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Investigating source areas of eroded sediments transported in concentrated overland flow using rare earth element tracers

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Abstract

Rare earth element oxides (REOs) have excellent potential for use as tracers in erosion studies. Using laboratory and field experiments we aimed to develop and test a simple application method for spreading REOs and to use REOs to determine the source of sediment to concentrated overland flow paths.

Tracks left by farm machinery (tramlines) in fields act as concentrated flow paths, delivering a large amount of surface runoff and entrained sediment to the field boundary however little is known regarding where this sediment is sourced from. Two field experiments were conducted to investigate this, one looking at whether sediment is entrained from different points along the length of the tramline and one looking at the area over which sediment is entrained from either side of a tramline.

Results from leaching tests and rainfall simulations clearly demonstrated the potential of this method for tracing sediment, there was very little movement of REOs through the soil profile and they were transported with sediment in overland flow.

In the field experiment a large proportion of the sediment transported in the tramline originated within the first metre either side of it. However, the total area over which eroded sediment collects and flows into the tramline is potentially large with small amounts of sediment eroded from the between 4 and 6 m being transported in the tramline.

REOs have an excellent potential for use as a tracer of soil erosion. They provide a quick and cheap method of identifying sources of eroded sediments and have good potential for use in determining erosion rates.

Keywords: Soil erosion; Concentrated flow; Tracer; Rare earth oxides; Sediment source

1. Introduction

Water erosion of agricultural soils has been widely recognised as a global environmental problem for many years. In the United Kingdom rates of erosion appear to have remained constant over the last 20 years (Evans, 2005). Soil surfaces that are bare or have low vegetation cover during the autumn and winter, such as winter cereal crops, are especially susceptible to erosion (Quinton and Catt, 2004). In areas where soils are readily erodible this problem can be serious with rates of erosion typically between 0.5 and 200 t ha^{-1} yr^{-1} (Chambers et al., 2000).

Erosion can cause a reduction in soil quality with negative impacts on soil structure and fertility potentially resulting in a loss of productivity. Eroded sediment also causes a reduction in water quality of nearby water bodies by increasing turbidity, reducing light penetration, clogging fish gills and destroying aquatic habitats through sedimentation. As soils erode they also transport other pollutants such as heavy metals (Quinton and Catt, 2007) and nutrients (e.g. Quinton et al., 2001; Haygarth, 2005) into watercourses contributing to a range of environmental problems including eutrophication.

Concentrated flow erosion, in the form of rills or gullies, is an important vector for sediment and pollutants to reach water courses as the rate of erosion is much higher from rills and

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gullies (Torri et al., 1987). Recently it has become apparent that the tracks left by farm machinery (tramlines) through fields are acting as concentrated flow paths and are responsible for delivering a disproportionate amount of material to the field boundary (Silgram et al., 2007). Tramlines are established at the time of sowing and are used throughout the growing season to prevent crop damage during spraying and fertilizing operations. Tramlines provide an important conduit for surface runoff and the sediment transported in it due to the bare compacted soil found within them. Earlier initiation of runoff, lack of crop cover, compaction and the channelling effect of tramlines have all been identified as factors contributing to the transport of sediment in tramlines (Fullen, 1985; Withers et al., 2006). Withers et al. (2006) found that runoff was initiated sooner in tramline areas than non-tramline areas and total runoff volumes were increased by up to 65%. Loads of suspended sediments were up to five times higher from areas with tramlines than from those without. Tramlines are clearly a very important feature in the landscape providing a pathway for the rapid transport of sediment. Despite their importance they have received relatively little research attention and little is know about where the sediment transported in the tramlines originates from.

