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Enrichment ratio of poorly crystallized iron mobilized with clay/silt-sized particles released via interrill erosion

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ABSTRACT

Soils under no-tillage (NT) and a moldboard plow tillage system (MT) were exposed to a field rainfall simulation to determine the soil poorly crystalline iron release during interrill erosion. Clay/silt-sized particles were captured in an overland flow produced by a rainfall simulation in the field. Two different soils (Calloway silt and Maury silt loam) were exposed to different kinetic energy wettings to evaluate the temporal clay/silt sized release, the variation of the enrichment ratio for poorly crystalline iron (ER_{Fe}) and the total poorly crystalline iron delivered (TID). The clay/silt sized particles release was continuous and independent of soil texture. In both soils the ERFe decreased over the time, but showing unexpected flushes. These extreme values appeared at different time, thus indicating that they were conditioned for the aggregate's rupture. However, no correlation was found with the flushes of clay/silt sized particles. The ER_{Fe} data suggested the presence of $Fe_{(ox)}$ easy-to-release in the soil surface, which does not depend on the wetting energy used for the aggregate breakdown. The variations in ER_{Fe} were due to a soil characteristic affected for submergence. Under intensive tillage (MT) in both soils, the high kinetic energy wetting determined the highest TID. A low TID value was observed with low kinetic energy wetting, which provide evidence of a continuous mobilization of poorly crystallized iron from these soils. This occurred because a flow transports process and a labile source of $Fe_{(ox)}$. Because the cover surface was not sufficient to stop the clay/silt sized particles and the $iron_{(ox)}$ mobilization it would be preferable to combine NT with contouring as a better solution.

1. Introduction

An often overlooked but relevant process related to interrill erosion is the mobilization of micronutrients, especially iron. Like other micronutrients, iron receives little attention due to its apparent innocuous environmental effects; however, it possesses a high potential risk for water pollution *per se* (EPA, 2013). In the environment, the poorly crystalline iron (hydr) oxides are relevant as a carrier for other pollutants (Devesa-Rey et al., 2011; Shan et al., 2010; Rhoton and Bennett, 2009).

Several studies have demonstrated that colloid-bound-heavy metal transport plays a crucial role in the environment (Jensen et al., 1999; Denaix et al., 2001; Keller et al., 2011) and that this process is more important than the transport of dissolved ions (Egli et al., 1999; Jensen et al., 1999; Klitzke and Friederike, 2007). Soil erosion is often implicated in the movement of contaminants that bind tightly to silt, clay, and organic materials (Rhoton and Bennett, 2009; Kuhn et al., 2012). In particular, its role in the transportation of P and pesticides has been well-studied (Boardman et al., 2009; Wang et al., 2009). Because heavy metals such as poorly crystalline iron bind tightly to soil colloids and organic matter, they should also move with the finest soil particles and soil carbon during erosion episodes. This movement is particularly true with interrill erosion, which is a selective process, often detaching and transporting clay and silt preferentially (Quinton et al., 2001; Issa et al., 2006). Rhoton et al. (2002a) observed that clay, organic carbon (OC), and poorly crystalline Fe oxide fractions were more common in river sediments than in the adjacent soils. The complexes are formed during the runoff process as the clay, OC, and poorly crystalline Fe oxides are eroded from the soil surface as dispersed particles and clay-sized aggregates. Other studies confirm these observations; for example, Lalonde et al. (2012) proposed an “onion model” to describe the chelation of organic structures with iron. They conclude that the relation OC:Fe observed in sediment largely exceeds the maximum sorption capacity of iron oxides, but is compatible with chelation structures. In addition, they suggest that iron oxides provide the association of organic compounds with clay through the covalent bonds. Lavoie and Auclair (2012) confirmed these observations by measuring sediment in lakes.

Quinton and Catt (2007) found that with small soil loss values, there is significant variation among the sediment metal enrichment ratios. However, this variation decreases as the amount of erosion increases.

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The increase in enrichment at lower magnitudes of soil loss likely reflects the variation in storm characteristics, i.e., short and intense events may produce the same amount of sediment as longer but lower intensity events; however, the energy and transporting ability of both rainfall and flow may differ between these different types of events. The detachment and transport of the finest metal-rich particles associated with the intensity of events could be responsible for this behavior (Quinton and Catt, 2007; Delpla et al., 2011; Li et al., 2012). This is a very important statement because low intensity events are more frequent than higher intensity storms. Biemelt et al. (2005) found that during rainfall simulations, there was no significant change in the Fe concentration measured in the sediment over time, indicating that soils can provide a continuous source of Fe to the overland flow. Poorly crystalline Fe (hydr) oxides have much larger and more reactive surface area than crystalline Fe (hydr) oxides (Duiker et al., 2003) i.e., they have an enormous capability to carry pollutants. This property determines an increased interest in studying this iron form and knowing how moving in runoff is (Rhoton et al., 2002a). Poorly crystalline Fe (hydr) oxides also were associated with soil aggregation and organic matter (Rhoton and Bennett, 2009). The strong relation with organic matter makes these compounds susceptible to be released under tillage (Jacinthe et al., 2004).

