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Review

Spent mushroom compost for bioremediation of petroleum hydrocarbon polluted soil: A review

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Abstract

The global anthem of wastes utilization has led to the use of agro-based wastes for production of edible mushrooms. Wastes have been utilized to produce mushrooms, and also generate larger amount of wastes. Several experimental trials on the alternative uses of spent mushroom composts have been reported. This review paper examined existing studies on the uses of SMC, and possibilities of utilization as amendment option to bioremediate petroleum hydrocarbon-polluted environment. Retinues of work have successfully reported the effectiveness of SMC in bioremediation, but a major limitation of these studies is that they are all laboratory-scale experiments. Thus, there is need to upgrade the use of SMC for bioremediation of petroleum hydrocarbon polluted soil to field-scale or in-situ level.

Keywords: Spent mushroom compost, petroleum, pollution, bioremediation.

INTRODUCTION

Contamination of soil environment by hydrocarbons (mostly petroleum hydrocarbons) is becoming prevalent across the globe. This is probably due to heavy dependence on petroleum as a major source of energy throughout the world, rapid industrialization, population growth and complete disregard for the environmental health. The amount of natural crude oil seepage was estimated to be 600,000 metric tons per year with a range of uncertainty of 200,000 metric tons per year (Kvenvolden and Cooper 2003). Release of hydrocarbons into the environment whether accidentally or due to human activities is a main cause of water and soil pollution (Kvenvolden and Cooper 2003). These hydrocarbon pollutants usually caused disruptions of natural equilibrium between the living species and their natural environment. Hydrocarbon components have been known to belong to the family of carcinogens and neurotoxic organic pollutants (Das and chandran, 2010). Bioremediation is the term used to describe biological strategies employed to repair of damaged environment. In the case of oil spills, the process exploits the catabolic ability of oil utilizing microorganisms. Several workers (Ijah and Antai, 1988; Okpokwasili and Okorie, 1988; Ijah, 2002, and Ijah, 2003) have described various applications of microorganisms in the bioremediation of oil polluted environment with encouraging results. Bioremediation is a big tool that transforms contaminants including petroleum hydrocarbons to less or no toxic end product rather that their transfer from one environmental compartments to another, as occurs in physical-chemical treatments such as extraction or incineration. In most cases, the treatment of oil contaminated environment has involved biostimulation, which of course involves the addition of nutrients to stimulate the spontaneous enrichment of the indigenous hydrocarbon oxidizing microbial population and bioaugmentation which involves using a consortium of microorganisms to depollute an impacted medium (Orji *et al.,* 2013). Bioremediation of pollutants by natural attenuation requires no human intervention, whereas implementation of accelerated and controlled biotreatment-based processes may be directed to exploiting microbial technology and bioprocess engineering to optimize the rate or extent of pollutant degradation (Zhu *et al.,* 2001; van-Hamme *et al.,* 2003). Biotreatment can be applied, using the following methods: composting, land farming and biopole, all of which exploit the biodiversity of the soil. However, they have the disadvantage of needing long process times and there is risk of contaminating air and aquifers by leaching. An interesting alternative approach which will not be faced with disadvantages or problems associate with composting, land farming and biopole, is the use of bioreactor in slurry phase biotreatment (Nwokoro and Okpokwasili, 2003; Kuyukina *et al.,* 2003). The use of bioreactor ensures that optimum process conditions be easily controlled. The use of bioreactor involves a preliminary slurry phase treatment of excavated soil in a bioreactor. The excavated soil which is contaminated with hydrocarbon is subjected to some physical treatment which separates stones and pebbles. The soil without stones and pebbles is then mixed with water to a required concentration which is dependent on the concentration of the hydrocarbon pollutants. This leads to optimization of conditions that favours bioremediation, during mixing, chemical exchange between soil particles and nutrient supplement/amendment agent occurs. This ensures that the surface areas of soil particles are optimally exposed to the degradative enzymes produced by microbial agents of bioremediation (Ururahy *et al.,* 1998; Nwokoro and Okpokwasili, 2003).

Sources of limiting nutrients for bioremediation of Petroleum hydrocarbon-impacted soil

In addition to a readily degradable carbon source, microorganisms require nutrients such as nitrogen, phosphorus, and potassium (NPK) for cellular metabolism and successful growth (Sihag and Pathak, 2014). In a contaminated site where organic carbon levels are always high, available nutrients can rapidly be depleted during metabolism. Therefore, it is very important to supplement contaminated soil with nutrients generally nitrogen and phosphorus to complement carbon utilization by the microorganisms. The amount of nitrogen required to establish bioremediation is a site-specific value, and can be determined through preliminary investigation, and conceptual site modeling. Previous reports show that a contaminated soil adjusted to C: N: P ratio of 120:10:1; 100: 15: 3, 5: 1: 0.5, 25:1:1 will be able to drive the biodegradation of petroleum hydrocarbon (Bogan *et al.,* 1978; Silag and Pathak, 2014).

