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The Impact of Management and Other Factors on the Size Distribution of Hillslope Eroded Sediment

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Brian Joseph Chomicki
August 2009

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DEDICATION

This research is dedicated foremost to my family, for if not for their unconditional guidance and support none of this would have occurred. Otherwise, this effort is dedicated to the progress of the future.

ACKNOWLEDGEMENTS

I would foremost like to extend my sincere thanks to my major professor, Dr. Daniel Yoder, for his continued assistance and guidance through the course of this Master's program. In addition, special thanks to my committee members Dr. Neal Eash and Dr. John Tyner, and Wesley Wright for their insightful input and support with completing this project. Finally, I must thank my peers, faculty, and staff of the University of Tennessee Biosystems and Engineering and Soil Science Department as well as USDA-ARS, for providing my stipend and Research Assistantship. This could not have happened without that aid, and I will continue to share the kindness and generosity that USDA-ARS / UTK-BESS have shown me to others as my career develops.

ABSTRACT

Land disturbances cause considerable environmental, economic, and health impacts from the detachment, transport, and deposition of sediment. The Revised Universal Soil Loss Equation-version 2 (RUSLE2) is an erosion and sediment transport model commonly used by regulatory agencies to develop management strategies that mitigate some of these impacts. RUSLE2 uses the eroded sediment size distribution (ESSD) at the point of detachment in mass transport calculations, which are generally assumed to obey particle diameter/fall velocity relationships consistent with Stokes Law. RUSLE2 currently estimates the distribution of eroded sediment by dividing the ESSD at the point of detachment into 5 size classes solely as a function of the matrix soil dispersed clay content.

The present model fails to describe the impacts of some popular sustainable agriculture systems because specific effects of soil management practices (tillage and residue), as they influence the ESSD, were not accounted for when the equations were developed. Additionally, the current relationships only describe ESSDs at the point of detachment, which fails to describe spatially related ESSD differences. Finally, the number of size classes currently used to describe the ESSD does not adequately represent true conditions.

This study revised current ESSD equations through an analysis of published research not accounted for in the current RUSLE2 model, with emphasis on the effects of management and scale. The research found that the proposed revisions to these equations better describe the size distribution of hillslope detached particles for four independent data sets (avg. RMSE = 182.5 micrometer) than the current approach (RMSE = 208.4 micrometer), partially by including previously unaccounted management factors. Spatial relationships as they influence the ESSD were also defined to aid RUSLE2 in modeling difference and correlations between the resulting sheet and rill

ESSD as either scale predominates. The resulting RUSLE2 modifications were found to be more accurate and describe a broader range of conditions, so these equations could ultimately be implemented in conjunction with a RUSLE-based field scale model to aid in managing chemical transport as well as sediment yield.

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CHAPTER I

INTRODUCTION AND GENERAL INFORMATION

Unchecked land disturbances cause considerable environmental, economic, and health impacts from the detachment, transport, and deposition of sediment. The combined effect of these individual erosion processes results in the transport of a distribution of primary particles and soil aggregates that varies is size depending on the contributing scale (Weakly, 1962; Swanson et al., 1965; Swanson and Dedrick, 1967; Meyer et al., 1975a; Gabriels and Moldenhauer, 1978; Meyer et al., 1980). To help mitigate erosion-based nuisances, both federal and state agencies have adopted laws (e.g., Clean Water Act 1973, 1987 Amendments) requiring that the "physical, chemical, and biological integrity" of both soil and water be "maintained". Such regulatory actions have resulted in both qualitative (certified inspector) and quantitative (predictive modeling) efforts to ensure compliance with these laws and regulations through the implementation of soil management practices to reduce erosion and sediment delivery.

Various erosion and sediment transport formulas exist and to estimate the amount of sediment eroded based on described field conditions. These models calculate the amount and size distribution of sediment delivered using either empirically-derived relationships or more analytical, process-based relationships. The eroded sediment size distribution (ESSD) of soil particles and aggregates is used in these models to calculate transport-energy related detachment, transport, and deposition rates. Because various models calculate detachment/deposition rates based on different (empirically derived vs. process-based) parameters, the ESSD needs to be defined for conditions specific to the working framework of a desired model (i.e., an appropriate ESSD for each model-compatible scale). In other words, a valid transport/deposition model should be able to make use of the other parameters controlling the associated erosion model (e.g., plot-scale, soil texture, etc).

The Revised Universal Soil Loss Equation (RUSLE) is one model used by regulatory agencies to ensure compliance with environmental regulations and government subsidy programs. RUSLE uses the ESSD at the point of detachment in mass transport calculations, generally assumed to obey particle diameter/fall velocity relationships consistent with Stokes Law, which states that fall velocity is primarily sensitive to particle size. Additionally, accurate estimates of the particle specific surface area (based on the particle diameter) are required for chemical transport modeling applications related to transported sediment masses. The Revised Universal Soil Loss Equation-version 2 (RUSLE2) currently estimates the distribution of eroded sediment by dividing the ESSD at the point of detachment into 5 size classes solely as a function of the soil matrix primary particle distribution, specifically the clay fraction (Foster, 1985).

Missing from these current modeling capabilities within RUSLE2 are the specific effects of soil management as it influences the eroded ESSD at the point of detachment. In addition, the currently defined relationships only describe sediment size distributions as they exist at the point of detachment, which fails to describe ESSDs as they are related to scale. It is also important that the management effects be reflected in the ESSD, so that the true impacts of management are reflected in the sediment transport results. For example, RUSLE developers have often fielded complaints from advocates of alternative agriculture, who claim that their high-biomass management schemes result in increased soil aggregation, reducing both detachment and transport. The management aspects of these schemes on erosion appear to be taken into account through the RUSLE2 management subroutines, but the impact on transport is not (USDA-ARS, 2008a, 2008b). Also, the number of size classes currently used to describe the size distribution of both primary particles and aggregates is too small to ideally characterize real conditions (Silburn and Loch 1989).

This study revised current ESSD equations through an analysis of published research generally not accounted in the science currently in RUSLE2, with specific

emphasis on modeling the effects of management and scale. These proposed revisions improve on previous RUSLE ESSD modeling capabilities by enabling a more diverse set of management-related user-input options. Additionally, since the size distribution of soil particles as they are detached by either raindrop or concentrated flow erosive forces is different, spatial relationships as they affect the ESSD were defined in the hopes of describing any correlations between the resulting combined sheet and rill ESSDs as either scale predominates. To achieve these objectives a new ESSD predictive modeling approach is proposed that describes the largest size of eroded sediment at various cumulative mass percentages instead of trying to estimate the mass percentage that exists at discrete size classes.

