

Poultry Litter Biochar: An Approach towards Poultry Litter Management – A Review

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ABSTRACT

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Poultry litter is an abundantly available waste biomass, which is used for direct land applications since a long time. Direct use of poultry litter on agricultural lands causes many environmental concerns like, nutrient runoff, eutrophication, flava odor, greenhouse gas emission due to decaying and microbial contamination. To reduce the environmental concerns, thermochemical conversion of poultry litter into biochar can be an economically sustainable approach. Poultry litter converted into biochar with pyrolysis process also produces additional value products, syngas and bio-oil. Use of poultry litter biochar can improve the soil fertility, water holding capacity and nutrient retention power. Poultry litter biochar also has capacity for remediation of organic and inorganic contaminants from soil and water.

Introduction

Biochar is a solid material obtained from the carbonization of biomass and may be added to soils with the intention to improve soil functions and to reduce greenhouse gas (GHG) emissions from the decomposition of biomass. Biochar is produced from intentionally heating a biomass feedstock via pyrolysis or gasification, typically in an oxygen limited environment, with the goal of creating a stable, carbon-rich product resistant to degradation in soils (IBI, 2012).

The characteristics of biochar, depends on how it is produced, and the raw material that is used (Kloss *et al.*, 2012). Various residual and waste products can be converted into

biochar including forestry, crop waste, food industry residual biomass and animal manures (Aditya Parmar, 2014). Temperature, residence time, rate of temperature increase, pre- and post-processing of feedstock and biochar, are the specific production parameters which affect the quality of the biochar, and can impact the nutrient availability to crops, the physical and chemical properties of the biochar, and the amount of stable carbon sequestered (Sun *et al.*, 2014). The choice of raw material significantly impacts the end product and its uses. More than 50% of the organic matter's carbon may be restored in a stable form as biochar, but it highly depends on the

production parameters. When the biochar is used as a soil amendment, a significant proportion of the recalcitrant biochar carbon can resist degradation for hundreds to even thousands of years, thus creating stable carbon pools (IBI, 2012). Biochar generally increases nutrient availability, soil organic matter, water retention, microbial activity and crop yield in soil while it decreases greenhouse gas emissions, need of fertilizers, nutrient leaching and erosion (Mohan *et al.*, 2014). In addition, during the production process of biochar bio-oil and process heat is created which have many alternative uses.

The waste generated in agriculture, food industries and forestry either processed or unprocessed are the main sources of feedstock for biochar production. Wood chips and pellets, tree cuttings, bagasse, distiller grains, press cakes from oil and juice industry, rice husk and crop residues are the main (Aditya Parmar, 2014). At present many other potential biomass sources other than lignocellulosic matter such as sewage sludge, dairy manure, poultry litter, human and animal waste such as excrements, bones, feathers are extensively studied and recognized as potential raw material for low cost adsorbent preparation.

Poultry litter is one of the most potential and ample available biomass which can be exploited as raw material for biochar production. Direct use of poultry litter with or as compost in soil is a long time practice but several studies (Crippen *et al.*, 2016; Uchimiya *et al.*, 2010a), shows the concerns of mineral runoff and other environmental threats associated with direct use of poultry litter. Environmental contamination may happen when poultry wastes are applied in excess for crop utilization potential in land, or is done under poor management conditions which causes nutrient loss from environmental factors such as soil erosion or surface runoff during rainfall, and other

parameters of concern are N, P, and certain metals (Cu and Zn in particular), as well as pathogenic microorganisms that may be contained in poultry waste (Williams *et al.*, 1999). Thermochemical conversion of poultry litter into biochar (a more stable form) can be an approach to lower the burden of environmental contamination associated with poultry litter.

Poultry litter

Poultry Litter is a mixture of poultry excreta, feathers, spilled feed and material used as bedding to absorb liquid fractions of excreta, which typically include wood chips, sawdust, wheat straw, peanut hulls, and rice hulls, in poultry operations at large scales. Poultry litter includes litter from meat chickens (broilers), egg laying chickens (layers) which are kept under barn conditions, turkeys, ducks and quails. According to a published report nearly 6.25 million tonnes of poultry manure is produced in India annually (Prabhu, 2009) (Table 2).

