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Biosolids and distillery effluent amendments to Irish short rotation coppiced willow plantations: Impacts on overland flow and surface water quality

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ABSTRACT

It's necessary to determine risks of pollution arising from amendment of organic by-products (OBs) to energy crops. The impact of applying two OBs on the quality of overland flow (OLF) from plantations of short rotation coppiced willow was assessed. Municipal biosolids (BS) and distillery effluent (DE) were spread annually on six 0.1174 ha treatment plots at rates of 100% (W-BS_{100}, W-DE_{100}), 50% (W-BS_{50}, W-DE_{50}) and 0% (W-BS_0, W-DE_0). The 100% rate was the maximum load of 15 t P ha^{-1} as per the current Irish regulation based on crop uptake of P. Surface flows were sampled over 18 months and tested for pH, electrical conductivity, $NO_3{}^-$, $PO_4{}^{3-}$, total P, K, Cu, Cd, Cr, Pb, Ni, and Zn. Results showed $NO_3{}^-$, Cu, Cd, Cr, Pb, Ni, and Zn concentrations in OLF were well below quality standard limits set out in European Union (EU) drinking water (DW) and surface water (SW) regulation. For P–$PO_4{}^{3-}$ and K, concentrations in OLF exceeded these limits. There were treatment responses for all OLF species, except P and Ni; in some cases there were large increases in OLF concentration as OB treatment rate increased. There was build-up in soil-P, -K and in heavy metals (HMs) following application of BS, but not distillery effluent (DE). Results suggest increased OB application could result in increased export from plots treated with OBs. Despite high $PO_4{}^{3-}$ and K OLF concentrations, the occurrence of OLF was rare and volumes lost from plots were low; actual exports of nutrient and HMs by this pathway were small. It was unlikely OLF streams transported particulate matter far from plots, and no preferential flow routes were available to the OLF streams. For these reasons, the OLF encountered during experiments did not pose any serious threat to the quality of nearby surface waters.

Capsule: Organic by-products (OBs), biosolid and distillery effluent, amended to short rotation coppice willow. Impact on quality of surface (overland) flows (OLF) assessed by analysis of nutrients and heavy metals (HMs). Evidence of export of all three major agricultural nutrients and some heavy metals. Concentrations of P and K exceeded DW regulation limits in some instances. However, small volumes and rare occurrence of OLF indicated no risk to nearby surface waters. The practice of OB amendment resulted in little risk to surface waters at these scales. If scaled up to plantation scale, in areas vulnerable to OLF, careful consideration must be made about P-loss (on a catchment scale) before amendments carried out.

1. Introduction

There is interest in using energy crop plantations for disposing organic by-products (OBs). There is little information regarding impacts of amendment to short rotation coppice willow (SRCW) plantations on overland flow (OLF) under Irish-conditions.

Application of OBs to energy crops is becoming more common; previous routes have been removed by European Commission (EC)

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directive 1999/31/EC on land filling and EC directive 91/271/EEC on sea dumping. The application of OBs to energy-crops provides nutrients to crops while removing the risk of pollutants from entering the food-chain. The risk of nutrient loss is low if OB amendments are well managed; although these materials contain low levels of nutrients they do contain significant organic matter. The application of OBs to SRCW may have ancillary benefits such as improvement in soil quality, the opportunity for producers to earn gate fees and the breakdown of pollutants via phytoremediation (Britt and Garstang, 2002).

Organic by-products are applied either as a wet solid or liquid effluent; they may be washed from land surfaces (Merrington et al., 2002) if topsoil is carried as a suspension in OLF streams. Tien et al. (2006) identified several OB constituents that cause SW contamination, including NO_3-, $PO_4{}^{3}$-, HMs and organic matter. If sites receiving OB amendments are close to SW bodies, excess nutrients and/or HMs could be washed into them. This may cause problems; excess nutrient will degrade soil quality and promote the eutrophication of SWs (Esteller et al., 2009). The introduction of HMs and pathogens can also result in soil degradation; loss of these materials to SW can result in serious pollution of aquatic ecosystems.

The potential for excess P to enter SW is the cause for much concern (Addiscott et al., 1991; Merrington et al., 2002). Clear links between BS amendment and SW pollution have been identified (Korboulewsky et al., 2002; Epstein, 2003); however, the undertaking of such work in Ireland is limited. It is also the case that due to greater interest in BS, little work has been done in assessing DE in this regard; its assessment is therefore relatively novel. Pollution from conventional OBs (such as manure) is known to be a factor in degradation of Irish SW (Toner et al., 1986; DEHLG, 2006a–c, 2007a,b); extending OB amendment practices to include applying BS and DE may exacerbate such problems.

Pollutants dislodged from amended OB or topsoil can be transported as adsorbents on soil particulates or dissolved in OLF. Nitrate-ions are soluble and readily transported, although nitrate is more associated with leaching to GW; surface-based nitrate loss can potentially contribute to SW pollution (Addiscott et al., 1991). Phosphates are less mobile than nitrates, remaining mostly bound in topsoil and OB. However, if topsoil particulates themselves become suspended in OLF, P-sorbed suspensions could be transported. Phosphates can form precipitates that could become suspended in OLF and transported from OB application areas.