In addition, cropland areas are likely to increase pollutant loads because of the intensive use of fertilizers and other chemicals in farm operation. When performing studies involving conservation tillage, Quinton and Catt (2007) mention that the tillage type has little impact on the enrichment of several metals. However, the use of tillage across the slope could enhance the enrichment of several metals, in particular lead (Pb). These are important issues that need to be confirmed to reduce the load of pollutants transported from croplands to rivers and lakes. Conservation practices and tillage systems can be combined to improve the control of pollutants; however, it is necessary to know how the finest particles, metals, and other potential pollutants are released and mobilized under tillage systems. One aspect that has recently received attention is the effect of the soil wetting rate on sediment loss (Ben-Hur and Lado, 2008; Wuddivira et al., 2009). The soil wetting rate is very dependent on the manner in which the soil surface is exposed to rainfall. The tillage system can modify the way in which the soil becomes wet when exposed to rainfall events. For example, when using moldboard plowing (MT) that produces a bare soil surface, the direct rainfall impact leads to a kinetic energy-related soil wetting process (Ben-Hur and Lado, 2008; Bielders and Grymonprez, 2010). The disintegration of soil aggregates will occur due to the direct impact of rainfall, developing kinetic energy detachment and transport processes.

In contrast, no-till (NT) determines a covered soil surface condition and the soil wetting occurs without any effect associated with the kinetic energy dissipation process (Licznar et al., 2008; Park et al., 2003). The disintegration of soil aggregates is likely to occur by slaking action under NT, and wash detachment transport processes will develop (Abrahams et al., 2001; Deng et al., 2008; Asadi et al., 2011). Thus, because under contrasting tillage systems the magnitude of aggregate disintegration could vary substantially, the release rate of clay/silt-sized particles into the overland flow could also consequently vary.

Thus, how these two different soil wetting processes affect iron release and how the eroded particles are enriched for are not well understood. Our goal is to determine the role of soil wetting in the mobilization of clay/silt-sized particles via interrill erosion and the effect on both the poorly crystalline iron enrichment ratio and the poorly crystalline iron delivery rate of eroded particles transported in the overland flow.

2. Materials and methods

The selected sites were under 15 years of continuous corn (*Zea mays* L.) on Maury silt loam (Typic Paleudalf), located at the University of Kentucky's Agricultural Experiment Station-Spindletop Farm (Lexington, KY). The other sites were under a soybean (*Glycine max* L. Merr.)/corn/tobacco (*Nicotiana tabacum* L.) 7 years rotation on Calloway silt (Aquic Fragiudult), located in a commercial farm (Owensboro, KY). Each of these locations was managed with moldboard plow and disc (MT) and also with no-till (NT) soil management. On average, the slope gradients on those sites were less than 2%, which is typical of millions of hectares of croplands. Soils were selected based on textural and soil stability differences that determine a different reaction to rainfall. As a consequence of the low tensile aggregate-strength, the greater the silt contents in soil, the greater the need to use surface cover to reduce soil erosion (Nearing et al., 1991; Knapen et al., 2007; Gumiere et al., 2009).

To test the hydrological response and sediment production under high- and low-energy wetting in the field, the experimental sites were exposed to simulated rainfall. Each of the 1 m^2 plots was surrounded by three galvanized metal borders of 12 cm height with a gutter attached at the end. The bottles were placed in a hole into the ground, to collect the samples at the gutter's outlet. A nozzle-type rain simulator with a pump and a solenoid valve was used to produce a rainfall of 87.5 mm h^{-1} for 1 h. The tower supporting the nozzle was surrounded by tarps to avoid raindrop deviation (Fig. 1a). Although this intensity represents an extreme event for this region, it was selected after field experiments to determine a proper intensity that expresses the soil stability differences and provides enough sediment for chemical and physical analysis.

Prior to the 1-h long rainfall simulation, the soils were exposed for 7 min to high and low kinetic energy, respectively, to simulate the situation of low and high kinetic energy wetting of the soil surface as a 5 day antecedent rainfall. This condition was necessary to accomplish with hydrological requirements and to standardize the antecedent soil moisture condition (AMC) at level II (SCS, 1956). The AMC II is the average case for runoff modeling. A resting interval of 3 min was established before the main rainfall simulation (Rienzi et al., 2013).

During the high kinetic energy wetting (HKE), the rainfall reached the bare soil surface (Fig. 1b). During the low kinetic energy wetting

Fig. 1. Rainfall simulator and details of the plots used in the study. a) General view of the tower used to support the nozzle and the tarps to avoid raindrops deviation in the field. b) Bare soil corresponding to the high kinetic energy wetting treatment (HKE). c) Covered soil corresponding to the low kinetic energy wetting treatment (LKE).