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Review

Harmonising conflicts between science, regulation, perception and environmental impact: The case of soil conditioners from bioenergy

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ABSTRACT

As the global population is expected to reach 9 billion by 2050, humanity needs to balance an ever increasing demand for food, energy and natural resources, with sustainable management of ecosystems and the vital services that they provide. The intensification of agriculture, including the use of fertilisers from finite sources, has resulted in extensive soil degradation, which has increased food production costs and CO_2 emissions, threatening food security. The Bioenergy sector has significant potential to contribute to the formation of a circular economy. This paper presents the scientific, regulatory and socioeconomic barriers to the use of the nutrient waste streams from biomass thermal conversion (ash) and anaerobic digestion (digestate) as sustainable soil amendments for use in place of traditional fertilisers. It is argued that whilst the ability of combined ash and digestate to remedy many threats to ecosystems and provide a market to incentivise the renewable bio-energy schemes is promising, a step-change is required to alter perceptions of 'waste', from an expensive problem, to a product with environmental and economic value. This can only be achieved by well-informed interactions between scientists, regulators and end users, to improve the spread and speed of innovation with this sector.

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1. Introduction

Food security, energy security and the development of sustainable waste management practices are some of the largest challenges facing society worldwide. With the global population continuing to grow beyond seven billion (Cleland, 2013), humanity is required to balance an ever-increasing demand for natural resources, with the need to sustainably manage ecosystems and the vital services that they provide. Striking such a balance, however, will not be an easy task. In the EU, the intensification of agriculture (aimed at yield increases which involves practices such as increasing land drainage, fertiliser and pesticide use as well as simplification of crop rotations) has resulted in the degradation of soils through the loss of organic matter (OM) and fertility, contributing to increased food production costs and CO_2 emissions, as well as diminished productivity and elevated use of fertilisers that are both finite and energy intensive to produce (European Environment Agency, 2010). Additionally, fossil fuels are still being used to provide approximately 80% of global energy generation capacity (Bonanno et al., 2013), contributing to climate change, price volatility and uncertainty in security of supply. A direct consequence of an ever increasing resource-intensive society is also the mass of waste generated and the necessity to develop sustainable practices for its disposal.

The severe constraints to continued growth that society faces are well illustrated, in that demand for primary mineral reserves, such as P, is already outstripping availability (Gilbert, 2009). This, coupled with the global population forecast to reach nine billion by 2050 (United Nations, 2013), represents the primary driver for innovation and the development of resource efficient, circular economies.

The bioenergy sector has significant potential towards the formation of a circular and sustainable economy. Underpinned by international policy and the increasing cost of fossil fuels (Macleay et al., 2013), biomass to energy schemes are becoming increasingly common (Bougnom et al., 2012). Across Europe, gasification, incineration, biomass boilers and anaerobic digestion (AD) are currently the dominant technologies being deployed to convert a wide range of biomass and waste biomass derived fuels into renewable energy (McKendry, 2002). The by-products generated from these technologies, such as ash from thermal conversion and digestate from AD, also have significant nutrient values and properties conducive to their use as soil conditioners and fertilisers (Bougnom et al., 2012). Whilst the use and impacts of biomass and waste biomass as a renewable fuel for energy generation are well understood, the opportunity to apply by-products from these processes to land in order to close the circular economy loop is still in its infancy. However, to date work and regulation have yet to address the full impact of the by-products generated on the ecosystem services upon which we ultimately depend (Millennium Ecosystem Assessment, 2005). If managed correctly, the bioenergy sector presents a unique opportunity to, in part, address the challenges facing agriculture, energy generation, and waste disposal. Through the careful development of cradle-to-grave solutions, the environmental economic and social gains of the rapidly expanding bioenergy sector could be maximised, with minimal risks to human health.

This paper addresses the scientific and legislative barriers to the generation of bioenergy derived soil conditioners, to both facilitate the bio-energy generation sector, and to take a holistic, ecosystems services approach to highlight the science required to optimise the use of resources and ensure responsible innovation. Although much of the existing literature available and reviewed in this paper is based in the EU, the scientific discussion and further research requirements that are detailed, are applicable on a global level. Before the full impact of applying ash and digestate to land can be understood, several questions must be addressed:

(i) What are the possible impacts on ecosystems following the application of ash and digestate to land?
(ii) How can we add value to bioenergy by-products in a way that can both drive the bio-energy sector and provide positive environmental benefits over traditional fertilisers?
(iii) How can regulatory, social and commercial perceptions be altered to allow successful and sustainable use of the waste streams derived from this technology?

Ultimately, success of bioenergy schemes and realisation of their potential environmental benefits require a new way of influencing and informing outdated regulations regarding ‘waste’ products to agricultural land. The following sections examine the existing understanding of the effects of bioenergy waste on soil and plant properties as well as the ecosystem functions that they underpin, with the specific aim of identifying knowledge gaps that require addressing before a sustainable fertiliser can be developed and implemented.

2. The technologies

2.1. Biomass thermal conversion

Biomass to energy thermal conversion plants operate through the combustion or gasification of biomass derived feedstocks for the generation of low-carbon heat and power. Feedstocks for such schemes typically comprise (but are not limited to) poultry litter, food residues, wood, straw and paper mill sludge. A review of commercial-scale power and CHP operations conducted at the time of writing (2013) based upon data available from the UK Department of Energy and Climate Change (DECC) and Renewable Energy Planning Database (REPD), identified 50, currently operational, biomass-dedicated plants (excluding small-scale domestic installations) are in operation, generating a total of 1849 MWe. As a result of this activity it can be estimated that currently 0.62 megatonnes of ash (both bottom and fly ash) (based on an assumption of 30% operational efficiency and operation for 7500 h per annum out of a total possible 8736 h per annum, to allow for routine maintenance and shut-down time) is generated per year requiring reuse or disposal, with a possible future total of 2 million tonnes per annum.

2.2. Anaerobic digestion

Anaerobic digestion is a biological process in which metabolism of organic waste materials in an oxygen-free environment results in the generation of an energy rich biogas. Biogas, which primarily consists of methane (60%) and carbon dioxide (40%) is captured and can be used to generate heat and power. Alternatively it can be purified and injected directly into the gas network. Currently, there are 121 AD units operating in the UK, with an additional 200 planning applications for unit installation approved (Defra, 2013). Hence it can be anticipated that a rapid increase the number of plants coming online will occur in the near future (Defra, 2013). Feedstocks for such schemes typically comprise sewage, farm slurries, food waste, crop residues, municipal solid waste and commercial and industrial waste. It is estimated that 2% of the EU's renewable energy target needs can be met from biogas produced from organic wastes, with potential economic gains ranging between €1.5 and €7 billion depending the scale of implementation (European Commission, 2010).

2.3. By-product compositions and applications

The composition of ash and digestate from bioenergy generation is dependent upon multiple factors, including feedstock and technology, hence, generalisations of the properties are difficult to make. Broadly speaking, bottom ash is typically characterised by low levels of xenobiotic contaminants and heavy metals (Knapp and Insam, 2011), a strong