Soil Restoration using Biochar and Brown Coal Waste (BCW)

Introduction

Traditional organic waste materials used to restore soil quality (SQ) vary in efficiency as mineral fertilisers (Chen et al., 2018). Some organic alternatives not used as fertilisers are used to increase C sequestration to improve greenhouse gas (GHG) emissions, work as soil conditioners to improve such qualities as water-holding capacity and microbial biomass and reduce pollutant bioavailability (Onagwu, 2019).
Although there are many long-term studies investigating the effects of traditional manures and fertilisers on SQ (Edmeades, 2003), studies show that their excessive use also indicates a ***risk*** of nitrogen leaching and phosphorous runoff (Horta et al., 2018) as well as being sources of GHG emissions (Peterson, 2018) and retaining significant levels of pathogens (Nolan et al., 2018).

Biochar and brown coal waste (BCW) offer higher soil stability and are emerging as possible alternative materials to use for SQ improvement (Amoah-Antwi et al., 2020).

Soil management with biochar and BCW

Biochar is a high carbon residue often produced by pyrolysis, thermal decomposition in the absence of oxygen (Peng et al., 2018). Methods of production of biochar feedstock include pyrolysis at varying degrees of temperature. The resulting material applied to soil positively affects, among other actions, liming capacity (ability to reduce soil's acidity), pH, cation exchange capacity (CEC), carbon (C) content (Yuan et al., 2011) and C sequestration reducing the potential increase in GHGs (Simo et al., 2019).

The diverse forms of biochar produced, owing to the production method and applied temperatures, require a specific choice of type and dosage of a form of biochar applicable to any particular use (O'Connor et al., 2018).

The downsides to biochar use are high production costs (Vochoska et al., 2016) and availability (Jones et al., 2012).

BCW or lignite is less economically mined coal than high-rank coal (Kashiwagi et al.,2015). Its properties make BCW favourable for adsorbing environmental pollutants, but its high humid acid content enhances nutrient storage when added to soils (Anemana et al, 2019).

Although a relatively cheaper resource than biochar, its conversion to an appropriate soil addition can also ***risk*** the production of organic and inorganic pollutants such as polychlorinated dibenzodioxins (PCDDs) and heavy metals (HMs) (Kopinke et al., 1995).

However, as coal use for energy generation has declined, more interest in its derivatives is being considered for agricultural uses.

Evaluating the effects of biochar and BCW on SQ

Soil is considered an ecosystem on its own and not just a part of an ecosystem (Laishram et al., 2012). SQ assessments of existing soils involve evaluating fertility and productivity while integrating multiple ecosystem functions (Bunemann et al., 2018). This uses a set of quality indicators (QIs) measuring dynamic soil properties. According to (Vogel et al., 2019), these properties are considered to be soil organic matter (SOM), soil water capacity, aeration and pH rather than the actual concentration of nutrients in the solution.

The QIs represent the physical, chemical and biological categories of these soil properties and can be used by farm managers to implement change (Amoah-Antwi et al., 2020).

