

## Use of Fly Ash as Time Marker in Soil Erosion and Sedimentation Studies

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### ABSTRACT

Accelerated erosion as a result of human and animal activities is a major environmental and economic problem throughout the world. The severity of accelerated erosion is affected by slope gradient, shape, and length and by tillage practices. Fly ash is the product of high temperature coal combustion and is easily identified by the high proportion of spherical particles in the magnetic fraction of soil. The incorporation of fly ash into soils dates to the beginning of the industrial era and invention of high temperature, coal-fired boilers. We first used its occurrence in soils of northwestern Illinois as a time marker in sedimentation studies and to separate geological sediments and accelerated erosion sediments. This study was conducted to quantify the post-settlement deposition in a sediment basin with a single outlet in small watershed. The total post-settlement sediment in the basin and delivered to the stream was an indirect measure of the total amount of soil removed from watershed hillslopes by accelerated soil erosion. In southern Illinois, the fly-ash marker was used directly on the upland as an indicator of soil loss from erosion. The extent of erosion was estimated by comparing the fly ash content at paired cultivated and uncultivated sites. The concentrations of fly ash in soils of a transect of a cultivated area were lower than those of paired soils of a transect in nearby uncultivated forest. Higher amounts of fly ash were found in A horizons at the uncultivated site than at the cultivated site for all respective landscape positions.

### INTRODUCTION

Accelerated erosion or the erosion as a result of human and animal activities including tillage is a major environmental and economic problem throughout the world. The severity of accelerated erosion is a result of sheet and rill erosion in combination with tillage and management practices. Soil erosion is a serious problem on farmland in the USA. The annual discharge from agricultural land to waterways in the USA is estimated at 1 079 million tons of sediments and 477 million tons of dissolved solids (Duttweiler and Nicholson, 1983). The 1987 RCA Appraisal estimated that sheet and rill erosion moves more than 3.4 billion tons of soil on the landscapes of non-federal rural land (USDA, 1987). In addition, wind erosion removes 1.2 billion tons of soil from cropland (USDA, 1987). The USDA estimate is greater, because it includes soil eroded

from one part of a field and deposited in another part, in addition to the sediment actually delivered to a stream. The extent of erosion and the phase of eroded soil is identified on the basis of the properties of soil that remains (Soil Survey Staff, 1993). Classes of erosion are defined in Chapter 4 of the Soil Survey Manual (Soil Survey Staff, 1993) on the basis of the percentage of original A horizon lost or the uppermost 20-cm if the original horizon was less than 20 cm thick. The objective of this paper is to present new fly ash methods of identifying eroded phases of a soil and quantifying the extent of sedimentation and soil loss from erosion in both urban and remote areas.

### Magnetic Susceptibility and Fly Ash Formation and Properties

Magnetic susceptibility can be used for detecting erosion or deposition on a soil surface. The magnetic susceptibility of sediment deposited is different from that of the original surface, as in the case of a buried soil (Fine et al., 1992). Magnetic susceptibility is the magnetizing ratio of material to the magnetic field inducing it. For soil it is the result of contributions of susceptibilities from the large number of different substances in soil.

Fly ash is particulate matter resulting from high temperature combustion of coal. It is produced in a variety of boilers, including those in steam locomotives and steam-powered farm machinery. The principal minerals in coal of the central USA are feldspars, pyrite, siderite, quartz, calcite, and clay minerals, mostly kaolinite (Harvey and Ruch, 1986). The minerals are vitrified above ~1473 K, and a common product is spherules composed of glass, quartz, mullite, wustite, and magnetite (Huffman and Huggins, 1986). Until recent technologies allowed removal of fly ash from stack gases emanating from boilers, the ash was a component of smoke and was deposited over a wide area around the sources, especially near coal-fired power plants. Recently, sphere occurrence and abundance have been used to identify sediments laid down during the industrial epoch (Locke and Bertine, 1986). The occurrence of ferrimagnetic minerals, usually embedded in the glassy phase, offers a convenient way to separate the spheres for identification and analysis.