The success of these proposed revisions were evaluated based on the ability to describe the effects of previously unaccounted management factors on the size distribution of hillslope detached sediment more accurately than the current RUSLE estimates. While limited, the resulting RUSLE modifications improve the accuracy of ESSD estimates and enable a more descriptive management plan to be modeled.

EROSION PROCESS CONCEPTUAL OVERVIEW

Research has demonstrated that eroded sediment exists as a mixture of various sizes of primary particles and aggregates (Weakly, 1962; Swanson et al., 1965; Swanson and Dedrick, 1967; Meyer et al., 1975a; Gabriels and Moldenhauer, 1978; Meyer et al., 1980). Kinnell (2005) identified four detachment/transport mechanisms that occur over the various hillslope erosion scales (interrill and/or rill):

1) Raindrop detachment and minimally splash transported ESSDs (RD-ST)
2) Raindrop detachment and raindrop-induced flow transported ESSDs (RD-RIFT).
3) Raindrop detachment and flow transported ESSDs (RD-FT)
4) Flow detachment with ESSDs transported by concentrated flow (FD-FT)

These detachment-transport processes result in different size distributions of eroded sediment that exist over localized scales, as seen in Figure 1.

The ESSD from a hillslope is initially generated in response to raindrop impact detachment forces. As raindrops impact the soil surface, soil particles and aggregates dislodge and are transported over a very small scale by the raindrop splash. Raindrops deliver erosive impact energy to the soil surface as a function of the raindrop mass, shape, impact angle, and fall velocity (Riezebos, 1985). Generally speaking, as the drop size increases, so does the detached proportion of larger aggregates. The kinetic energy is directly related to the raindrop size, which in turn dictates the eroded particle distribution and mass detached. For example, the impact of a 5 mm diameter raindrop contains 125X more energy than a 1 mm drop (Furbish et al., 2007). Additionally, the RD-ST rate and ESSD is related to the kinetic energy of the falling raindrop and soil characteristics (De Ploey and Savat, 1968; Quansah, 1981; Al Durrah and Bradford, 1982b; Torri et al., 1987; Truman, 1990; Sharma et al., 1991).

Terry (1998) identified three RD-ST stages that occur when raindrops impact the soil surface in the absence of ponded water:

1) The collision and deformation of a falling raindrop at the soil surface.
2) The rupture and collapse of the drop into a thin disk of fluid spraying radially outwards from the point of impact.
3) The jetting of daughter ejection droplets in parabolic trajectories away from the original drop landing position.

The amount of sediment transported by rainsplash has been shown to decrease exponentially with the distance away from the impact location (Poesen and Savat, 1981; Savat and Poesen, 1981; Torri et al., 1987; Legout, 2005). Leguedois et al. (2005) observed splash transport distances associated with a 252 J m^{-2} h^{-1} (or 29 mm h^{-1}) rainfall intensity of various size fractions of the ESSD ranging from 4-23 cm away from

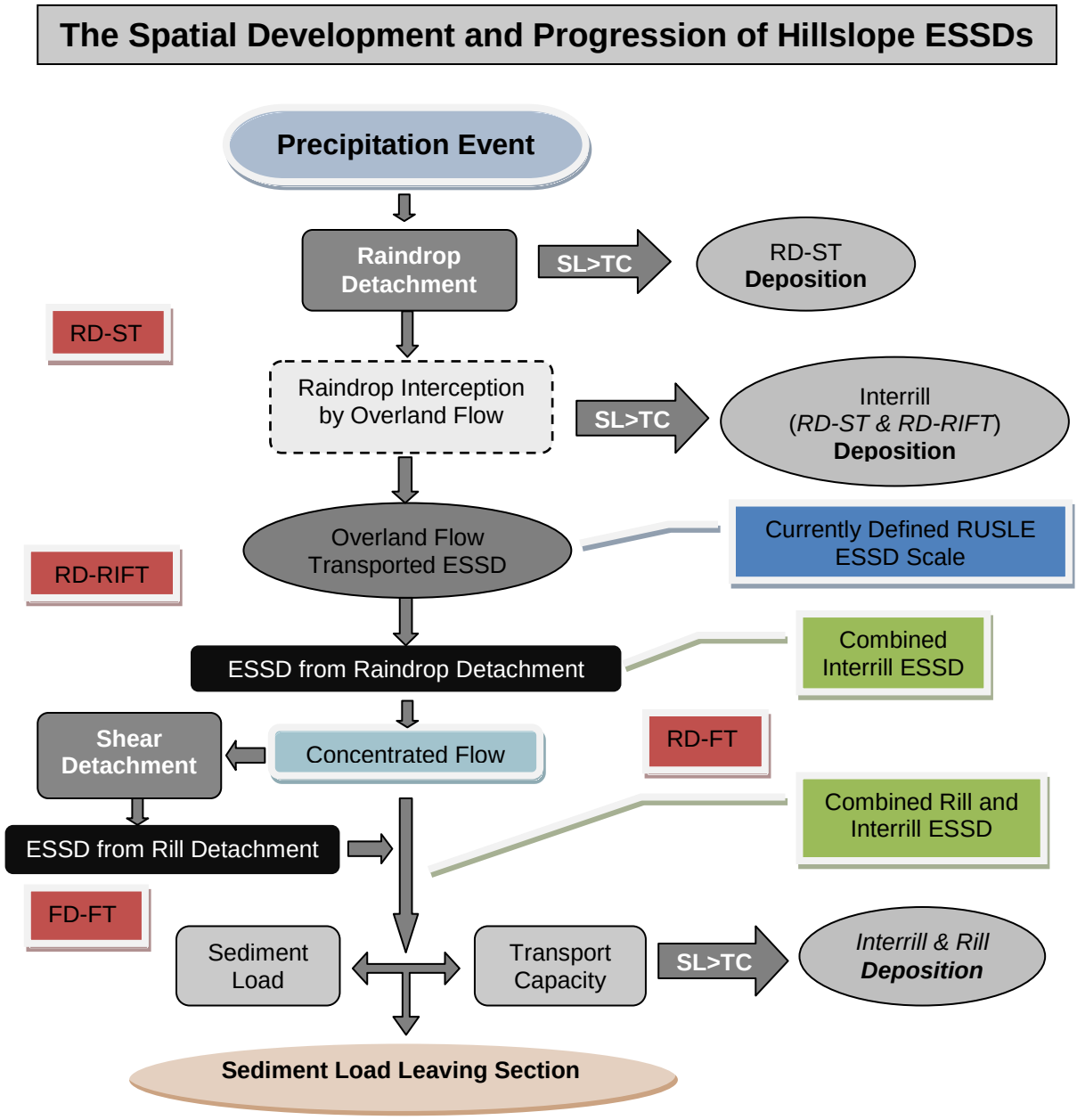


Figure 1: Hillslope ESSD process overview based on Toy et al. (2002). Terminology from Kinnell (2005) shows distinct ESSDs as a function of spatially unique detachment/transport mechanisms. Red-shaded boxes are located at individual areas that exhibit a unique ESSD. Darker green-shaded boxes represent the RUSLE ESSD scales that the proposed revisions are intended to describe. Blue-shaded box represents the scale that the old ESSD equations currently describe.

