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; Okokwasili 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$_4$NO$_3$ 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 algal 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, piggy 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, SMG’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, capsicum, 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 disease 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 comports 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 byproduct 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. Hampsen 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 bagasse, 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
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 bioaugmentation. 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.

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