branches |
|---|---|---|---|---|---|
| To–100% soil (control) | 12.56 | 72.71[b] | 10.25[d] | 1[b] | 14 |
| T1–10% SMS + 90% soil | 12.49 | 93.17[a] | 13.47[b] | 5[a] | 15 |
| T2–20% SMS + 80% soil | 12.50 | 87.58[a] | 14.58[a] | 5[a] | 18 |
| T3–30% SMS + 70% soil | 12.31 | 88.37[a] | 14.63[a] | 6[a] | 17 |
| T4–40% SMS + 60% soil | 12.50 | 71.23[b] | 11.94[c] | 3[b] | 18 |
| Significance | ns | * | ** | ** | ns |
| CV(%) | 3.31 | 6.27 | 4.01 | 14.65 | 13.04 |

**Table 2.** Yield parameters of roselle as affected by varying levels of spent mushroom substrate mixed to soil as soil conditioner

| Treatments | Mean no. of fruits | Mean fruit equatorial diameter (mm) | Mean fresh fruit weight (g) | Mean fresh calyx weight (g) | Mean dried calyx weight (g) | Mean no. Seeds | Mean dried weight of seeds (g) |
|---|---|---|---|---|---|---|---|
| To–100% soil (control) | 25[c] | 26.52[ab] | 241.22[c] | 146.25[c] | 18.91[c] | 443[ab] | 17.10 |
| T1–10% SMS + 90% soil | 42[abc] | 27.66[a] | 428.04[ab] | 264.50[ab] | 34.35[ab] | 794[ab] | 26.62 |
| T2–20% SMS + 80% soil | 49[ab] | 27.78[a] | 509.69[ab] | 317.46[a] | 39.31 [a] | 944[a] | 34.79 |
| T3–30% SMS + 70% soil | 62[a] | 26.68[ab] | 544.05[a] | 319.12[a] | 38.29[ab] | 1047[a] | 34.42 |
| T4–40% SMS + 60% soil | 35[bc] | 25.69[b] | 340.02[bc] | 206.72[bc] | 25.20[bc] | 498[b] | 16.14 |
| Significance | * | * | * | * | * | * | ns |
| CV(%) | 20.39 | 2.84 | 15.53 | 14.12 | 15.55 | 29.38 | 36.56 |

**Table 3.** Physical and chemical properties of soil before and after production of roselle

| Soil analysis before production of roselle | | | | | |
|---|---|---|---|---|---|
| Treatment | Organic matter (%) | Available phosphorous (ppm) | Available potassium (ppm) | Texture | pH |
| To–100% soil (control) | 2.57 | 24.12 | 518.88 | Heavy | 7.63 |
| T1–10% SMS + 90% soil | 3.81 | 67.97 | 560.86 | Heavy | 8.08 |
| T2–20% SMS + 80% soil | 5.03 | 142.93 | 655.39 | Heavy | 8.07 |
| T3–30% SMS + 70% soil | 6.07 | 249.48 | 861.96 | Heavy | 8.07 |
| T4–40% SMS + 60% soil | 6.93 | 204.63 | 943.75 | Medium | 7.87 |
| Soil analysis after production of roselle | | | | | |
| Treatment | Organic matter (%) | Available phosphorous (ppm) | Exchangeable potassium (cmol/kg) | Texture | pH |
| To–100% Soil (control) | 2.32 | 22.54 | 1.49 | Fine | 8.07 |
| T1–10% SMS + 90% soil | 3.98 | 62.72 | 2.68 | Fine | 8.09 |
| T2–20% SMS + 80% soil | 5.43 | 214.30 | 3.72 | Fine | 8.10 |
| T3–30% SMS + 70% soil | 7.29 | 343.40 | 4.76 | Fine | 8.07 |
| T4–40% SMS + 60% soil | 7.57 | 279.58 | 4.28 | Fine | 8.14 |

The highest number of fruits was recorded in T3 (62). However, this treatment is statistically comparable to T2 (49) and T1 (42). T2 and T1 are also comparable to T4 (35) while T1 and T4 are comparable to To (25).