Composition of poultry litter

According to analysis conducted by Weiping Song (2012), poultry litter contains magnesium (Mg), calcium (Ca), sulphur (S), nitrogen (N), phosphorus (P), iron (Fe), manganese (Mn), potassium (K) (Song and Guo, 2012). All these are the elements which are necessary for plant growth. Thought the nutrient content may vary considerably depending upon the conditions such as feed, bedding material, handling conditions etc.

Poultry litter management

In India, poultry production has been rising at the rate of 8 percent per annum, with an annual turnover of US\$ 7 500 million (Rajesh Mehta). This massive poultry farming produces tons of wastage in terms of litter/manure which has been used for composting,

pelletizing, and converting to electricity, steam and biogas over the years. The most common use of the poultry litter is land application (Dunkley, 2011). It is also used as fish feed and livestock feed (M. Mohamed Amanullah, 2010). Poultry litter has been used as either the sole fertilizer or in combination with traditional inorganic fertilizers. Due to the concerns over N and P losses to surface waters after the land application of poultry litter, there's a need for regulation of poultry operations.

Challenges in poultry litter management

Despite of having several ways for using poultry litter, still it has some limiting factors which include handing, loss of nutrients, GHG emission during land application and long term storage, surface water contamination, emission of ammonia, nitrate emission, runoff of dissolved phosphate, immobilization, nutrient loss during long term storage due to volatilization and microbial contamination. Since poultry litter contain manure also, which has high moisture content due to which it cannot be applied to crops directly due to caustic effect on foliage (M. Mohamed Amanullah, 2010). Kithome *et al.*, (1999), also reported that storage and direct land application of untreated poultry litter has many disadvantages like, odors, fly breeding and pathogen growth (Kithome, 1999). There is an immediate need for the additional strategies to effectively deal with this waste product. Converting the waste biomass into biochar can be a way better solution and it will help in carbon sequestration too. Poultry litter biochar offers a number of unique benefits in terms of field applications as well as in environmental pollution remediation.

Poultry litter biochar

Poultry Litter (PL) biochar is made from chicken manure and the bedding used in poultry operations like wood shavings, saw

dust, straw or other organic materials—as well as feathers, feed spillage and mortalities (IBI, 2012).

Poultry litter biochar production techniques

Poultry litter biochar can be produced by thermal conversion techniques, which include slow pyrolysis, fast pyrolysis, hydrothermal carbonization, torrefication and gasification. Pyrolysis of the animal manure waste is the most frequently used technique to obtain the higher char yield. Pyrolysis process is highly dependent on heating rate, pressure, residence time, peak temperature, heat transfer rate, vapor-solid interactions (Judy A Libra, 2011).

Pyrolysis is the thermochemical decomposition of biomass in the oxygen free environment and is complex process, which can be categorized in three main stages (Demirbas, 2004)

Dehydration: Biomass = water + dry organic mass

Initial charring: Dry organic mass = tarry vapors + primary char

Final Charring: Primary char = tarry vapors + secondary char

The tarry vapor is a mixture of heavier hydrocarbons, water vapors and non-condensable gases including CO₂, CO, H₂, CH₄, C₂H₂ and C₃H₆ (Mingxin Guo, 2012).

Pyrolysis process is of two types slow and fast and can be performed into muffle furnace, bed reactors, kiln furnace, tube furnace with N₂ flow to create oxygen free environment. Fast pyrolysis is characterized by high heating rates and short vapor residence times, and a moderate (in pyrolysis terms) temperature of around 500°C is usually used (Brownsort, 2009).