the raindrop impact site. The greatest transport length occurred for sediment particles ranging from 100-200 μm, and the splash lengths decreased for both finer and coarser sediment sizes. Transport of larger particles (50-2000 μm) occurred as individual particles, whereas smaller particles were transported in splash droplets. Furbish et al. (2007) found that soil slope along with raindrop characteristics have an impact on the transport distance of rainsplash detached soil. Generally, more sediment is transported in the down-slope direction. The downslope distance transported was found to be a function of both the raindrop size and impact angle (slope). Larger drops tend to transport a larger total mass of sediment, as well as larger particle sizes in that mass. Additionally, larger raindrops, which fall at greater velocity, tend to transport particles further. The resulting ESSD of the rainsplash-detached sediment is spatially distributed outward from the impact site, and this effect is impacted by specific rainfall, slope, and soil conditions (Chaplot and Le Bissonnais, 2003), and is the combined result of both aggregate detachment/breakdown processes and the transport of detached sediment by the remaining available kinetic energy (Legout et al., 2005).

Although RD-ST mechanisms are significant to the detachment of particles, when considering the ESSD generated from a larger scale, this transport is in all directions, so the net impact of RD-ST processes on the ESSD are overshadowed by the effects of other transport mechanisms that are more unidirectional. These other detachment/transport mechanisms are more applicable for empirically based models because the resulting ESSDs are generated from a more representative scale. Thus, while the transport effects associated with RD-ST scale overall contributes negligibly to the measured ESSD on the normal empirically-modeled scale, Splash-Detachment is the predominate detachment mechanism acting during the initial stages of precipitation events and for small/interrill scales.

Once precipitation rates surpass infiltration rates, runoff occurs as overland flow, which generally starts out as shallow and slow. Shallow overland flow or sheet flow occurs relatively uniformly over the landscape and transports rainsplash-detached

aggregates and primary particles downslope in the runoff (Young and Wiersma, 1973; Meyer, 1981; Kinnell, 1990). Initially, raindrop detachment-rainfall induced flow transport (RD-RIFT) processes tend to occur, as runoff energy is not sufficient to move soil material unless raindrops initially suspend the particles. RD-RIFT occurs as raindrops penetrate the ponded depth of the overland flow and either detaches soil particles or re-suspend previously detached soil particles that have been transported locally and deposited by raindrop splash (Kinnell, 2005). In addition, the depth of overland flow or surface ponding has been shown to affect the size and amount of splashed soil (Mutchler, 1967; Mutchler and Young, 1975; De Ploey, 1981; Poesen and Savat, 1981; Torri et al., 1987; Kinnell, 1991). Specifically, as the overland flow depth increases, the raindrop detachment rate decreases due to the cushioning effects of the water depth, which absorbs and disperses the raindrop kinetic energy (Palmer, 1964; Moss and Green, 1983).

In raindrop detachment-flow transport (RD-FT) cases the overland flow energy is great enough to remove loose surface particles that were detached by raindrop impact, but the effect of raindrop splash transport forces on particle entrainment is greatly reduced. RD-FT contains sufficient energy to remove loose or previously detached soil particles, but does not maintain enough energy to detach soil particles. RD-FT is a more efficient removal system than RD-RIFT, and therefore can transport larger particles (Kinnell, 2005). Oftentimes, both processes (RD_RIFT and RD-FT) occur simultaneously in the same flow pathway, resulting in the transport of coarser material by splash transport mechanisms and finer material by flow. The resulting ESSD associated with the interrill overland flow sediment load can therefore transport coarser material if the raindrop impact forces can initially detach the soil particles (Kinnell, 2005).

Shallow overland flow eventually concentrates sufficiently to initiate flow detachment, which begins to form rills. Direct splash transport of sediment to the rills does not usually occur; rather, shallow overland flow entrains the rainsplash detached

(and deposited) sediment and moves the sediment load laterally to rills as the scale is increased (Young and Wiersma, 1973). Flow detachment in a rill occurs when the concentrated flow energy (shear stress) exceeds the soil's critical shear stress (Figure 1; Rauws and Govers, 1988; Nearing et al., 1997; Toy et al., 2002). Furthermore, rill detachment rates are more sensitive to runoff discharge rates as compared to the slope gradients, which suggests that stream power (flow shear stress x velocity) may be the most important hydraulic detachment parameter (Nearing et al., 1997; Nearing et al., 1999; Zhang et al., 2002; Zhang et al., 2003). In addition to flow hydraulic characteristics, rill detachment rates are greatly affected by soil properties such as soil type, bulk density, texture, cohesion, soil strength, organic content, water content, infiltration, and seepage effects (Khanbilvardi and Rogowski, 1986, Nearing et al., 1988; Owoputi, 1994; Morgan et al., 1998). The distribution of detached soil particles resulting from flow down-cutting actions are different from the interrill size distribution, not only because of the very different detachment mechanism involved, but also because a sediment load already exists in the rill due to contributions from the interrill areas that provide flow to the rills. This means that the flow in the rills may be carrying substantial sediment with a unique ESSD even before any detachment in the rill can occur (Alberts et al., 1980; Alberts et al., 1983; Luk et al., 1993; Merten et al., 2001). Once within the rills, whether erosion of new material or deposition of existing sediment load occurs is a complicated function of the flow transport capacity, the existing sediment load, and whether the excess transport capacity has the energy intensity required to detach new particles. The resulting distance a particle can be transported before deposition (and ultimately the ESSD) is therefore a function of both the soil detachment and hydraulic transport conditions. Rill erosion or flow detachment-flow transport (FD-FT) processes should therefore be analyzed separately from interrill (RD-ST, RD-RIFT, and RD-FT) processes because the mechanisms that govern the ESSD and erosion rate of the separate processes are distinct. RUSLE2 lumps the impacts of these processes in estimating erosion because the scale at which the underlying data were collected