The largest mean fruit equatorial diameter was recorded in T2 (27.78mm), which was comparable to T3 (26.68mm), T1 (27.66mm), and To (26.52mm). Meanwhile T3 and To are comparable to T4 (25.69mm).

In terms of the mean fresh fruit weight T3, T2 and T1 were comparable which had 544.05 g, 509.69 g, and 428.04 g respectively. T2 and T1, however, are also comparable to T4 (340.02 g). Likewise, T4 and To (241.22 g) are comparable.

The heaviest fresh calyx weight was observed in T3 with 319.12 g but this treatment was comparable to T2 with 317.46 g and T1 with 264 g. Despite on that T1 is comparable to T4 (206.72 g) and T4 is comparable to To weighed 146.25 g.

On the mean dried calyx weight T2 (39.31 g) was the heaviest but it is comparable to T3 and T1 weighed 38.29 g and 34.35 g respectively. T3 and T1, However, are comparable to T4 weighed 25.20g meanwhile T0 had the lightest dried calyx weight with 18.91 g but it is statistically comparable to T4.

With 1,047 seeds, T3 had the most seeds counted, but this is comparable to T2 and T1, which had 944 and 794 seeds respectively. T0 had the smallest seed count with 443 but it is comparable to T4 (498) and T1 (794).

Table 3 presents the physical and chemical properties of soil before and after the production of roselle. Soil analysis showed that the organic matter had increasing value from T0 to T4 ranging from 2.57% to 6.93% before the production of roselle while the data after the production was ranging from 2.32% to 7.57% where T0 (100% soil) was the lowest while T4 (40% SMS + 60% soil) was highest. Available phosphorous was also improved ranging from 24.12 ppm to 249.48 ppm before production while 22.54 ppm to 343.40 ppm after production where T0 was the lowest while T3 was the highest. Available potassium was also rising from lowest 518.88 ppm obtained from T0 to highest 943.75 ppm obtained from T4 in before production, however the analysis unit of potassium was changed after production where it became exchangeable potassium which ranging from 1.49 cmol/kg to 4.76 cmol/kg where T0 was consistently the lowest and T3 was the highest. Soil texture was analyzed heavy from T0 to T3 while medium texture was observed in T4 before transplanting of roselle meanwhile after transplanting the term was changed in fine texture which observed in all the treatments. The recorded pH after production of Roselle is ranging from 7.63 acquired from T0 while the highest pH held by T1 with 8.08. After production of Roselle pH recorded lowest from T0 and T3 with 8.07 whereas the highest pH was T2 with 8.10. The NPK of the soil applied with SMS at 10% to 40% were increased before production of Roselle and more improved after production of roselle except for the phosphorous of T1 from the 67.97 ppm before production down to 62.72 ppm after production of roselle. Soil pH was also improved except for T3 that became stable. NPK of the control treatment (T0 - 100% soil) was noticed decreased after the production of Roselle.

**Discussion**

The high significant result implied that at 20% and 30% level of mixed spent mushroom substrate to soil provide a best stem growth diameter meanwhile at 10%, 20% and 30% level gives best development of the primary branches of roselle. The identical inference was noted regarding the ultimate plant height and yield, with the 10%, 20%, and 30% levels producing the optimal plant height and yield for Roselle. The outcome supports the conclusions drawn by Roy *et al.* (2015) that the height and branching of *Capsicum annuum* L. were positively impacted by the application of spent mushroom substrate from oyster mushrooms and spent compost from button mushrooms, at a rate of 250gm of SMS per kg of soil. Plant growth and yield is also aided by SMS's inclusion of N, P, K, Mg, Na, and trace elements such as: Cu, Fe, Mn, Zn, Mo, B (Jasińska, 2018). Reusing of SMS has been reviewed by Jasińska (2018) to be an effective growing medium for a variety of vegetables, including broccoli, cauliflower, tomatoes, cucumbers, tulips, spinach, and peppers. However, the plants' responses vary depending on the degree of SMS incorporation. According to the resent research of Verma *et al.* (2020) plant growth is significantly enhanced when the soil is combined with SMS at a ratio of 75% SMS to 25% soil. However, at 75% SMS to 25% soil ratio contradicts on this study which at 40% SMS + 60% soil noticed a detrimental effect on roselle growth and yield parameters. The primary nutrients (NPK) were perceived to have increased compared to the control treatment. However, the reduction in roselle growth at 40% level can be ascribed to the high alkalinity of the treatment. This is because the soil is naturally alkaline and was further increased due to the lime added to neutralize the acidity mushroom substrate. According to Ansari (2013), roselle can thrive in pH levels up to 8.0. However, T1 to T3 exceeded this requirement.