Table.1 Thermochemical process, resident time and primary product (Mohan *et al.*, 2014)

Thermochemical process	Temp. range	Heating Rate	Pressure	Residence Time	Desired Product
Slow Pyrolysis	350-800	Slow (<10°C/min)	Atmospheric	Hours-seconds	Biochar
Torrefaction	200-300	Slow (<10°C/min)	Atmospheric	Minutes-hours-	Stabilized Friable biomass
Fast pyrolysis	400-600	Very fast (~1000°C/s)	Vacuum-atmospheric	seconds	Biooil
Gasification	700-1500	Moderate to very fast	Atmospheric-elevated	Seconds-minutes	Syngas
Hydrothermal carbonization	175-250	slow	-	Hours	Hydrochar

Slow pyrolysis is characterized by slower heating rates, long solid and vapor residence times and usually a lower temperature than fast pyrolysis, typically 400°C. Char is the target product often, but always there will be liquid and gas product formation occur, although these are not always recovered (Brownsort, 2009).

Characteristics of poultry litter biochar

Soil with high cation exchange capacity will be able to retain cationic nutrient in the root zone and prevent the nutrient from deep leaching and it is evidenced that soil amendment with PL biochar have improved soil nutrient retention (Mingxin Guo, 2012). Cely *et al.*, (2015) studied different kind of manure derived biochars and reported that chicken manure pyrolyzed at 300°C having the high cation exchange capacity and elevated stability, and potentially this type of biochar can be used in nutrient poor soils to increase the crop yields (Celya, 2015).

Similar results were also reported by Gaskin *et al.*, (2008), which showed a significantly higher CEC in low temperature (400°C) poultry litter biochar than in peanut hull and pine chip biochars at the same temperature (Gaskin, 2008).

A study by Das *et.al.*, (2008) highlighted PL biochar with an ash content of 26% versus ash content of approx 2% from pine chip derived biochar (Das *et al.*, 2008). Isabel M. Lima *et al.*, (2015), studied wood chips biochar and chicken litter biochar for heavy metal adsorption and reported higher ash content in chicken litter (11.6%) and chicken litter derived biochar (13.5 and 40.1%) then wood chips raw (3.08%) and derived biochar (2.6 and 5.6%) at different pyrolysis temperatures (Lima *et al.*, 2015). Higher ash content is particularly useful for low pH soils as a liming agent.

Apparently, poultry litter biochar contain lower carbon content then plant material derived biochars, and this is confirmed by Das *et al.*, (2008) and Isabel M. Lima *et al.*, (2015).

Poultry litter biochar have higher electrical conductivity than biochars derived from wood, corn stover, grasses and tree leaves (Mingxin Guo, 2012). Study conducted by J.M. Novak *et al.*, (2009), showed that pH of poultry litter biochar was higher than the pH of peanut hulls, pecan shells, switch grass and related it with the presence of Ca and Mg in the poultry manure, probably due to the concentration of these nutrients through the

pyrolytic process (Jeffrey M. Novak *et al.*, 2009).

Poultry litter biochars have higher nutrient contents, and being a recalcitrant material than raw poultry litter, it is safer for land applications. Gaskin *et al.* (2008) reported that the amount of Nitrogen (N) conserved after pyrolysis is lower for poultry litter versus other feed stocks, and they concluded that high initial nutrient content of poultry litter biochar ensures the resultant amount is still significantly higher overall (Gaskin, 2008). Similar results were reported by Mingxin Guo *et al.* (2012), they found incensement of nutrient content in pyrolytic PL biochar than raw poultry litter except nitrogen (N) and found N loss higher at higher pyrolytic temperature. Further they suggested that animal manure biochar production should be at lower temperature to conserve the nitrogen (Mingxin Guo, 2012).

Poultry litter biochar: Benefits

It will reduce the cost to dispose of poultry litter, especially in the areas of highly concentrated poultry operations, where nutrient overload is causing environmental hazards (Phil Covell, 2011).

By the production of biochar from poultry litter the storage of the material can be easy and decaying of the biomass can be prevented and it reduces the liability related to pollution from poultry litter for a relatively longer period. Converting poultry litter into biochar can significantly reduce in coop odour. Poultry litter contain phosphate and nitrogen (ammonium ions), which may cause eutrophication but converting PL into PL biochar reduce the risk.

Poultry litter biochar is recalcitrant material and can therefore resides as a significant proportion of the soil carbon fraction aided by its potential for a prolonged life within the soil (Revell, 2011).