The type and quantity of nutrients added into a polluted soil affects the bioremediation of such environment. Different reports on application of different fertilizers exist. A good property of a fertilizer for soil amendment in order to achieve bioremediation is that the fertilizer should be oil-loving (oleophilic). The use of inorganic fertilizers like NPK, KNO_3, NH_4NO_3 etc has been widely practised both at laboratory and field scales. However, a major limitation of inorganic fertilizer is the ease at which it could be leached into water bodies causing agal bloom (eutrophication). This results in fish poisoning and death. In addition, the inorganic fertilizer can also get leached by gravitational influence into the groundwater making them unfit for human consumption. In view of this, most researchers have used organic fertilizer to supply limiting nutrients to microorganisms degrading crude oil in the environment. This technology is cheap, and environmentally friendly. The organic manures/ fertilizers previously used for bioremediation are cow dung, poultry droppings, piggery wastes, composts manures/ farm yard manures (Orji *et al.,* 2012; Orji *et al.,* 2013).

Spent mushroom compost is the residual compost waste generated by the mushroom production industry. It is readily available and its formulation generally consists of a combination of wheat straw, dried blood, horse manure and ground chalk, composted together. It is an excellent source of humus, although much of its nitrogen content must have been used up by the composting and growing mushrooms. It remains, however, a good source of general nutrients (0.7% N, 0.3% P, 0.3% K) plus a full range of trace elements), as well as a useful soil conditioner (Rinker and Alm, 1990). However, due to its chalk content, it may be alkaline, and should not be used on acid-loving plants, nor should it be applied too frequently, as it will overly raise the soil's pH levels. Mushroom compost may also contain pesticide residues, particularly organochlorides. Previously, SMC's have been applied for various biotechnological processes. Notably, *Agaricus bisporus* spent substrate has been shown to have positive impacts on soil physical and physico-chemical properties (Ranganathan and Selvaseelan 1997); as organic fertilizer and soil conditioner for crop farming purpose. In addition, *Agaricus blazei* spent substrate has been utilized as organic fertilizer (Ranganathan and Selvaseelan 1997). Other spent mushroom composts previously used to amend soil include Sawdust substrate used for growing of *Lentinus edodes. Agaricus bisporus* spent substrate has been previously used for the production of Chrysanthemum (Rathier 1982). There are several research reports on the practical use of *Agaricus bisporus* spent compost for the Production of Asparagus, beet root, cauliflower, cabbage, capsicums, celery, cucumber, lettuce, mustard, onion, potato, radish, snap bean, spinach, sugar beet, tomato (Faassen *et al.,* 1992; Abak and Gul 1994; Maher *et al.,* 2000). Jonathan *et al.* (2014) defined SMC as the leftover of wastes after different flushes of mushrooms have been harvested. The report by Jonathan *et al.* (2014) also documented the use of SMC for growth of Nigerian vegetables, good soil conditioner, soil ameliorant, and Potential organic fertilizer. The successful use of combined SMC and poultry manure have been shown to be useful in the control of drought and leaf curl disesase in Okra (*Abelmoschus esculentus*) cultivars.