The collection of spatially distributed erosion data is a generic problem in soil erosion research. Spatially distributed data are important not only for understanding soil erosion processes, but also for the development and validation of soil erosion models (Zhang et al., 2003a). The need to identify sediment source areas has led to the development of a number of different tracer techniques including ^{137}Cs (e.g. Porbera, 2006), ^{7}Be (e.g. Schuller et al., 2006), ^{210}Fe (e.g. Motha et al., 2002), magnetic susceptibility (e.g. Blake et al., 2006) and glass or plastic beads (e.g. Cochrane and Flanagan, 2006). Of these, ^{137}Cs has received the most research attention and has become an established method for studying the redistribution of soil on hillslopes. However, many of the tracers above suffer from having poor resolving power when it comes to for the identification of sediment source areas. In the case of ^{137}Cs it is possible to identify accumulation areas and loss areas but not to explicitly link the two. For the spatial validation of models or for studies linking pollutant source with sink explicitly linking source areas with receptors is a necessity.

Rare earth element oxide (REO) tracers provide a promising alternative to the approaches described above and have been successfully used in several studies (e.g. Wei et al., 2003; Polyakov et al., 2004; Lei et al., 2006). Rare earth elements, or lanthanides, range from atomic numbers 57 to 70 in the periodic table. Although called the 'rare earths' they are not uncommon in the natural environment and occur in a number of minerals, although concentrations in soil are generally low. The oxides of rare earth elements are very stable and non-toxic making them suitable for application in the environment. They also satisfy the characteristics of sediment tracers identified by Zhang et al. (2001). Namely that: they should be bind strongly to soil particles; not interfere with sediment transportation; be easy and inexpensive to measure; have low background concentrations; not be easily taken up by plants and not be damaging to the environment.

REOs were first used as a horizon marker, rather than as a tracer, by Knaus and van Gent (1989) to investigate accretion in a wetland habitat. Initial studies on the use of REOs as tracers were conducted by Tian et al. (1994) who concluded that REOs could potentially be used to accurately determine the spatial distribution of soil erosion. Matisoff et al. (2001) also developed a similar method, determining that REOs provided a robust method for tracing soil movement with tagged particles and behaved in the same manner as untagged material. Since then considerable development work has been conducted by Nearing and his research group. Zhang et al. (2001) determined that REO oxides were evenly incorporated in aggregates sized between <0.053 mm and 6 mm, but with some preference for binding with the fraction smaller than 0.053 mm. They also found no REO vertical movement of REOs in the soil profile after leaching with deionised water. Laboratory studies have demonstrated the potential of this technique for generating spatially and temporally distributed data allowing quantification of soil redistribution (Zhang et al., 2003b; Polyakov et al., 2004). Field application of REOs has been successful allowing mapping of soil redistribution in a small watershed over short and multi-year timescales (Polyakov et al., 2004; Kimoto et al., 2006a). Although REOs bind strongly with silt and clay their preference for binding with small particle sizes means that they are less suitable for use with coarse soils. Kimoto et al. (2006b) worked on gravelly sandy loam soils where they found that errors were higher because of selective deposition in coarse materials, while this did not preclude the use of REOs as tracers in these soils, it did lead to increased complexity of analysis in order to determine sediment loss rate and analysis costs. REOs have also been used to study the processes of rill formation (Wei et al., 2003; Xue et al., 2004, Lei et al., 2006).

In this paper we set out to do two things: to develop and test a simple application method for spreading REOs and to use REOs to determine the source of sediment to concentrated overland flow paths. This paper reports the findings of laboratory experiments on REO application method and two field experiments, one looking at whether sediment is entrained from different points along the length of the tramline and one looking at the area over which sediment is entrained from either side of a tramline.

2. Methods

2.1. Laboratory studies

A bulked soil sample was collected from three mid and lower slope areas at the study site (see below) in order to determine background concentrations of rare earth elements.

Dry soil samples were ground to <2 mm, background rare earth element concentrations were determined using extraction with an aqua regia digest in open glass tubes in a block digester (McGrath and Cunliffe, 1985) followed by analysis using a Thermo Elemental X7 inductively coupled plasma-mass spectrometer (ICP-MS). Although not used in some previous studies with REOs (e.g. Polyakov and Nearing, 2004) this method is a standard method for the extraction of heavy metals from soils