

A SIMPLE METHOD FOR IMPROVING SOIL LOSS MEASUREMENT IN USLE TYPE EXPERIMENTS.

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Abstract

Soil erosion experimentation around the world commonly uses field runoff plots from which runoff and soil loss is collected. Volume of the collected water-sediment mixture is commonly so great that sub-sampling techniques are required to estimate total soil loss in any erosion event. It has been shown that the commonly used method involving a collection tank, agitation of the water-sediment mixture and then sub-sampling can lead to serious under-estimation of total soil loss. This paper outlines and illustrates a practical, simple method for reducing the error by timing any lag that occurs between completion of stirring and sample collection, and measuring the settling velocity characteristics of the sediment involved.

Additional key words: USLE, error in USLE, soil loss measurement, settling velocity, Oden theory.

Introduction

Soil erosion experimentation around the world commonly uses hydrologically defined runoff plots with runoff and soil loss measured at the exit of the plot by collection in a tank system. Following an erosion event, sediment collected in the “silt collection box” is thoroughly stirred, seeking to ensure a uniform distribution of sediment throughout the depth of water in the tank. As soon as feasible after stirring, i.e. after a short time, a sub-sample of the water-sediment mixture in the tank is taken by immersing a collector to a substantial depth beneath the surface of the water in the tank. The (oven dry) mass of this sample of known volume is then factored up to the complete volume of water collected to give the total soil loss from the plot during the erosion event.

Soil loss data obtained in this way provides the major body of data collected world wide on soil loss under different soil, climate, and management conditions. In particular it is the basis of the large body of data collected in the USA and summarised in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965, 1978). Experimentation carried out at Scone, NSW, showed that this commonly used method of measuring soil loss could lead to serious error, with actual soil loss being underestimated by a factor of approximately 3 (Lang 1990,1992). This work thus cast doubt on the correctness of the USLE database on soil loss that has been relied upon to the present day to validate process-based erosion prediction technologies (Zhang et al., 1986; Tiwari et al. 2000). Other authors have also noted that there was substantial potential for error in the sampling techniques (Silburn and Hunter, 2002, Herweg and Ostrowski , 1997).

The magnitude of error in this methodology is expected to depend upon at least the following four factors:

- a) Whether stirring of sediment in the collection was sufficiently vigorous to justify the assumption made that it has achieved a uniform distribution throughout the collection tank.
- b) The lag time between completion of stirring of collection tank contents and sub-sampling.
- c) The settling velocity distribution of the sediment collected in the tank.
- d) The actual detailed technique of sediment sampling. ie the method and utensil used to dip the sample.

The aim of this paper is to employ the existing theory of sediment settling in water to yield a practical method of making a correction to the estimate of soil loss for errors incurred due to issues (b) and (c) listed earlier.

Thus a correction method will be developed and experimentally tested to allow a correction for:

- (i) any slight delay between stirring and sampling, and to
- (ii) tailor this correction to the soil type involved, as characterised by its settling velocity characteristics.

Further experimentation was also carried out which has implications for the errors listed as (a) and (d).

Materials and Methods

A measured mass of soil was added to some 250mm depth of water in a circular container of diameter 565mm, to yield a mixture of sediment concentration of 20 kg m⁻³. The mixture was stirred vigorously with a spade, and samples of the water-sediment mixture taken simultaneously at three depths. The time period between cessation of stirring and sampling was measured with a stopwatch (around 4 seconds). Samples were taken from just below the water surface, just above a hand placed on the container bottom to avoid collecting deposited sediment, with the third sample taken mid-way between the upper and lower samples. Sample containers were 73mm internal diameter and 105mm in length. Containers were inserted in a downward facing direction, and inverted on reaching the required depth. This procedure was replicated four times for each of the two soil types: a vertosol and a krasnozem. Sample data were converted to sediment concentrations which were then plotted against sample depths, yielding an average sediment concentration for the entire depth. The result was then used to calculate the mass of sediment in suspension at the time.

The physical basis of the correction method is as follows. Neglecting any error of the type described in (a) above (which is generally unknowable), it is assumed that the sediment is fully stirred with uniform spatial distribution of both sediment density and size (or settling velocity) characteristics. This condition is assumed to exist at time t=0.