Composting of petroleum hydrocarbon-impacted soil with spent mushroom composts

Generally, composting is defined as aerobic degradation of solid domestic organic waste into a form that can be used as amendment material for soil (Odokuma, 2012). Semple *et al.* (2001) also defined composting as an aerobic process that relies on the actions of microorganisms to degrade organic materials, resulting in the thermogenesis and production of organic and inorganic compounds. Composting is the process by which most composts are produced. Thus, a composting bioremediation strategy relies on mixing the primary ingredients of composting with the contaminated soil, wherein as the compost matures, the pollutants are degraded by the active microflora within the mixture (Semple *et al.,* 2001). Semple *et al.* (2001) had previously documented the high promise of using non-mushroom composts for bioremediation of explosive, chlorophenol, aromatic hydrocarbon, petroleum hydrocarbons, and pesticide polluted soil. Composting is a relatively new clean-up strategy and because of this, there are a limited number of studies to comment upon (Semple *et al.,* 2001). Spent mushroom compost (SMC) is an abundantly produced bye product of the mushroom industry. The mushroom industry is the biggest solid-state-fermentation industry in the world, with 5 kg of SMC generated from the production of 1 kg of mushrooms (Lau *et al.,* 2003). Its uses have generally been limited to soil conditioning and fertilizing, while the majority of the product is landfilled (Chiu *et al.,* 1998). The over-abundance of SMC makes the development of sustainable management practices and new uses for SMC of prime importance in the mushroom industry (Ntougias *et al.,* 2004). SMC contains high levels of residual nutrients and enzymes, which may be beneficial for stimulating microbial degradation of organopollutants like hydrocarbons (Chiu *et al.,* 1998; Lau *et al.,* 2003). These microorganisms include xenobiotic degraders. They act as consortium of fungal mycelia, and bacterial cells which on utilisation of hydrocarbons of environmental concerns will build biomass, and de-pollute such environment. Harmsen *et al.* (1999) reported that SMC is useful compost for the biodegradation of fuel contamination. In this case, sediment that had been contaminated with mineral oil and landfarmed for two years was combined with SMC derived from the production of two mushroom types. The addition of SMC led to the biodegradation of Polycyclic aromatic hydrocarbon (PAH's) 20.6 to 41.7 % and mineral oil 1.8 to 4.0 %. Generally, SMC is composed of two layers: a compost layer made from straw, manure, and gypsum, and a casing layer made from peat and chalk (Stewart *et al.,* 1998). The first layer undergoes high temperature (thermophilic) composting followed by pasteurization and conditioning, while the second layer actually serves as the base for mushroom growth. After three to four weeks of mushroom cultivation and flushing/ harvesting the resulting substrate or compost is considered spent (Ntougias *et al.,* 2004). The different phases in composting select for specific organisms that predominate the compost for only a short period of time. This results into a higher microbial diversity or population following harvest and consequent release of relevant extracellular enzymes for biodegradation of pollutants (Ball and Jackson, 1995).

Composting materials used in Nigeria for mushroom production

Different carbon sources have been employed in Nigeria for commercial production of edible mushrooms. In mushroom, agro-industrial wastes which are inedible by man are transformed into highly valued food protein for direct human consumption. Mushrooms are known to grow on oil palm (fibre and bunch) wastes, dried chopped maize straw, cotton wastes, chopped cocoa pods, tobacco straw, used tea leaves, rice straw, Sugar cane bargase, newsprint, old rags, and sawdust (Banjo *et al.,* 2004). There are technical report on the production of oyster mushroom (*Pleurotus pulmonarius*) using sawdust as substrates, and palm kernel cake, brewers wastes, and urea as supplement (Banjo *et al.,* 2004). Kuforiji and Fasidi (2005) in Nigeria had previously developed standard operating procedures (SOP's) for production of paddy straw mushroom (*Volvariella volvacea*) from cotton wastes, rice straw, sorghum chaff, and *Mannsonia altissima.* Thereafter composting for mushroom compost, the spent mushroom composts are often generated as wastes and dumped indiscriminately in the Nigerian

PLATE A: SMC produced from Sawdust. **(Photo by ORJIFA)**

PLATE B: SMC produced from Cotton Waste. **(Photo by ORJIFA)**

PLATE 3: Pulverized spent Brewers' Spent Grain Compost. **(Photo by ORJIFA)**

PLATE 4: SMC in a Mushroom House in Nigeria **(Photo by ORJIFA)**

environment. Thus finding alternative uses for the spent mushroom compost is necessary at this point.

Microbes in spent mushroom composts and roles in bioremediation

The SMC previously studied by few other scholars are never sterile but contain a consortium of hydrocarbon degrading microorganisms. Thus, when to compost or land farm hydrocarbon polluted soil, it provides good limiting nutrient that bio-stimulates the indigenous hydrocarbon degraders, and introduces other friendly (non-genetically modified) microorganisms into the polluted environment (notably mushroom) to complement the degradative efforts of the indigenous microorganisms. This former technology is called bioaugumentation. Mycoremediation is a form of bioremediation in which fungi are used to decontaminate the area, and refers specifically to the use of fungal mycelia in bioremediation (Chukwura, 2012). One major or primary role of fungi in such ecosystem is decomposition, which is performed by the mycelium. The mycelium secretes extracellular enzymes, and acids which break down lignin, and cellulose, the two main building blocks of plant fibre. These are organic compounds composed of long chains of carbon and hydrogen structurally similar to many organic pollutants (Chukwura, 2012). The key to mycoremediation is determination of the right fungal species to attack a specific pollutant. Generally, wood degrading fungi like the species associated with mushroom composting and production are particularly effective in breaking down aromatic pollutants (toxic components of petroleum), as well as chlorinated compounds and persistent pesticides (Chukwura, 2012). Treatment of hazardous wastes requires composting matrices which will provide an optimal environment for metabolism, and effectiveness of composting is usually determined by various factors such as moisture content, porosity, concentration of biodegradable organic matter etc.