Among them, T4 experienced the most significant pH increase, reaching 8.14 after production. This led to severe nutrient deficiency in roselle.

According to Velez *et al.* (2022), alkaline pH reduces water capacity and greatly limits the availability of Fe, P, Mn, and Zn. The findings indicated that the pH values measured in T1 to T3, falling between 8.07 and 8.10, are still acceptable for roselle, as it only displayed mild signs of nutrient deficiency.

The use of SMS as a soil conditioner has been shown to improve soil, which supports to the report of Jasińska (2018) that spent mushroom substrate is good source of N, P, K, Mg, Na, and trace elements such as: Cu, Fe, Mn, Zn, Mo, B.

**Conclusion**

Roselle growth and yield had observed to be influenced by the addition of spent mushroom substrate to the soil. Fully developed primary branches and stem diameter showed highly significant differences, whereas fruit equatorial diameter, number of fruits, fresh fruit weight, dried calyx weight, number of seeds, and final plant height all showed significant results.

As compared to control treatment (100% soil) the chemical properties of soil treated with increasing levels of spent mushroom substrate (10%, 20%, 30% and 40%) was enhanced before and after production of Roselle. With the exception of phosphorous in T1 which decreased from 67.97 ppm to 62.72 ppm subsequently. The pH of the soil has improved with most treatments, except for T3 whose pH was stabilized.

It was found that 75% of the evaluated growth and yield parameters of Roselle had been positively influenced by mixing SMS to the soil within 10% to 30% concentrations. According to the results of the study, the most effective proportion of spent mushroom substrate added to soil for the simultaneous production of Roselle is 10%, 20%, or 30%. Nonetheless, it is imperative to consider the pH of the soil.

**Recommendation(s)**

Soil physical and chemical properties were enhanced by applying spent mushroom substrate from 10% to 40% level before and after the cultivation of roselle. However, most of the growth and yield attributes of roselle were consistently improved when SMS was applied at concentrations between 10% and 30%. Hence, it is recommended to incorporate spent mushroom substrate in soil within the range of 10% to 30% concentrations as a potential soil conditioner for the simultaneous production of Roselle. But, it is also crucial to consider the pH level of the soil. In cases where the soil is highly acidic, the addition of SMS up to 40% can also be recommended to further increase the pH.

**References**

**Ansari M, Eslaminejad T, Sarhadynejad Z, Eslaminejad T.** 2013. An overview of the Roselle plant with particular reference to its cultivation, diseases and usages. European Journal of Medicinal Plants **3(1)**, 135-145. https://doi.org/10.9734/EJMP/2013/1889.

**Eslaminejad T, Zakaria M.** 2011. Morphological characteristics and pathogenicity of fungi associated with Roselle (*Hibiscus sabdariffa*) diseases in Penang, Malaysia. Microbial Pathogenesis **51(5)**, 325-337. DOI: 10.1016/j.micpath.2011.07.007.

**Grandel D.** 2020. Soil pH: Dealing with acidic and alkaline soils. OMEX. Retrieved from https://omexcanada.com/blog/soil-ph/.

**Jasińska A.** 2018. Spent mushroom compost (SMC) retrieved added value product closing loop in agricultural production. Acta Agraria Debreceniensis **150**, 185-202. https://doi.org/10.34101/actaagrar/150/1715.

**Liu D, Ding Z, Ali EF, Kheir AMS, Eissa MA, Ibrahim OHM.** 2021. Biochar and compost enhance soil quality and growth of Roselle (*Hibiscus sabdariffa* L.) under saline conditions. Scientific Reports **11(1)**. DOI: 10.1038/s41598-021-88293-6.