As poultry litter biochar is a rich source of macro and micro nutrients which are necessary for the plant growth, it will reduce the cost and usage of synthetic fertilizers for crop production and is much lighter, which make it easier to transport than the raw litter (Revell *et al.*, 2012).

Use of poultry litter biochar reduces the nutrient runoff if applied directly to soil. Steiner *et al.*, (2010), claimed that when mixed with compost prior to field application poultry litter biochar, can help retain nutrients in the soil which might otherwise be lost (Steiner *et al.*, 2010).

The excess heat generated from PL biochar production process (pyrolysis or gasification) may reduce the heating fuel requirements and it may be used directly onsite in different production and processing facilities (IBI, 2012). It will be an approach for combine heat and power (CHP).

Ro *et al.*, (2010) used a commercial pilot-scale pyrolysis reactor system to produce combustible gas and biochar from different manures and found that approximately 50% of the feedstock energy was retained in biochar and 25% in produced gases. He further suggested copyrolysis of wet animal wastes with the addition of dried and energy dense feedstock such as waste plastic pellets, to produce valuable biochar and extra power simultaneously (Ro, 2010). Potential for added income from selling biochar to a local market or a distributor.

Uses of poultry litter biochar

As a soil amendment

Soil amendment with biochar derived from different agricultural waste is a long time practice. Ogawa *et al.*, (1994), described that early Japanese farmers using unique manure called 'haigoe' prepared by adding human

waste to rice husk biochar and leaving it for some time before planting crops. The discovery of Terra Preta (in Portuguese meaning —dark earth) soils in the central Amazon Basin implicates that biochar may be an ideal soil amendment for fertility improvement (Neves, 2001). Biochar may retain $\text{NH}_4\text{-N}$. Steiner *et al.*, (2008) reported increased recovery of ^{15}N -labeled N fertilizer on charcoal-amended soil in comparison to soil without charcoal (Steiner, 2008).

Higher soil enzymatic activity is a positive indicator of higher soil fertility and good quality, changes in enzymatic activity indicates about the changes taking place in the soil environment (Ouyang, 2014). In general, a positive effect of biochar amendment is observed in most studies which focus on soil biological properties, including enzymatic activity (Mierzwa-Hersztek *et al.*, 2016).

Chan *et al.*, (2008), produced two biochars from poultry litter under different conditions and tested them in a pot trial for assessing the yield of radish (*Raphanus sativus* var. Long Scarlet). They applied four ratios of biochar, with and without nitrogen application and found detectable increases in dry matter yield of radish in biochars without N fertilizer even at lower application rate of biochar. The yield increase (%), compared with the unamended control rose from 42% at 10 t/ha to 96% at 50 t/ha of biochar application (Chan, 2008). Similar findings were also reported by many other investigators.

Coomer *et al.*, (2012) studied poultry litter biochar effect on early season cotton growth and indicated that the higher level PL biochar with fertilizer showed significant increases in plant height, dry weight and leaf, area over controls, and reported highest level of biochar (3,000 kg biochar/ha) with additional urea fertilizer (50 lb. N/acre) provided the best growth response (Coomer, 2012).

Increased sorption capacity of the soil was reported by Paz-Ferreiro *et al.*, (2012) after amendment with biochar and mineral components into the soil (Paz-Ferreiro *et al.*, 2012).

Ameloot *et al.*, (2013b) showed that the type of biochar alone has a significant effect on soil enzymatic activity, they proved that poultry litter biochar produced at 400°C and amended to soil caused a significant increase in the activity of dehydrogenases enzyme, whereas the same biochar obtained at 500°C reduced the activity of these enzymes over two times compared to the control (Ameloot, 2013b.).

Mierzwa-Hersztek *et al.*, (2016), observed a positive correlation between the poultry litter biochar dose and activity of the soil enzymes, with an increase of 3% and 32% in the activity of dehydrogenase and ureases in the soil amended with a higher dose of PL biochar. They reported a dose of 2.25 or 5 t DM ha^{-1} of poultry litter biochar to soil, reduced the soil acidity and increased the content of nitrogen and organic carbon when compared to the control (Mierzwa-Hersztek *et al.*, 2016).