### Use of Fly Ash as a Time Marker in Sedimentation Studies

The use of fly ash and magnetics would provide a time marker extending back to at least 1850, which in Illinois coincides with European settlement and initial

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cultivation. Fly ash related to steam-locomotive use in the state may be widespread, inasmuch as installed track increased from initial construction in the 1850s to 16 000 km in the 1920s. Some fly ash may be derived from steam-powered farm equipment. Threshers and self-propelled tractors, the latter coming into greatest use from 1880 to about 1920 (Wik, 1953), would produce magnetic fly ash, their boilers being fed by soft (bituminous) coal. For economic and supply reasons, however, many steam boilers on farms were fired with straw or wood which probably produced highly siliceous, glass-phase fly ash.

Jones and Olson (1990) found fly-ash spheres were present in large amounts in soils and sediments near urban areas and in smaller quantities in rural locations in Illinois. Fly ash had the potential of being an easily identified time marker in sedimentation studies. These air-borne spheres have been deposited on soils and sediments since the 1850s, the time of settlement and the use of high-temperature boilers, which is also nearly contemporaneous with initial cultivation in Illinois. The fly ash present in soils can be used to identify sediments accumulated since European settlement and to interpret the stratigraphy of sediments and their relationships to underlying soils. The usefulness of fly-ash incidence in soils profiles will be aided by study of carefully chosen sites near sources of the ash: e.g., undisturbed areas in cemeteries first used in the mid-19th century that are adjacent to and downwind from railroads or rural power plants. Because some particles are in the silt and sand size ranges and are not prone to easy eluviation, their distribution in the soil may give valuable information regarding biotic and abiotic mixing and pedoturbation of subsurface horizons since settlement. Knowledge of mixing characteristics will help interpret evidence of erosion, or accretion on, soil profiles as well as the time frame for these events.

#### **Quantification of Post-settlement Deposition in a Sediment Basin**

Jones and Olson (1990) developed a method to identify and characterize fly-ash content with depth in selected Illinois soils and to determine fly-ash incidence in soils near to and remote from ash sources. Fly ash has the physical appearance of mostly opaque spheroids of siliceous glass, mostly with diameters of less than 20 microns. Fly-ash particles are able to travel long distances in an airstream because of the low settling velocities of particles ranging from 1 to 20 microns with respect to normal wind speed (Wark and Warner, 1976). Fly ash was found 45 km from a coal-powered plant in Glasgow, Scotland (Rose, 1996). Jones and Olson (1990) identified occurrences of magnetic fly-ash sphere in soil and sediments recently eroded from and currently in aggrading or depositional positions on three Illinois landscapes. The depth at which fly ash spheres occur in a soil profile and their abundance provided evidence of minimum length of time required for the given thickness of sphere-bearing sediment to accumulate. Because accelerated erosion and consequently sedimentation are synchronous with the large increase in bituminous coal use (Locke and Bertine, 1986; Gschwandtner et al., 1985), eroded sediments

deposited on sideslopes as well as aggrading positions were found to contain fly ash. Soils from both urban and remote areas of Illinois were found to contain magnetic fly-ash spherules. For example, a concentration of >75% occurred in the magnetic fraction of the surface horizon (mostly in the top 12.5 cm) of soil on an uncultivated, stable ridgetop near Springfield, IL. On the nearby Sangamon River floodplain, fly ash occurred in large numbers to the 25-cm depth, and in lesser numbers to 45 cm, the top of a buried, organic C-rich layer. This buried layer may represent the surface in the 1850s, when railroads and perhaps also industrial boilers were introduced. In depositional horizons of soils from remote sites, fly ash occurred at levels of < 1%; it probably came from steam locomotives and perhaps steam-powered farm machinery. At depositional sites, the buried A horizon contained fly ash, but subjacent horizons did not. This pattern indicates that fly ash occurrence is useful in distinguishing the pre-settlement surface, thereby making possible the determination of rates of sedimentation at a particular site.