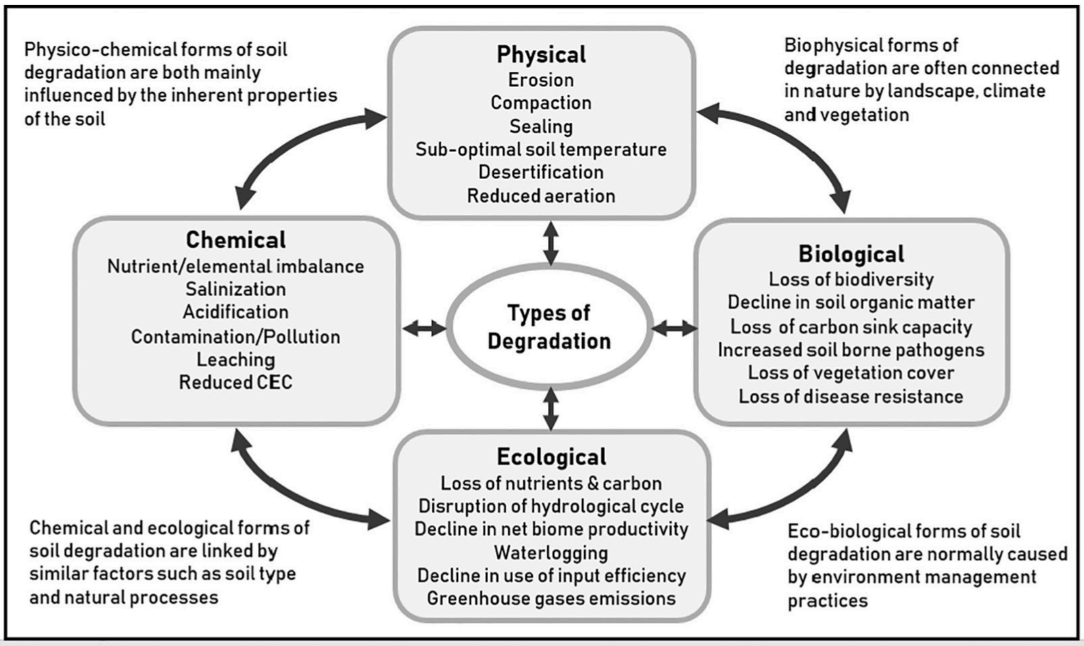

Fig. 1. Conceptual presentation of the types of soil degradation: chemical, physical, biological and ecological – with the various forms in which degradation occurs. Figure shows how the different types of soil degradation are interlinked. Adapted and modified from Lal, 2015 and Gomiero, 2016.

The figure above, taken from (Amoah-Antwi et al., 2020), represents the three categories of soil properties, how they are interlinked, and how they may affect each other and the entire soil ecosystem through forms of degradation. However, it also indicates by visual representation the elements of consideration for the derivation of QIs for each category of soil property.

Physical QIs are good indicators of water storage, gaseous exchange, depth of root penetration and erosion (Pandey et al., 2018). *BCW* has a high moisture content and levels of organic compounds, making it of interest in its use as a soil amendment (Krol-Domańska and Smolinska, 2012).

Changes to CEC, pH and nutrient availability indicate chemical QIs. Biochar can induce changes in these areas (Hailegnaw et al., 2019) and can also immobilise and sequester soil pollutants (Ogbonnaya and Semple, 2013).

Biological QIs are a crucial index of productive soils (Biswas and Naher, 2019). *Biochar and BCW can promote* the relative abundance of arbuscular mycorrhizal fungi (AMF) (Wang et al., 2019), ultimately modifying residual soil C and enhancing microbial activity (Thies et al., 2015). AMF agglomeration also increases the hydrological properties of the soil, and they are essential for establishing and maintaining arable crops (Vasconcellos et al., 2013).

Summary

Biochar and BCW are considered a possible substitute and/or supplement to the traditional use of organic matter to revitalise soil conditions; the relatively higher cost of production and availability of biochar and treatment necessary for BCW appear to retard greater use.

Even so, soil management using these materials offers, among other items, better liming capacity (ability to reduce soil's acidity), pH, cation exchange capacity (CEC), carbon (C) content and C sequestration. Evaluation of these improvements is made by way of quality indicators for the three major categories of soil quality.

Further investment and research regarding these materials are implied.

Conclusion

Soil applications of carbonised waste organic materials, such as biochar and BCW, hold substantial promise for the restoration of SQ. Generally, the addition of high C sources of organic matter to soils does not necessarily correlate with increased soil fertility. Still, the associated increased C sequestration is linked to improvement in other soil conditions (e.g. enhanced soil pH and microbial activity), which increases the availability of nutrients. Biochar can be used to amend polluted soils and promote plant-available nutrients.

There is a need, through coordinated research, to increase confidence in the performance parameters of the different types of biochar and BCW. The costs of producing biochar and processing the relatively cheaper BCW pose legitimate questions about the economic feasibility of these materials for large-scale applications. A way forward would be the continued investment in low-cost technologies to reduce the production costs of biochar and investigation through further research into the potential of BCW derivatives.