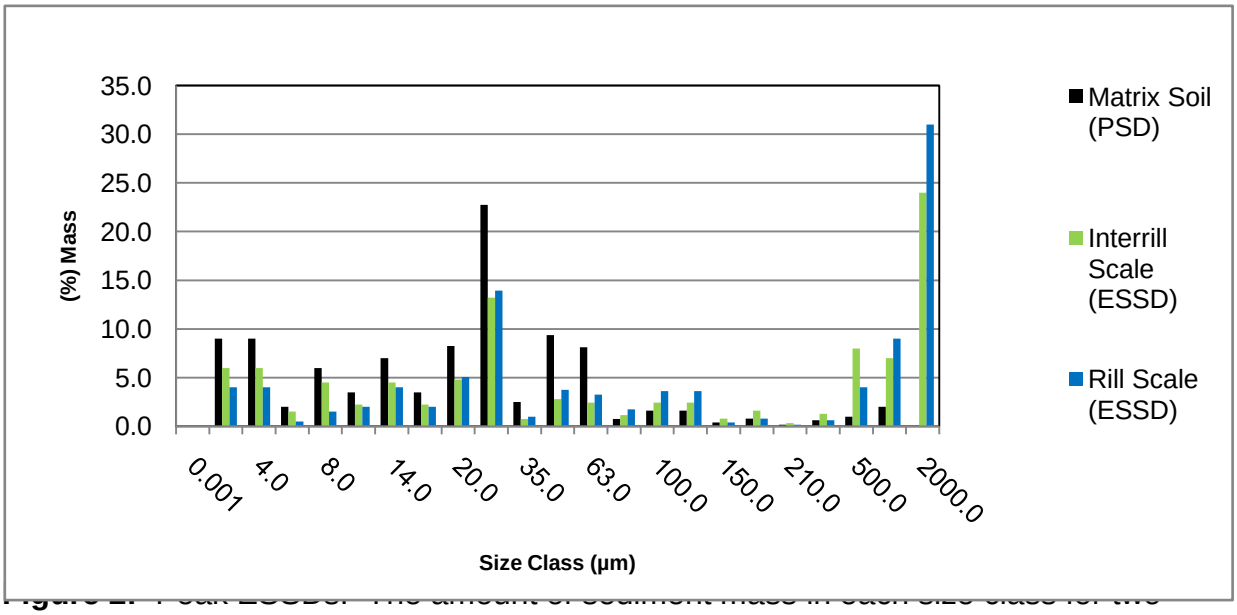
includes all of them, but RUSLE2 also includes an estimate of the rill-interrill ratio, providing a means of teasing apart the different processes.

Processes that govern other types of erosion such as wind, gully, and watershed-scale erosion rates are also governed by separate, distinct mechanisms, but are beyond the scope of this project and RUSLE applications. These processes will therefore be excluded from the following discussion, and the subsequent analyses will be restricted to characterizing ESSDs associated with various scales and treatments.

In order to evaluate how ESSDs are influenced by various scales and treatments, an ESSD needs to be evaluated against others. The next section will present the typical ways used to describe the ESSD and will introduce and demonstrate how variable factors specifically influence ESSDs.

DESCRIBING THE ESSD

The ESSD is commonly measured by wet sieving the undispersed eroded sediment (both primary particles and aggregates > ~63 µm) through various sized mesh sieves and measuring the mass percentage of the total that is retained for each sieve diameter size. The finer sediment (< ~63 µm) is then analyzed by other methods such as the hydrometer, pipette, laser diffraction, etc. These analytical techniques are also commonly used to measure the Particle Size Distribution (PSD) of bulk matrix soils. In this report, it will be assumed that the PSD is for the dispersed matrix soil. The subsequent values of mass measured for each size range is commonly reported as a peak size distribution (Figure 2). In addition to being represented by the mass in various size “bins” (i.e., Figure 2), the PSD and ESSD can also be represented as a cumulative size distribution curve (or S-curve; Figure 3), where D-values or distribution values can be selected to describe the percentage of the total mass below a specific size. A D-value describes the cumulative mass percentage of



different scales with moderately tilled soils under no residue coverage. The soil matrix PSD is also presented for a silt loam soil with 18% matrix clay content (Gilley 1986).

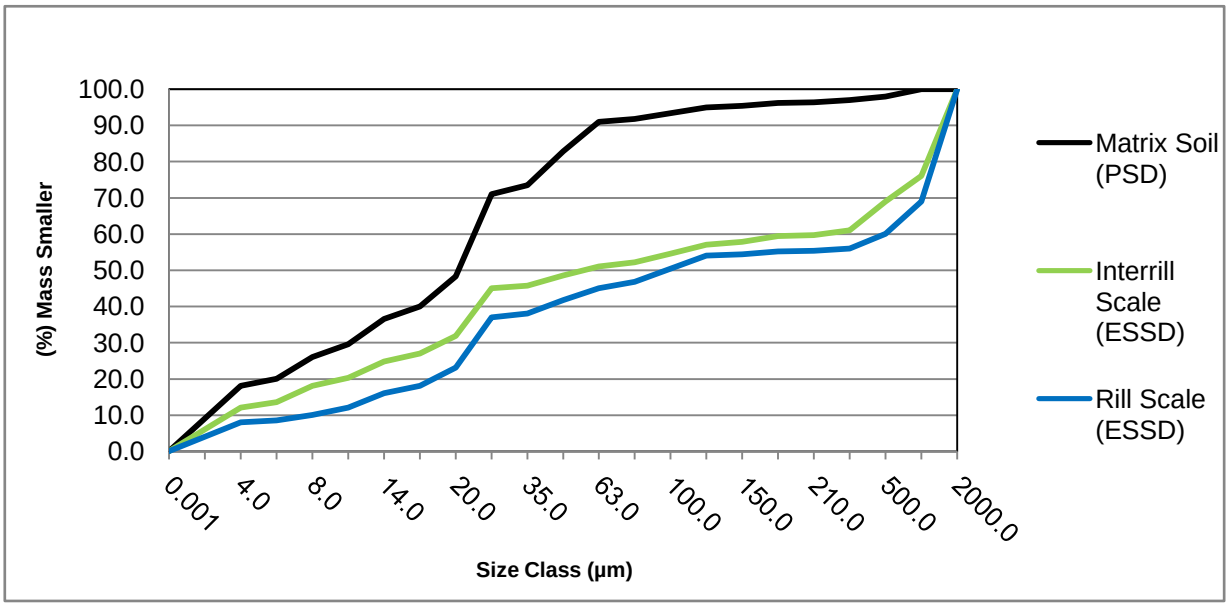


Figure 3: PSD and ESSD cumulative S-Curves. The lines show the cumulative sediment mass for two different scales with moderately tilled soils under no residue coverage. The soil matrix cumulative PSD is also presented for the soil, a silt loam soil with 18% matrix clay content (Gilley 1986).

eroded sediment that is below a specific size. Therefore, using D-values allows comparison of the size composition of various ESSDs, based on the mass.