Poultry litter biochar have many valuable effects on soil properties, including improvement in the water holding capacity (WHC), cation exchange capacity (CEC), bulk density (BD), and nutrient status and these properties should be considered during formation an appropriate rate of application (Revell *et al.*, 2012).

Use of Poultry litter biochar in poultry farming: A new insight

Gerlach and Schmidt (2014), pointed out the use of biochar as feed additive and as litter amendment. With a very high water holding capacity biochar can absorb up to 5 times its own weight of water and can adsorbs very

efficiently both organic molecules such as amino acids, fatty acids, proteins and urea and also mineral compounds such as ammonium, ammonia and nitrate (Gerlach, 2014).

Biochar can lock the moisture and organic and inorganic nitrogen compounds in, if used in litter, which decreases the risk of footpad diseases. High adsorption capacity of biochar makes it possible to reduce the use of lime in the litter, thereby reducing the pH of the litter and manure, which in turn reduces ammonia emissions (Gerlach, 2014).

If poultry litter is converted to biochar onsite it will be useful for the above mentioned areas and reduce the burden of transportation and environmental harm.

As a plant nutritional value additive

Low temperature poultry litter biochar is rich in plant macro and micro nutrients like Mg, Ca, Fe, K, P, N, S, and due to its relatively higher cation exchange capacity biochar is anticipated to retain more nutrients in soil and decrease nutrient leaching (Mingxin Guo, 2012). There are studies which prove soil fertility improvement after addition of biochar.

Study by A. Inal *et al.*, (2015), evaluated the effect of processed poultry manure and poultry litter biochar at different concentrations on soil chemical properties of a calcareous soil and growth of bean (*Phaseolus vulgaris*) and maize (*Zea mays*) plants. They reported increase of plant growth and plant nutrients like N, P, Mn, Zn, Cu concentrations in soil and also reported the increased concentration of exchangeable cations (K, Ca, Mg) in soil (Inal, 2015). These results revealed that poultry manure biochar can be used effectively for agricultural purpose.

Greenhouse plotting experiments carried out by Mingxin Guo *et al.*, (2012) showed that chemical fertilizer and poultry litter biochar amendment soil plants had stimulated plant growth (Mingxin Guo, 2012).

For environmental management

From a long time carbonaceous material have been used as sorbents for organic and inorganic contaminants in soil and water (Ahmad *et al.*, 2012). Anthropogenic activities, such as smelting, mining, use of pesticides, fertilizers, sludge, dyes, antibiotics are responsible for the input of heavy metals and organic contaminants into the soil and water at a higher level, biochar has the ability to absorb organic contaminants, immobilized heavy metals and nutrient from soil (Mingxin Guo, 2012). Biochars have a non-carbonized fraction which may interact with soil contaminants and oxygen containing carboxylic, hydroxyl and phenolic surface functional groups in biochar could effectively bind soil contaminants (Ahmad *et al.*, 2014; Uchimiya *et al.*, 2010c).

Cao *et al.*, (2009) investigated the sorption capacities of dairy manures biochar produced at low temperatures (200°C and 350°C) and found that the biochar was six times more effective in removing lead (Pb) from wastewater than a commercial activated carbon (Cao and 2009).

Uchimiya *et al.*, (2011) investigated alkaline soils amended with broiler litter-derived biochars and steam-activated carbons for the retention of Pb (II), Cd (II), and Ni (II). Majority of Pb (II) was retained, more than half of added Cd (II) and Ni (II) remained soluble, in soil without biochar and a proportional decrease in soluble Cd (II) and Ni (II) concentrations was observed with increase in the dose of broiler litter biochar from 5 to 20%, which proves enhanced

immobilization of heavy metals with the addition of broiler litter biochar in soil (Uchimiya *et al.*, 2010b). Comis (2010) reported that PL biochar binds certain toxic chemicals such as copper, cadmium and zinc from water [(Comis, 2010 (November/December)].