The Oden theory for sedimentation of a polydisperse suspension (Oden 1924) given for example in Lovell and Rose (1988), describes the settling of an initially uniform sediment suspension of depth L. After settling for time t there are two classes of particles:

- (a) those that have completely deposited on the bottom of the container, and
- (b) those for which only some of the particles have deposited.

Using equation (6) in Lovell and Rose (1988) an expression follows relating the actual mass of sediment collected from the tank at time t, Ms(t), to the correct total mass of sediment in the tank (M). This ratio of M to Ms(t), which is of the nature of a correction factor, is given by,

$$M / M_s(t) = \left(\sum_{i=1}^k p_i - \frac{t}{L} \sum_{i=1}^k p_i v_i \right)^{-1} \dots\dots\dots(1)$$

where the sediment is divided into I settling velocity classes of fraction p_i = M_i/M where M_i is the mass of sediment in the size class i; k the number of sediment classes that are still in suspension (k ≤ I); v_i is the settling velocity of size class i sediment; and L is the depth of the sediment-water mixture in collection tanks.

Since M_s(t) is obtained by sampling, and all terms on the right hand side of equation (1) are known if the sediment's settling velocity characteristic is determined, this allows the actual but unknown mass M to be calculated. The k classes of sediments remaining in suspension after a lag time of t are those with settling velocities satisfying:

$$v_i \leq \frac{L}{t} \dots\dots\dots(2)$$

Using the approximate settling velocity characteristics for either soil, M was then estimated using Equation (1), and compared with the value of M, which is known in the experiment (though unknown in the field studies).

Results and Discussion

Table 1 shows that the sampled mass is a serious under-estimation of the actual mass of sediment in the container.

The ratio of actual mass of sediment to that obtained from sampling, ranging from 4.34 to 3.85 for the two soils investigated is also generally compatible with the finding of Lang (1990,1992) and Silburn and Hunter (2002) that although this ratio could vary widely, the ratio was commonly of the order of 3.

Table 1 shows that use of Equation (1) to estimate M substantially improves the estimate based on sampling alone by a factor of the order of 3. However, the ratio of actual to sampled mass is of order 4 for the two soils investigated (Table 1). Thus there still remains a significant error of underestimation that is evidently due to the errors of type (a) and (d) listed earlier.

Table 1. Comparison between actual, measured and corrected mass of sediment.

Soil Type	Sampled mass Ms(t) (kg)	M estimated from Eqn.(1) (kg)	Actual M (kg)	Ratio of Actual/Sampled mass
Vertosol	0.279	0.909	1.210	4.34
Krasnozem	0.334	0.746	1.229	3.85

Fig. 1 is based on Equation (1), showing that the required correction factor for the two soils assuming an initially uniform sediment distribution as a function of the lag time between completion of stirring of collection tank contents and sub-sampling. It can be seen that the required correction factor increases rapidly as the lag time increases, the magnitude of the required correction vary between the soils as a result of their differing settling velocity characteristics.