Development of either the PSD or ESSD cumulative curves requires some interpolation based on the generally sparse data. Interpolation methods may vary depending on the soil characteristics, but for the purpose of this research all unreported size classes were linearly interpolated between the nearest adjacent values. Since ESSDs vary with scale, parameters needed to be defined that enabled independent analyses to be evaluated without conflicting responses due to scale. The next sections will review efforts made to distinguish between scales, then will review how management practices contribute to this variability. Once these conditional responses are reviewed, an overview of how RUSLE uses the ESSD in subsequent sediment delivery calculations is presented.

ESSD SCALE RELATED VARIABILITY

It is important to consider ESSD responses as affected by various detachment / transport mechanisms because, as depicted in Figure 1, highly variable detachment / transport conditions occur over different scales and can alter the resulting ESSD.

As discussed earlier, the splash-wash scale is typically controlled by the raindrop induced transport mechanism. Since raindrop characteristics such as drop diameter, intensity, slope angle, etc., govern the detachment-transport mechanism responsible for the ESSD, these conditions will result in an ESSD that is characterized by splash-induced (minimally washed) transport capacity for a relatively short scale ($<1m^2$). RD-ST scales tend to erode larger particles, but the acting transport mechanism is not likely capable of transporting these types of ESSDs across a significant distance. For example, notice that ESSD variability exists within this scale depending on the acting transport mechanisms (splash vs. wash), slope, and/or rainfall intensity (Figure 4).

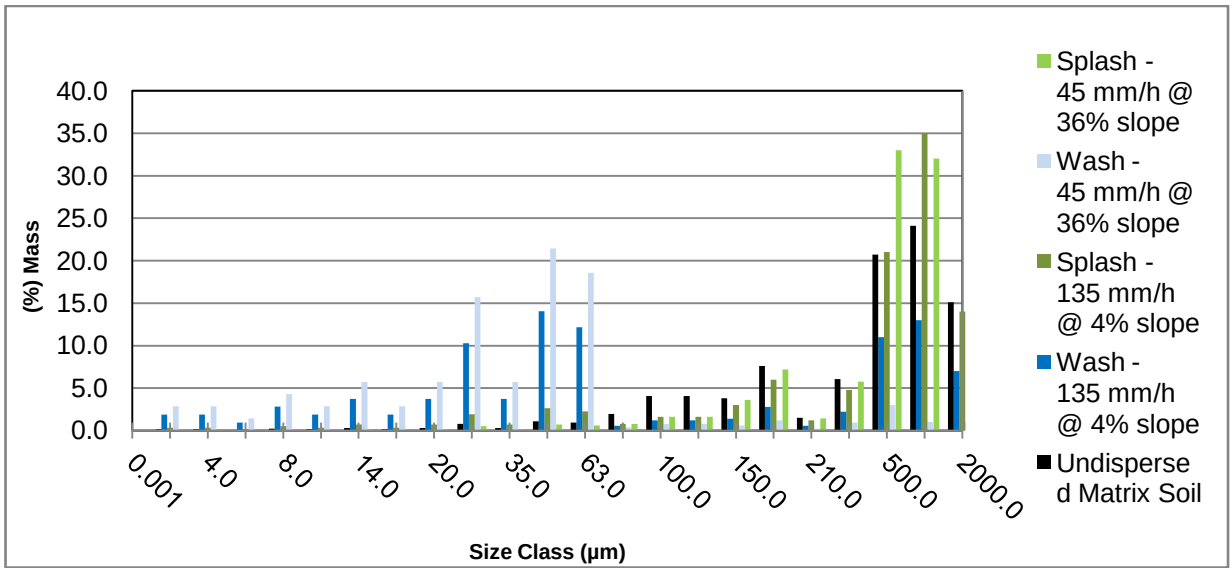


Figure 4: Splash/ Wash peak ESSDs. The bars show bin-based peak ESSDs for splash and wash detachment / transport mechanisms (Wan 1998).

If we observe the ESSD generated at a less localized interrill scale (i.e., where RD-RIFT detachment/transport mechanisms are characteristic), it is apparent that the wash transported ESSD is noticeably different than that from the RD-ST scale (Figure 4). The RD-ST scale ESSD contains more coarse sediment compared to other less localized interrill RD-RIFT (wash) scales. The acting detachment mechanisms are the same for both scales (Figure 1), which suggests that transport mechanisms are different.

Since the data collected for the USLE/RUSLE erosion estimation approach and for most sediment transport approaches were collected on a larger scale, inclusion of these small-scale splash/wash phenomena are probably not appropriate, but additional statistical support is needed to confirm whether this assumption is valid for both splash (RD-ST) and wash (RD-RIFT) scales (*Discussed in the CHAPTER IV: ANOVA Overview and Analysis*).

If a typical (FD-FT) interrill generated ESSD is compared to a typical (RD-FT) rill generated ESSD (Figure 5), it is apparent that the ESSD associated with the (FD-FT) rill

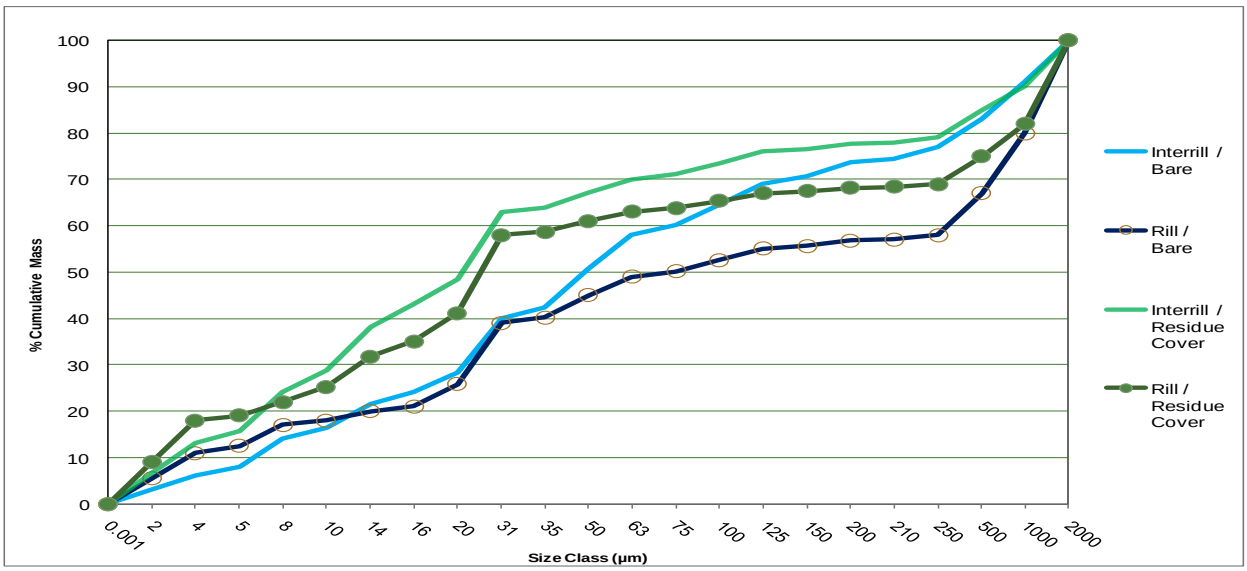


Figure 5: Cumulative S-Curve ESSDs; treatment-scale relationships. Cummulative ESSDs for two different scales for moderately tilled soils under no- and high- residue coverage (Gilley, 1986).