Experiments done by Guo *et al.*, (2010), revealed rapid and significantly higher adsorption affinity of poultry litter-based activated carbon than commercial activated carbons derived from bituminous coal and coconut shell for heavy metals and also reported that releases of nutrients and metal ions from litter-derived carbon did not pose secondary water contamination risks (Guo, 2010).

Isabel M. Lima *et al.*, (2015) used three different activation protocols (acid, base and steam) for pine wood and chicken litter biochars to obtain higher surface area to increase Cu ion adsorption and reported changes in various chemical properties due to biochar activation, which led to significant changes in surface functionality resulting increased copper ion adsorption (Lima *et al.*, 2015).

Tests done by the USDA Agricultural Research Service (ARS) and Western Kentucky University demonstrated that a combination of PL biochar and poultry litter were effective in reducing ammonia emissions by more than 90%—highlighting that biochar could be used to reduce ammonia emissions in livestock production facilities (Lovanh, 2010). These results show that the biochars have potential to minimize nutrient leaching in agricultural fields.

Cu²⁺, Cd²⁺ and Zn²⁺ adsorption by broiler litter bio-chars (activated) made from fast pyrolysis was reported 95%, 83%, and 90%, respectively and increase in surface area was

also reported due to activation process (Lima *et al.*, 2010).

To promote utilization of poultry litter as a source material for manufacturing low-cost activated carbon (AC), Guo and Song (2011), prepared activated carbon from pelletized broiler litter and used it in wastewater treatment for benzene. Although the sorption capacity of obtained biochar was found lower than that of top-class commercial AC for benzene, but their findings suggested poultry litter as a cost-effective feedstock for low-cost AC production which can be used for pre-treatment of wastewater contaminated by organic pollutants and heavy metals (Guo, 2011).

Lima *et al.* (2005) compared poultry manure-based carbons with two commercial carbons and three traditional precursors, coal, coconut and wood carbons for Ni, Zn, Cd and Cu adsorption from solutions containing individual ions or the four metal ions present together and reported outperformance for poultry manure based biochar.

The activation strategy, longer activation times and higher water flow rates, are the influencing factors to determine the ability of carbon to absorb the metal, in the presence of a single metal solution (Lima, 2005).

Granular activated carbon was made from broiler litter and cake, which was further examined for Copper remediation and comparative studies with commercial carbons revealed the broiler cake-based carbon as having the highest copper ion efficiency (Lima & Marshall, 2005).

Other applications of poultry litter biochar

As a value-added strategy for recycling the organic waste, poultry litter can be utilized as a precursor material to synthesize activated

carbon for treating heavy metal-contaminated water (Uchimiya *et al.*, 2010b). Poultry litter biochar can be an attractive solution for storm water treatment as it can bind with toxic metals and having the good water retention potential, this approach can improve water quality and ease the burden on public water treatment systems (IBI, 2012).

Generally, plant based biochars are low in nutrient contents due to their insufficient ash, nitrogen, phosphorous and potassium contents, which is a disadvantages compared to traditional fertilizers for supplying crop nutrients Poultry litter biochar is high in ash content, which may have positive effects on soil agricultural and biochemical properties (Celya, 2015).

Liang *et al.*, (2014), also observed an increment of the drought resistance of both the bacterial and fungal networks on an Acrisol amended with poultry litter biochar (Liang *et al.*, 2014).

Poultry production is growing day by day and so the waste generated. Production of biochar from poultry litter is a promising, practically effective and environmentally sustainable approach to manage the organic waste. Affinity of poultry litter biochar to bind with metals and minerals make it useful for soil and water remediation. In many ways pyrolysed poultry litter is proven to be more effective to use rather poultry litter. Although literature is available for PL and PL biochar still there is scope for future research in the field of energy production, poultry litter and derived biochar induced toxicity in soil, amount of biochar to be used for different kinds of soils for amendments. It is important to understand how biochar made from poultry litter affects soil properties and crop production. Besides it negative effects of poultry litter biochar should not be neglected.

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