References

Amoah-Antwi, Collins., Kwiatkowska-Malina, Jolanta., Thornton, S.F., Fenton, O., Malina, G, Szara, E., 2020, 'Restoration of soil quality using biochar and brown coal waste: A review', To be published in Science of The Total Environment, vol. 722, Issue: Number 1, pp 2, 5 & 11 [Preprint] viewed 11 April 2020 https://www.sciencedirect.com/science/article/pii/S0048969720313644

Anemana, T., Óvári, M., Szegedi, A., Uzinger, N., Rékási, M., Tatár, E., Yao, J., Streli, C., Záray, G., Mihucz, V.G., 2019, 'Optimization of lignite particle size for stabilization of trivalent chromium in soils', *Soil and Sediment Contamination: An International Journal,* vol 29, no. 3, pp. 272-291.

Biswas, J.G., Naher, U.A., 2019, 'Soil nutrient stress and rice production in Bangladesh', in J. K. Biswas, M. Fujita, M. Hasanuzzaman, K. Nahar (Eds.) *Advances in Rice Research for Abiotic Stress Tolerance.* Woodhead Publishing, pp. 431–445.

Bunemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J.W., Brussaard, L., 2018, Soil quality – a critical review, *Soil Biology & Biochemistry,* vol 120, pp.105–125.

Chen, Y., Camps-Arbestain, M., Shen, Q., Singh, B., Cayuela, M.L., 2018. The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review. *Nutrient Cycling in Agroecosystems*, vol.111, pp.103–125.

Edmeades, D.C., 2003. 'The long-term effects of manures and fertilisers on soil productivity and quality: a review', *Nutrient Cycling in Agroecosystems,* vol.66, pp.165–180.

Hailegnaw, N.S., Mercl, F., Pracke, K., Száková, J., Tlustoš, P., 2019. 'Mutual relationships of biochar and soil pH, CEC, and exchangeable base cations in a model laboratory experiment.' *Journal of Soils & Sediments*, vol.19, no. 5, pp. 2405–2416.

Horta, C., Roboredo, M., Carneiro, J.P., Duarte, A. C., Torrent, J., Sharpley, A., 2018, 'Organic amendments as a source of phosphorus: agronomic and environmental impact of different animal manures applied to an acid soil', *Archives of Agronomy & Soil Science,* vol. 64, no. 2, pp. 257–271.

Jones, D.L., Rousk, J., Edwards-Jones, G., DeLuca, T.H., Murphy, D.V., 2012. 'Biochar- mediated changes in soil quality and plant growth in a three-year field trial.' *Soil Biology & Biochemistry,* vol. 45, pp. 113–124. https://doi.org/10.1016/j.soilbio.2011.10.012

Kashiwagi, T., Ishino, H., Takagi, T., Hirose, K., 2015, 'Mine mouth power generation system based on upgraded brown coal (UBC.)', *R and D: Research and Development Kobe Steel Engineering Reports,* vol. 64, no. 1, pp. 28-32.

Kopinke, F.-., Pörschmann, J., Remmler, M, 1995,'Sorption behavior of anthropogenic humic matter', *Naturwissenschaften* vol. 82, pp**.** 28–30. https://doi.org/10.1007/BF01167866

Krol-Domańska, K., Smolinska, B., 2012,' Advantages of lignite addition in the purification process of soil polluted by heavy metals', *Biotechnology and Food Sciences,* vol. 76, no. 1, pp. 51–58.

Laishram, J., Saxena, K.G., Maikhuri, R.K., Rao, K.S., 2012, 'Soil quality and soil health: a review', *International Journal of Ecology and Environmental Sciences*, vol. 38, no. 1, pp. 19–37.

Nolan, S., Waters, N.R., Brennan, F., Auer, A., Fenton, O., Richards, K., Bolton, J.D., Pritchard, L., O'Flaherty, V., Abram, F., 2018, 'Toward assessing farm-based anaerobic digestate public health risks: comparative investigation with slurry, the effect of pasteurization treatments, and use of miniature bioreactors as proxies for pathogen spiking trials', *Frontiers in Sustainable Food Systems.* https://doi.org/10.3389/fsufs.2018.00041.