detached scale contains a larger proportion of coarser sediment, relative to the (RD-FT) interrill scale. This can be seen in Figure 5 where a greater percentage of larger sediment exists in the ESSD for the longer scale (22.1 m) compared to the same percentage of eroded mass for the shorter scale (3.8 m). In other words, the interrill scale erodes a greater percentage of smaller sized sediment as indicated by both higher cumulative mass (D-value) for a specific size class or by a lower size class for a specific cumulative mass value, but this decrease occurs over various size classes depending on the treatment and scale. This difference between interrill and rill generated ESSDs can be attributed to a combined effect of increased detachment-transport energies associated with the larger (rill) scales characteristics.

Management practices also affect the ESSD, and the response is different depending on the scale. Figure 5 demonstrates that although residue coverage tends to increase the amount of smaller sediment transported, this effect is not as distinct for larger rill scale ESSDs. For example, 25% (D-25) of the cumulative eroded mass is less

than 10 µm for the high residue interrill ESSD and less than 13 µm for the high residue rill ESSD. For the D-75 value, 75% of the cumulative eroded mass is less than 125 µm for the high residue interrill ESSD and less than 1,000 µm for the high residue rill ESSD. In other words, if we compare the largest differences between D-values seen for both interrill and rill scales, significant differences can be seen depending on the treatment. For the longer plot (22.1 m), the reduction in the amount of coarser material is not as significant as for the shorter plot (3.8 m).

As noted in Figure 5, treatments significantly affect the ESSD. Since it is both detachment and transport forces that contribute to the ESSD, these should be evaluated with respect to treatment practices, because while a treatment might impact the ESSD, responses might vary depending on the scale considered. Since the processes that govern the composition of the ESSD are spatially variable (Figure 1), the next sections will present typical ESSDs that exist for these scales as well as very briefly identify how treatments affect these ESSDs.

SCALE 1DEFINED

Because the findings of this research are intended for RUSLE applications, scales were evaluated on conditions typical to similar modeling capabilities designed for interrill and rill scales. As can be seen in Figure 1, there are several scales that contribute to what is going to be regarded as Scale_Interrill for this analysis: RD-ST, RD-RD-RIFT, and RD-FT. The decision of where to make theoretical distinctions is difficult, but initial research demonstrated that the most significant difference that impacts field-scale ESSDs is between rill and interrill scales. Therefore the conceptual distinction between these scales is set at where shallow overland flow starts to concentrate into rill flow conditions (FD-FT). The following discussion will address the mechanisms that exist for Scale_Interrill, and how these mechanisms act to deliver a distinct ESSD separate from Scale_Rill. Additionally, any limitations to this approach will be reviewed.

Meyer et al. (1975a, 1975b) found that interrill sediment is composed of more fine sediment than is rill-eroded sediment, because more intense local impact-detachment mechanisms (i.e., raindrop impact) act on the interrill area, in effect demolishing large aggregates and leaving smaller aggregates and particles susceptible to interrill (and subsequent rill) transport. Also, interrill erosion exhibits low transport capacity when compared to rill erosion, because of the comparatively low flow energy resulting from the very shallow sheet flow. The low transport capacity does not typically detach sediment and readily deposits coarser sediment from the sediment load resulting in more fines being transported (Swanson and Dedrick, 1967; Young, 1978; Alberts et al., 1980). This shows up as an enrichment (higher concentration than in the PSD) of finer sediment. This enrichment process is more likely to be directly affected by the transport mechanisms associated with interrill processes, so any management practices that impact the proportion of fines do so on the interrill scale and should be investigated relative to either detachment or transport mechanisms expected for this scale.

Shallow overland flow can thus impact the ESSD in several ways: by absorbing raindrop impact forces, which reduces detachment rates; by increasing transport distances of finer sediment; or through the selective transport of finer particles (Parsons et al., 1998; Kinnell, 2005). Because of this, the ESSD of transported soil particles from interrill areas is limited by either the (raindrop) detachment availability or by the transport capacity of the overland flow (Parsons, 1996; Sutherand et al., 1996a, 1996b; Kinnell, 2006).

Soil texture can also have an impact on the interrill ESSD. Gabriels (1999) observed the erosion rate and ESSD variability for two soils (sandy loam and loamy sand) at various small slope lengths (0.3 - 0.9 m). The soil matrix texture was the factor deemed most responsible for the relationships observed between slope length and soil loss. For both soils, increasing the slope length tended to increase the overall interrill erosion rate, but the coarser soil (loamy sand) exhibited a decrease in erosion rate per unit slope length as length increased. As slope length increased, both soils

demonstrated an enrichment of particles smaller than 50 µm, but for the coarser soil (loamy sand), the larger detached particles tended to deposit out. It is important to note that this study was conducted on an interrill scale where selective transport was shown to have an apparent effect on the ESSD depending on where this distribution is measured. Furthermore, this research indicates the significance of how the slope length acts on the ESSD of detached soil particles at the interrill scale, and how this effect is variable across soil textures.

Of greatest concern relative to this phenomenon are soils high in sand, which warrants further concern when including these soils in the subsequent analyses. From the transport-limiting enrichment results exhibited by high sand soils on the interrill scale, it was noted that transport-limiting conditions can exist as a result of scale and/or soil. Furthermore, scale was shown to be a limiting factor when larger sediment was detached. Therefore one can assume that scale will be a significant factor on the ESSDs that are generated from high sand soils, and that these soils should not be analyzed in the same manner as other soils because of this concern. From these results it is assumed that high sand soils and small-scale splash/wash detachment-transport mechanisms exhibit unique relationships within the ESSD, especially as the matrix PSD varies between soils. These soils and scale were therefore removed from the analysis unless otherwise noted, with the intention of analyzing them separately at some later time.

The above findings suggest that over a certain range of scales the ESSD is generated by similar detachment-transport mechanisms, but as scale increases more mechanisms contribute to the ESSD variability. Based on these findings, an interrill scale hereafter referred to as Scale_Interrill, will be used to categorize ESSDs generated primarily as a response to raindrop-detachment forces with shallow overland flow transport (RD-FT). Because several detachment-transport mechanisms exist for this scale (RD-ST, RD-RIFT, RD-FT), certain data are not applicable, since they do not describe the conditions that RUSLE is intended to model (RD-ST). Specifically, since

splash transport can transport particles larger than shallow overland flow transport mechanism can actually move, and since in the USLE/RUSLE studies splash transport would be in all directions and would be negligible compared to shallow flow transport, studies were excluded where the ESSD is primarily a function of splash transport. These are generally very small-scale lab studies that made a specific effort to measure splash transport. Additionally, since the transport capacity is often a limiting factor for very coarse soils, high sand soils were removed from consideration to prevent any erroneous inclusion of data in later analyses. This might possibly restrict the subsequent analysis to be only applicable within the range of clay content from the soils that were used to develop the equations.