Kreznor et al. (1990) quantified the post-settlement deposition in a 2.49 ha sediment basin with a single outlet in a 10.5 ha watershed and estimated the sediment delivery to a first-order stream in northwestern Illinois. Buried A horizons (dated using fly ash as a time marker) identify the pre-settlement (~1854) surface, which was overlain by as much as 116 cm of sediment. Volume of the sediment within the basin was calculated in 11 394 m<sup>3</sup> with a weight of 16 480 Mg. Based on representative measurements of post-settlement sediment delivery obtained from research of drainage basins having similar size or soil characteristics, it was inferred that 20 975 Mg of sediment was delivered to the stream with a total of 37 455 Mg of soil being removed from the watershed hillslopes as a result of accelerated soil erosion. The measured rate of post-settlement sediment accumulation has been approximately 0.34 cm yr<sup>-1</sup>.

#### **Erosion Patterns on Cultivated and Uncultivated Hillslopes Determined by Soil Fly Ash Contents**

Hussain et al. (1998) determined the extent of soil removal from a hillslope due to accelerated erosion and its subsequent deposition on a lower landscape position using the presence, depth distribution, and concentrations of fly ash, organic carbon and intensity of magnetic susceptibility to identify the remaining original soil and as a sediment marker. The study was done by comparing the amount of fly ash contained in the soil profile at different landscape positions of a cultivated site with that in an uncultivated woodland site. Fly-ash deposition started in 1855 with traffic on the Illinois Central railroad between Chicago and Cairo, Illinois. In 1889 and 1928 additional rail lines were located closer to the both sites. Measures of organic C, magnetic-mineral content, and magnetic susceptibility decreased regularly with depth at both sites. Magnetic susceptibility was generally higher on the uncultivated site as compared to the cultivated site on all landscape positions except the lower footslope. In comparison with the uncultivated site, fly ash on interfluvial and shoulder landscape segments of the cultivated site was 50 percent

less, 35 percent less on backslope and 67 percent less on depositional lower footslope position. Considering the whole transect, the cultivated site had 47 percent less fly ash in the upper 22.5 cm soil profile as compared to the cultivated site. These results indicated that 10.6 cm or 47 percent of the upper soil layer has been eroded since 1855 (142 years) from the hillslope due to accelerated erosion induced by cultivation. For the backslope, the presence of 65 percent or 15 cm of the original surface soil layers and 67% of the fly ash at the cultivated site places the soil in the moderately eroded phase of the Grantsburg soil.

## SUMMARY

In the above studies the potential for use of fly ash as a time marker in sedimentation studies and as an index of erosion was demonstrated. We found fly-ash spheres were present in large amounts in soils and sediments near urban areas and in smaller quantities in rural locations in Illinois. Fly ash had the potential of being an easily identified time marker in sedimentation studies. These air-borne spheres have been deposited on soils and sediments since the 1850s, the time of settlement and the use of high-temperature boilers, which is also nearly contemporaneous with initial cultivation in Illinois. The fly ash present in soils can be used to identify sediments accumulated since European settlement and to interpret the stratigraphy of sediments and their relationships to underlying soils. We initially used its occurrence in soils of northwestern Illinois as a time marker in sedimentation studies and to separate geological sediments and accelerated erosion sediments. Buried A horizons were dated using fly ash as a time marker to identify the pre-settlement (~1854) surface, which was overlain by as much as 116 cm of sediment from accelerated erosion and underlain by more than 400 cm of geological sediments.

In southern Illinois, the concentrations of fly ash in soils of a transect of a cultivated area were lower than those of soils of a transect in a nearby uncultivated forest. It is postulated that tillage and accelerated erosion could have redistributed the fly ash on the cultivated site. Higher amounts of fly ash were found in A horizons at the uncultivated site and the amount of fly ash decreased with depth at the cultivated site for all landscape positions. For the backslope, the presence of 65% or 15 cm of the original surface soil layers and 67% of the fly ash at the cultivated site places the soil in the moderately eroded phase of the Grantsburg soil. The estimated annual soil loss amounts to 7.3 Mg ha<sup>-1</sup> yr<sup>-1</sup> for the previous 142 years.

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