It is thought 25% of Irish soils demonstrate some P-excess (Tunney et al., 2000); low-input cultivation of energy crops such as SRCW on high P-Index soils could reduce soil P (Hasselgren, 1998). Organic by-products tend to release nutrients slowly, reducing chances of immediate “flushing” (Merrington et al., 2002). The loss of K to SW is not a major pollution issue in Ireland; it's not a limiting factor in eutrophication and does not have any serious health consequences for humans (Merrington et al., 2002). However, the limited information available on K loss makes it appropriate to include it in any generalized survey.

The ability of OLF to transport particulates could result in transport of HMs; such metals bind to organic matter in soil (and OB), and may become mobile if disturbed (Alloway and Jackson, 1991). Some HMs can form precipitates in soil moisture and OLF and could also be transported to SW via OLF.

Overland flow was first studied by Horton (1940); OLF arises when the infiltration capacity of soil is overwhelmed during rainfall (termed infiltration-excess) or when soil is unable to absorb more water (saturation-excess) (Pielou, 1998; Keane and Collins, 2004). In Ireland, infiltration excess is rare (due to low intensity rainfall and the low erodibility of Irish pasture land soils) (Keane and Collins, 1989). Saturation excess is far more common, particularly on wet land. Potential changes in Irish rainfall patterns may increase incidences of saturation excess OLF, particularly in Western areas (Charlton et al., 2006).

The plantations used in this study contain hybrid varieties of SRCW (a member of the genus *Salix* (family *Salicaceae*) (Argus, 1997). The high transpiration and low nutrient requirement of SRCW facilitates disposal of large volumes of watery OB; and plantations have been found to be effective repositories for wastewaters containing N and P (Guidi et al., 2008). This aspect of SRCW may have implications for OLF disposal, as high water throughput may prevent saturation-excess conditions. *Salix viminalis* L. and *S. Schwerinii* L. were used and are considered very suitable for Northern European conditions (Larsson, 1998); SRCW's average energy-content is 19 MJ kg^{-1} (Dawson, 2007). Earlier cultivation reports vary from 7 to 12 t DM ha^{-1} yr^{-1} under Irish conditions (Dietrich et al., 2008). Willows' N requirement is 150 to 400 kg N ha^{-1} (P and K inputs are relatively low); however, bulk makes the cost of transportation prohibitive (Teagasc, 2008, 2010). Willow is well known to be very water hungry, with a requirement 35% to 45% higher than common tillage crops (Caslin et al., 2010) and it is often used to dry out wetter lands.

Willow's high transpiration is potentially beneficial as it facilitates phytoremediation. Hasselgren (1998) found SRCW will phytoremediate soils receiving OBs with minimal environmental impact. During cultivation, individual SRCW plants are placed in straight rows (Caslin et al., 2010) forming regular channels that may become rutted. The effect of such features has not been studied, but OLF could be directed by such “crop-ridges”.

The study is exploratory in nature, and is based on the “edge of plot” approach (Mulla et al., 2005) and does not quantitatively investigate the fate of nutrients or HMs once transported past the boundaries of each plot, though conjecture is made on the likelihood of risk to SW occurring based on what is observed on plots themselves. The OBs studied are biosolids (BS), a processed sludge from wastewater treatment and distillery effluent (DE), a watery by-product of alcoholic beverage production. This work examines the frequency of OLF events; the relationship between precipitation and OLF; the exports of nutrients and heavy metals (HMs) from plots and the likelihood of SW degradation following BS and DE amendment to short rotation coppiced willow (SRCW) plots. Other work was also conducted on the impacts on groundwater (Galbally et al., 2012, 2013) and this paper does not deal with that issue.

2. Materials and methods

2.1. Study area

The study area is located in the Teagasc (Irish agriculture and food development authority) Agricultural Research Centre in Oak Park, Carlow, Ireland. The facility (Lat. 52°51′55″N; Long. 6°54′43″W) is 350 ha in area and situated 55.8 m above mean sea level (AMSL). The soil underlying the plantation is a light-textured gravelly soil, with a shallow topsoil layer underlain by a pan of discoloured subsoil associated with (grey/brown) G/B podzols.

The effective porosity of Oak Park soils is 25% (averaged across all soil-types encountered in Oak Park) with vertical travel times through profile of 0.02 to 0.03 m d^{-1} to GW. Oak Park top soils are well tilled and structured; surface compaction is minimal which reduces run-off.

Slopes on plots sites were gentle well below 5%; the plantation is therefore not prone to OLF from a topological perspective. To prevent cross contamination, each plot was isolated by a shallow trench (or “berm”). A buffer zone of 60 m also separated the two application areas (one for BS and one for DE) in order to prevent interaction.