SCALE 2 DEFINED

Since the ESSDs from rill scales are distinct from interrill scales, any subsequent analysis will need to address this difference. It is for this reason as well as the ones below, that the rill scale will be separated from Scale_Interrill analyses. The following discussion will address the mechanisms that exist for rill scale, and how these mechanisms act to deliver a distinct ESSD. Additionally, limitations to this approach will be reviewed.

Rill detachment/transport mechanisms include flow with sufficient amounts of energy to detach larger particles (Meyer et al., 1975a; Armstrong and Stein, 1996). Nearing et al. (1991) found correlations between overland flow detachment rates and flow depth, slope, and mean weight diameter of the soil particle. Additionally, once particles are entrained, rill transport mechanisms are able to transport larger particle sizes due the higher energy available for transport (Young, 1978; Alberts et al., 1980). The selective transport of finer particles in rills is therefore assumed to be minimal. This assumes that any resulting enrichment processes tend to occur disproportionately on interrill areas, and that the resulting sediments are transported easily through the rill areas, where the transport capacity is generally larger (Foster and Meyer, 1975).

Malam Issa et al. (2006) found that the relative distributions of interrill and rill eroded sediment became less different at large field scales. These results suggest a transport-limited process occurring at larger scales, which means that the sediment mass and ESSD delivered to the field edge depend more on the runoff and its transport capacity than on the ESSD at the point of detachment. Dunford et al. (1993) found that the transport capacity tended to limit the erosion rate of larger particles, while detachment supply tended to limit the erosion rate of smaller particles. Additional studies demonstrate conflicting opinions on whether or not different rill-scale ESSDs occur as a function of the dominant detachment mechanism, or due to a transport limiting condition (Farmer, 1973; Meyer et al., 1975b; and Young, 1978; Alberts et al., 1980).

In either case, enrichment mechanisms pose significant considerations when designing management plans. For example, one might be concerned with the offsite impact of smaller size fractions, which disproportionately tend to be generated from interrill areas. Therefore, a management practice such as surface residue could be implemented to intercept raindrop impact forces and help reduce the amount of fine sediment being detached and transported. This would be due not only to the surface protection provided by the residue, but also by the surface residue increasing the roughness seen by the shallow sheet flow, reducing the transport capacity and causing larger sediment to be deposited. Intrinsic to this reasoning is a critical concept important to understanding the ESSD generated by rill erosion processes. That is, the rill ESSD is a function of both rill and interrill processes, so the resulting ESSD will vary under alternate management conditions and will do so as a function of how management affects interrill or rill specific detachment and/or transport mechanisms (Figure 1).

The above considerations suggest that the ESSD generated from rills is a function of distinct detachment-transport mechanisms separate from Scale_Interrill. Based on these findings, the rill scale, from now on referred to as Scale_Rill, will be

used to distinguish the soils for which the ESSDs are defined primarily as a response to runoff , whether that be to transport sediment fed to the rills from the interrill areas, or to detach sediment within the rills. Since the runoff at this scale can exist and not detach particles, efforts will be needed to distinguish between these conditions so that the resulting ESSD is also reflective of Scale_Interrill conditions. Because a Scale_Rill grouping was assigned to any data from a plot with a length of >15 m, the data will need to be evaluated to distinguish between these conditions so that the resulting equations are derived based on either rill (flow) detachment or large scale interrill (raindrop) detachment mechanisms.

Once the significant scales are identified, the effects of management practices on the ESSD need to be addressed so that ESSD responses from similar treatments and scales can be evaluated in the later analyses (ANOVA, Regression, and Validation).

MANAGEMENT EFFECTS ON THE ESSD

Land use is the single most controllable factor in terms of options one might have to affect erosion rates and ESSDs. Land use factors refer to both the general land use conditions (construction, agricultural, etc.), along with any specific implemented support practices such as residues, vegetative filter strips, etc. Land use conditions and support practices will be collectively referred to as management conditions, and are generally implemented to preserve the integrity of the soil, to increase productivity, or specifically to reduce sediment delivery from the site. Management conditions can be both constructive and destructive to the soil structure.

Various management conditions can influence both the surface and subsurface conditions related to erosion processes and, as a result, alter the ESSD (Alberts et al., 1981; Annabi et al., 2007; Cogo et al., 1983; Six et al., 2000a; Whalen and Chang 2002; Williams et al,. 2000). For example, surface residue generally absorbs raindrop and surface runoff energy, resulting in less energy available to detach and transport soil particles. Aggregate stability is critical to resisting detachment by disruptive erosion

forces, so the degree of aggregation and any process that increases or decreases aggregation can be important to modeling the ESSD. Vegetation can increase the structure of aggregates through the presence of plant exudates, root development, and/or the decomposition of organic matter (Tisdall and Oades, 1982). Tillage disturbances tend to break down aggregates into smaller aggregates and primary particles, and result in a finer ESSD (Deizman et al., 1987). Specific examples of these processes as they affect the ESSD are described in the following sections.

TILLAGE

The importance of modeling aggregation with respect to transport modeling becomes increasingly critical to accurate estimates of the ESSD of eroded soils when aggregates are destroyed. Tillage practices can destroy soil structure through the mechanical disruption of cohesive aggregates. This disturbance degrades aggregates in relation to the intensity of the disturbance and the prior degree of aggregation.

Tillage-based practices significantly reduced the macro-aggregate proportion and increased the micro-aggregate fraction of the ESSD when compared to no-tillage practices (Deizman et al., 1987; Six et al., 2000a; Mikha and Rice, 2004). Increased cultivation intensity decreased the soil organic matter carbon and altered the ESSD corresponding to native vegetation, no-till, and tillage-based plots. Increased cultivation intensity shifted the ESSDs in both treatments from a greater percentage of macro-aggregates to an increased percentage of micro-aggregates (Six et al., 2000a).

Cogo et al. (1983) found that under bare conditions chisel-plowed soils produced the smallest aggregates when compared to No-till, moldboard plow, chisel-disked, and moldboard-disked. Tests were run shortly after tillage operations were complete and the largest aggregates were found to result from the more destructive tillage operations (i.e., chisel-disked and moldboard-disked tillage operations). Less intense disturbances associated with No-till treatments were in the midrange of the two aggregate size differences possibly due to the added impact of residue cover. Under the presence of

residue, the size distribution of eroded sediment was fairly consistent for all conditions except for chisel plowing. The diminished effect of residue on altering the ESSD from the chisel plow treatment was attributed to an increase in runoff as compared to the other operations.