Limitations of spent mushroom composts (SMC) bioremediation research

Mushroom production being the largest solid state fermentation industry in the world (Lau *et al.,* 2003) and with so much waste being produced, it is extremely important to find a good use for SMC. The laboratory scale evidence of the use of spent mushroom compost as source of limiting nutrient and hydrocarbon utilizing fungi (White rot fungi) for bioremediation is criticized as many believe that the white rot fungi/mushrooms will not survive field conditions, thus the technology is not transferable to the field. Thus from previous studies the argument against the transfer of SMC composting technology to the field for pilot-scale bioremediation has created a major gap that must be bridged through research.

Economic Implications of utilization of spent mushroom compost (SMC) for bioremediation

Generally, spent mushroom compost is available in tonnes in different mushroom houses owned by Government (Research Institutes), and organized private sectors. There is no value for SMC in Nigeria. In fact it constitutes great nuisance in the environment as it can be discharged carelessly. Value addition into the large amount of SMC generated in Nigeria can be possible through development of standard operating procedures (SOP's) for alternative utilization of the waste. Soil amendment for cropping, bioremediation, utilization as microbial mat/ biological ion exchange column, immobilization into bricks, blocks are possible ways of using and converting the waste to wealth.

CONCLUSION

Efforts by scientists across the globe to utilize wastes accruing from agro-allied processing have actually solved the problem momentarily but also create similar problems Thus, as we utilize agro-allied wastes such as sawdust, cassava peels, cotton waste, brewers spent grains (BSG) etc for mushroom cultivation and large amount of SMC is generated as waste into the environment. Gratitude is one of the non-governmental agencies that have been on the vanguard against losses in cassava, and this has led to use of cassava peels for edible mushroom cultivation. What happens to the cassava peel based SMC, thereafter mushroom production? The aim of Gratitude will be better achieved if and only if there are alternative uses of cassava peel SMC after flushing. In addition, scientific research should focus on extensive characterization of SMC to determine its physico-chemical, and microbiological compositions. The proper understanding of limiting nutrients and mineral elements composition of SMC is required to adjust the nutrient deficiencies of petroleum hydrocarbon polluted soil in order to drive bioremediation.

REFERENCES

Abak K, Celikel G, A. Gul A (1994). Comparison of some Turkish originated organic and inorganic substrates for tomato soilless culture. *Acta Horticulturae*, *366*:423-427.

Banjo NO, Abikoye ET, Kuboye AO (2004). Comparison of three nutrient supplements used as additive to sawdust during the cultivation of oyster mushroom (*Pleurotus pulmonarius), Niger. J. Microbiol. 18(1-2):* 335-338

Bogan BW, Schoenike B, Lamar RT, Cullen D (1996). Expression of lip genes during growth in soil and oxidation of anthracene by *Phanerochaete chysosporium*. *Applied Environmental Microbiology, 62:* 3697-3703.

Chiu SW, Ching ML, Fong KL, Moore D (1998). Spent oyster mushroom substrate performs better than many mushroom mycelia in removing the biocide pentachlorophenol. *Mycol. Res. 102*(12):1553-1562

Chukwura EI (2012). Microbial transformation of Biospheric wastes for economic growth. 21st Inaugural Lecture, Nnamdi Azikiwe University, Awka-Nigeria

Das N, Chandran P (2011). Microbial degradation of Petroleum hydrocarbon contaminants: An Overview. *Biotechnology Research International*, Hindawi Access to Research Publishers, Egypt, 1-13

van Faassen HG, Leggink G, van Faassen HG, and Meulenbroek JL (1992). Nitrogen cycling in high input versus reduced-input arable farming. *Agriculture and Environment in Eastern Europe and the Netherlands: proceeding*, 86-105.

Harmsen J, van den Toorn A, Heersche J, Riedstra D, van der Kooij A (1999). Use of residual substrate from mushroom farms to stimulate biodegradation of poorly available PAHs, In: Bioremediation Technologies for Polycyclic Aromatic Hydrocarbon Compounds Eds. Leeson, A., and Alleman, B.C. Columbus: Batelle Press: 87-92

Ijah UJJ, Antai SP (1988). Degradation and mineralization of crude oil by bacteria. *Niger. J. Biotechnol. 5*: 79-87.

Ijah UJJ (2002). Accelerated crude oil biodegradation in soil by inoculation with bacterial slurry. *J. Environ. Sci.* 6 *(1):* 38-47.