O’Connor, D., Peng, T., Zhang, J., Tsang, D.C.W., Alessi, D.S., Shen, Z., Bolan, N.S., Hou, D., 2018, ‘Biochar application for the remediation of heavy metal polluted land: a review of in situ field trials’, *The Science of the Total Environment*, vol. 619–620, pp. 815–826. https://doi.org/10.1016/j.scitotenv.2017.11.132

Ogbonnaya, U., Semple, K.T., 2013,’ Impact of biochar on organic contaminants in soil: a tool for mitigating risk?’, *Agronomy*, vol. 3, pp. 349–375. https://doi.org/10.3390/agronomy3020349.

Onagwu, B.O., 2019, ‘Organic amendments applied to a degraded soil: short term effects on soil quality indicators, *African Journal of Agricultural Research*, vol. 14, no. 4, pp. 218–225. https://doi.org/ 10.5897/AJAR2018.13457.

Pandey, V., Gautam, P., Singh, A.P., 2018, ‘Assessment of physical properties of soil under different land-use systems in a Mollisol’, *Journal of Pharmacognosy and Phytochemistry,* vol. 7, no.6, pp. 2645–2648.

Peng, X., Deng, Y., Peng, Y., Kai, Y., 2018, ‘Effects of biochar addition on toxic element concentrations in plants: a meta-analysis, *The Science of the Total Environment*, vol. 616–617, pp. 970–977. https:// doi.org/10.1016/j.scitotenv.2017.10.222.

Petersen, S.O., 2018, ‘Greenhouse gas emissions from liquid dairy manure: prediction and mitigation’, *Journal of Dairy Science*, vol. 101, no. 7, pp. 6642–6654. https://doi.org/10.3168/jds.2017-13301.

Simo, I.J., Schulte, R., O’Sullivan, L., Creamer, R., 2019,’ Digging deeper: understanding the contribution of subsoil carbon for climate mitigation, a case study of Ireland’, *Environmental Science & Policy*, vol. 98, pp. 61–69. https://doi.org/10.1016/j.envsci.2019.05.004.

Thies, J.E., Rillig, M.C., Graber, E.R., 2015, ‘Biochar effects on the abundance, activity and diversity of the soil biota’ In Lehmann, J., Joseph, S. (Eds.), *Biochar for Environmental Management: Science and Technology and Implementation*, Earthscan Books Ltd, London, pp. 327–389.

Vasconcellos, R.L.F., Bonfim, J.A., Baretta, D., Cardoso, E.J.B.N., 2013, ‘Arbuscular mycorrhizal fungi and glomalin-related soil protein as potential indicators of soil quality in a recuperation gradient of the Atlantic Forest in Brazil’, *Land Degradation & Development,* vol. 27, no.2, pp. 325–334. https://doi.org/10.1002/ldr.2228.

Vochozka, M., Maroušková, A., Váchal, J., Straková, J., 2016, ‘Biochar pricing hampers biochar farming, Clean Technologies and Environmental Policy, vol. 18, pp. 1225–1231. https://doi.org/10.1007/ s10098-016-1113-3.

Vogel, H.-J., Eberhardt, E., Franko, U., Lang, B., Ließ, M., Weller, U., Wiesmeier, M., Wollschläger, U., 2019,’ Quantitative evaluation of soil functions: potential and state’, *Frontiers in Environmental Science,* p. 10. https://doi.org/10.3389/fenvs.2019.00164.

Wang, J., Wang, G.G., Zhang, B., Yuann, Z., Fu, Z., Yuan, Y., Zhu, L., Zhang, J., 2019, ‘Arbuscular mycorrhizal fungi associated with tree species in a planted forest of Eastern China’, *Forests, vol.* 10, p.424. https://doi.org/10.3390/f10050424.

Yuan, J.H., Xu, R.K., 2011, ‘The amelioration effects of low-temperature biochar generated from nine crop residues on an acidic Ultisol’, Soil Use and Management, vol. 27, no. 1, pp.110–115. https://doi.org/10.1111/j.1475-2743.2010.00317.x