**Maghirang R.** 2019. Roselle. Agriculture Monthly. Retrieved from https://www.agriculture.com.ph/2017/11/28/roselle/

**Mahari WAW, Peng W, Nam WL, Yang H, Lee XY, Lee YK, Lam SS.** 2020. A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry. Journal of Hazardous Materials, 123156.
DOI: 10.1016/j.jhazmat.2020.123156.

**Muchena FB, Pisa C, Mutetwa M, Govera C, Ngezimana W.** 2021. Effect of spent button mushroom substrate on yield and quality of baby spinach (*Spinacia oleracea*). International Journal of Agronomy **2021**. DOI: 10.1155/2021/6671647.

**Ngan NM, Riddech N.** 2020. Use of spent mushroom substrate as an inoculant carrier and an organic fertilizer and their impacts on Roselle growth (*Hibiscus sabdariffa* L.) and soil quality. Waste Biomass Valor **12**, 3801-3811 (2021).
https://doi.org/10.1007/s12649-020-01278-w.

**Norhayati Y, Ng WH, Adzemi MA.** 2019. Effects of organic fertilizers on growth and yield of Roselle (*Hibiscus sabdariffa* L.) on BRIS soil. Malaysian Applied Biology **48(1)**, 177-184.

**Paula FS, Tatti E, Thorn C, Abram F, Wilson J, O'Flaherty V.** 2020. Soil prokaryotic community resilience, fungal colonization and increased cross-domain co-occurrence in response to a plant-growth enhancing organic amendment. Soil Biology and Biochemistry **107937**.
DOI: 10.1016/j.soilbio.2020.107937.

**Phan C-W, Sabaratnam V.** 2012. Potential uses of spent mushroom substrate and its associated lignocellulosic enzymes. Applied Microbiology and Biotechnology **96(4)**, 863-873.
DOI: 10.1007/s00253-012-4446-9.

**Ribas LCC, de Mendonça MM, Camelini CM, Soares CHL.** 2009. Use of spent mushroom substrates from *Agaricus subrufescens* (syn. *A. blazei*, *A. brasiliensis*) and *Lentinula edodes* productions in the enrichment of a soil-based potting media for lettuce (*Lactuca sativa*) cultivation: Growth promotion and soil bioremediation. Bioresource Technology **100(20)**, 4750-4757.
DOI: 10.1016/j.biortech.2008.10.059.

**Roy S, Barman S, Chakraborty U, Chakraborty B.** 2015. Evaluation of spent mushroom substrate as biofertilizer for growth improvement of *Capsicum annuum* L. Journal of Applied Biology & Biotechnology **3(03)**, 022-027.
https://doi.org/10.7324/JABB.2015.3305.

**Vélez Bermúdez I, Schmidt W.** 2022. Plant strategies to mine iron from alkaline substrates. Plant and Soil **483**. DOI: 10.1007/s11104-022-05746-1.

**Verma D, Didwana VS, Maurya B.** 2020. Spent mushroom substrate: a potential sustainable substrate for agriculture. Retrieved from https://www.researchgate.net/publication/347489805_Spent_mushroom_substrate_a_potential_sustainable_substrate_for_agriculture.

**Wang H, Xu M, Cai X, Feng T, Xu W.** 2020. Application of spent mushroom substrate suppresses *Fusarium* wilt in cucumber and alters the composition of the microbial community of the cucumber rhizosphere. European Journal of Soil Biology **101**. DOI: 10.1016/j.ejsobi.2020.103245.

**Wuana RA, Mbasugh PA.** 2013. Response of Roselle (*Hibiscus sabdariffa*) to heavy metals contamination in soils with different organic fertilizations. Chemistry and Ecology **29(5)**, 437-447.
DOI: 10.1080/02757540.2013.770479.

**Yu H, Liu P, Shan W, Teng Y, Rao D, Zou L.** 2021. Remediation potential of spent mushroom substrate on Cd pollution in a paddy soil. Environmental Science and Pollution Research.
DOI: 10.1007/s11356-021-13266-1.