Ijah UJJ (2003). The potential use of chicken-drop microorganisms for oil spill remediation. *The Environmentalist. 23*: 89-95.

Jonathan SG, Olawuyi OJ, Babalola BJ (2014). Effect of arbuscular mycorrhizae fungus, spent mushroom compost, and poultry manure on drought and leaf curl resistance of Okro (*Abelmoschus esculentus*). *Niger. J. Mycol.* 6: 37-47

Kuforiji OO, Fasidi IO (2005). Factors affecting the yield of *Volvariella volvacea* in various agro-wates. *Niger. J. Microbiol. 19(1-2):* 550-555

Lau KL, Tsang YY, Chiu SW (2003). Use of spent mushroom compost to bioremediate PAH-contaminated samples. *Chemosphere, 52*: 1539-1546.

Lau KL, Tsang YY, Chiu SW (2003). Use of spent mushroom compost to bioremediate PAH-contaminated samples. *Chemosphere, 52*: 1539-1546.

Maher MJ, Smyth S, Dodd VA, McCabe T, Magette WL, Duggan J, Hennerty MJ (2000). Managing spent mushroom compost. Project 4444. Teagasc, Kinsealy Research Centre, Malahide Road, Dublin 17.

Ntougias SZ, Georgios I, Kavroulakis N, Ethaliotis C, Papadopoulou, KK (2004). Bacterial diversity in spent mushroom compost assessed by amplified rDNA restriction analysis and sequencing of cultivated isolates. *Systematic and Applied Microbiology, 27:* 746-754

Nwokoro CG, Okpokwasili GC (2003). Ex-situ Bioremediation of oil-contaminated sediment. *Niger. J. Microbiol.* 7(2): 105-109.

Odokuma LO (2012). The Genius in the microbe: An indispensable tool for the management of Xenobiotic mediated Environmental flux. 87th Inaugural Lecture, held at Ebitimi Banigo Hall, University of Port Harcourt, Nigeria

Okpokwasili GC, Okorie BB (1988). Biodegradation potentials of microorganisms isolated from engine lubricating oil. *Tribology International, 21 (4):* 215-220.

Orji FA, Ibiene AA, Dike EN (2012). Laboratory-scale Bioremediation of Petroleum hydrocarbon polluted mangrove swamps in the Niger Delta using cow dung, *Malaysian J. Microbiol. 8(4):*219-228

Orji FA, Ibiene AA, Okerentugba PO (2013). Bioremediation of Petroleum hydrocarbon polluted mangrove swamps in the Niger Delta using Nutrient formula from water hyacinth. *Am. J. Environ. Sci. 9(4):*348-366.

Ranganathan DS, Selvaseelan DA (1997). Effect of mushroom spent compost in combination with fertilizer application on nutrient uptake by potato in an Ultic Tropudalf. *J. Indian Society of Soil Sci. 45*(3):515-519.

Rathier TM (1982). Spent mushroom compost for greenhouse crops: *Chrysanthemum*, tomatoes and marigolds. *Connecticut Greenhouse Newsletter 109:*1-6.

Rinker DL, Alm G (1990). Cultivation of commercial mushrooms on spent compost. *In: Abstracts in Horticultual Research in Canada-1990. Canadian Horticultural Council Conference,* 27-28.

Semple KT, Reid BJ, Fermor TR (2001). Impacts of composting strategies on the treatment of soils contaminated with organic pollutants. *Environmental pollution, 112*:269-283.

Sihag S, Pathak H (2014). Factors affecting the rate of Biodegradation of Polyaromatic hydrocarbons, *Int. J. Pure and Appl. Biosci. 2(3)*:185-202.

Stewart DPC, Cameron KC, Cornforth IS (1998). Inorganic N release from spent mushroom compost under laboratory and field conditions. Soil Biology and Biochemistry, 30(13):1689-1699.

Stewart DPC, Cameron KC, Cornforth IS (1998). Inorganic N release from spent mushroom compost under laboratory and field conditions. Soil Biology and Biochemistry, 30(13):1689-1699.

Ururahy AFP, Marins MDM, Vital RL, Gabardo IT, Jr. Pereira N (1998). Effects of aeration on biodegradation of petroleum waste, *Rev. Microbiol. 29 (4)*: 254-258.

van Hamme JD, Singh A, Ward OP (2003). Recent advances in Petroleum Microbiology. *Microbial Molecular Biology Review, 67 (4):* 503.549.

Zhu X, Venosa AD, Suidan MT, Lee K (2001). Guidelines for the bioremediation of marine shorelines and freshwater wetlands. Report under a contract with office of Research and Development, US Environmental Protection Agency.