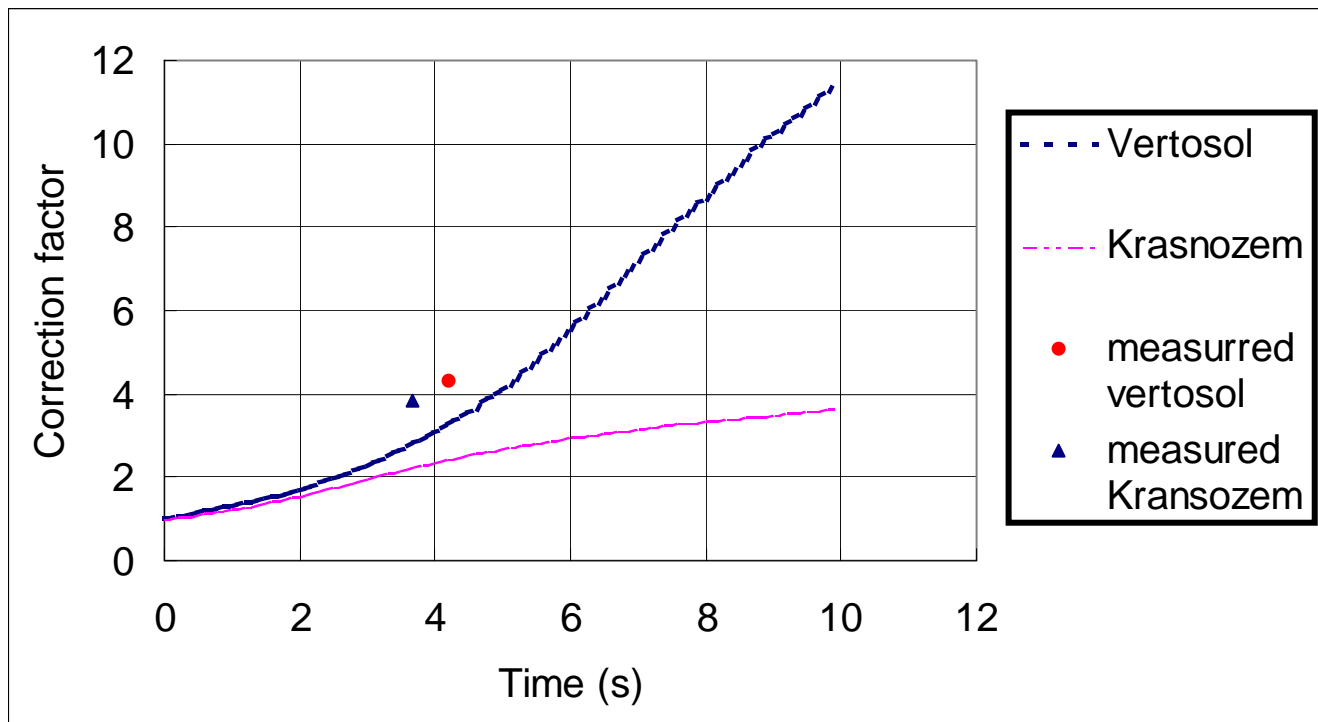


Figure 1 Measured and estimated correction factor for two different soils.

Stirring of the type employed in USLE-type experimentation is unlikely to satisfy the assumption that stirring achieves a uniform distribution of all particle sizes throughout the entire depth of the mixture in the collection tank. To investigate this assumption a further experiment was carried out in which, following the stirring of a vertosol mixture, replicate sediment samples were taken after $t = 3.5$ seconds at the three depths in the mixing tank described earlier. These samples were wet sieved, utilising sieves of 2, 1, 0.5, and 0.25mm. Sediment of size <0.25 mm was also collected, with results shown in Table 2.

Table 2. Sieve fractionation of samples taken at three depths from a stirred vertosol mixture. Data is soil mass (g) of dry soil.

Sieve size (mm)	Sampling location and weight in grams		
	Near surface	Middle depth	Just above the bottom
>2	0	0.01	6.01
>1	0	0.08	3.11
>0.5	0.29	0.06	2.95
>0.25	0.23	0.55	1.93
<0.25	0.55	0.96	1.25

Table 2 shows that there was no sediment in the upper two larger sieves for the sample taken just below the water surface, and sediment collection increased with decrease in sieve size. This pattern was similar for samples taken at mid-depth, though some soil was collected on all sieves. In contrast, for the sample taken near the bottom of the container, sediment collection decreased with decrease in sieve size, and collections in the larger sizes were much greater than for samples taken higher in the mixture.

This evidence, although taken at $t = 3.5$ seconds, provides a strong indication that it is extremely unlikely that sediment of all sizes was uniformly distributed throughout the entire water depth at $t = 0$. Hence, error due to this cause is likely to be another significant contributor to mass underestimation by sampling.

From this exploratory study it appears that a simple practical method improves the estimate of the total soil loss in those field studies which employ the “silt collection box with stirring” technique generally employed in the USLE type experimentation. An estimate of time t between stirring and sampling, and measurement of the sediment settling velocity characteristics are the only additional information needed to use the correction, i.e. Equation (1).

In the reported experiments sampling was carried out at three depths in each of the four replicates. This should have yielded a more accurate estimate of $M_s(t)$ than if only single samples were taken, as was the common practice in USLE experiments.

Conclusion

This work indicates the possibility of serious error in the factors of the USLE. These factors (such as K , L and LS) are widely used in predictive computer programs. The simple method given in the paper allows a substantial measure of correction in the estimate of soil loss from runoff plots provided the further information is collected as described

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