Tillage can also destroy aggregates through bio-chemical processes related to physical disturbances. Since added residue increases organic matter, which promotes aggregation (See *Residue Cover Section*), any decreases in organic matter (OM) percentages could also have impacts on the aggregate stability. This means that additions of OM and their impact on aggregation cannot be modeled without taking into account the tillage scenario, as studies have shown that tillage can lead to a net overall loss in OM even for systems with high OM additions (Reicosky, 1995).

Since tillage practices tend to destroy soil macro-aggregates, with the extent of destruction primarily related to tillage intensity, specific considerations are warranted to account for variable tillage-related management practices. These responses should reflect increases in finer proportions of eroded sediment associated with intense tillage practices and whether these responses are similar for both erosion scales should be evaluated.

RESIDUE COVER

Vegetative residue cover is known to protect the soils surface from erosive mechanisms by shielding the soil surface from raindrop impact and by reducing the runoff velocity of the overland flow (Alberts and Neibling, 1994). Martinez-Mena et al. (1999) quantified a reduction in raindrop impact energy by 50% and runoff energy by 75% due to the presence of vegetative cover, but it appears that what raindrop impact energy does hit the surface still has the same effect on ESSDs.

This limited influence on the resulting ESSD has been attributed to a decrease in raindrop impact and especially runoff (detachment and transport) energy due to the

presence of surface cover (Meyer, 1972; Lattanzi et al., 1974; Alberts et al., 1981; Alberts and Moldenhauer, 1981; Cogo et al., 1983; Palis et al., 1990).

Although vegetative surface residues are very effective in reducing the total mass of eroded sediment, they appear to selectively erode finer particles. Runoff enrichment processes caused by surface residues (as mentioned above) have been attributed to transport mechanisms, most notably occurring in the interrill areas (Gilley et al., 1986). In general, residue reduces the runoff velocity, decreasing the transport capacity and increasing sediment settling. This decreased transport capacity, along with surface detachment protection associated with residue cover, results in transport of a finer sediment as compared to that under bare conditions.

This conditional effect was observed in studies by Gilley et al. (1986), who noted that the enrichment of fines was observed throughout the slope length on interrill areas, but that the enrichment was less pronounced when rills were allowed to contribute to erosion processes**.** When rills were active, larger particles were additionally transported, due to the increased transport capacity associated with an increased rill flow and velocity with increased length, and due to flow erosion occurring within the rills themselves.

A subsequent study by Gilley et al. (1987) examined the comparative effects of soybean and sorghum residues on the ESSD at various slope lengths. Rates of both applied residues were found to alter the ESSD as slope length increased, but the results were inconsistent in describing a clear trend between residue rate and significant differences in the resulting ESSD. Different ESSDs were observed under various residue rates, along with increased proportions of larger size fractions as transport processes acted over the increased slope length. Some inferences in the study suggest that residue type and loading rate (residue mass per area) could be influential, but results were limited.

The effects of a vegetative canopy (leaf inclination, leaf orientation, effective canopy area, leaf sub-catchment area, leaf area index, lowest canopy area, largest canopy area, and canopy overlap area) on particle detachment by raindrop impact did not demonstrate any significant difference in ESSD values as compared to the bare soil (Foot, 2005). The additional protection attributed to the presence of canopy cover was thought to be offset by larger drips, which collect and fall off the plant as a larger (more energetic) drop. This experiment used plastic plants and sand instead of real plants and soil, so the results might not be accurately represent true physiological responses such as how certain plants intercept raindrops and deliver them to the soil surface through flow down the plant stem. The results qualitatively demonstrate the energy-related erosion effects that result under canopy conditions and suggest that canopy cover, while it may have an impact on the total mass eroded, has little significant impact on the ESSD.

Besides its effects on reducing erosion and causing selective transport, residue has been shown to have secondary effects on the ESSD due to the added inputs of organic matter to the soil nutrient balance. These additions of organic material such as vegetative residue, compost, bio-solids, etc., contribute to long-term aggregate development as a result of vegetation decomposition, which releases organic acids and residues that cement particles together (Gale, 2000; Six et al., 2000a). Specific aggregation processes resulting from residue additions can be attributed to increased micro-/macro-organism populations in response to the added nutrient substrate (residue). As these populations degrade organic materials, exudates are secreted that cement particles into larger and stronger aggregates (Oades, 1967).

Aggregate formation has been shown to affect different size fractions depending on the active aggregate forming process. Gulser (2006) found that forage cropping decreased the proportion of aggregates <500 μm and increased the proportion of aggregates > 1,000 μm. Increased addition of OM has been found to enhance both macro- (>250 μm) and micro-aggregation (< 250 μm) development and stability by

various mechanisms (Tisdall and Oades, 1982; Mikha and Rice, 2004; Annabi et al., 2007).

Specifically, Tisdall and Oades (1982) described the organic agents responsible for various aggregate size development and classified these organic binding agents into three categories: transient (mainly polysaccharides), temporary (fungal hyphae and roots), and persistent (humus; resistant aromatic components associated with polyvalent metal cations and strongly sorbed polymers). Macro-aggregate formation (>250 μm) was attributed to soil management conditions, which promote root and fungal hyphae binding of smaller aggregates into larger ones. Micro-aggregate formation was attributed to the presence of humic, persistent organic binding agents.

Annabi et al. (2007) found that both immature and mature composts of municipal solid waste, bio-waste, and co-composted sewage sludge and green waste increased the aggregate stability by means of distinct mechanisms. Fungal biomass and increased hydrophobicity associated with enhanced microbial activity were the dominant mechanisms that increased the aggregate stability associated with immature compost additions. Mature compost additions increased the aggregate stability through added inter-particle cohesion strength resulting from the diffusion of organic substances into the aggregate. While the percent of water stable aggregates did increase compared to regular conditions, long term cattle manure applications were shown to destabilize larger dry-sieved soil macro-aggregates (> 12.1 mm) to smaller (< 2.0 mm) micro-aggregates (Whalen and Chang, 2002). This degradation of larger aggregates was attributed to the added presence of monovalent cations contained in the manure, which act as dispersive agents when they reach high enough concentrations.

Because ESSD relationships with organic matter are still unclear, the following analyses were limited to qualitative interpretations of OM effects on the ESSD for conditional terms. However, it was important to consider the effects of OM on the resulting ESSD when interpreting data because of the relationship that OM can have

with aggregation. Soils high in organic matter (OM) tend to have a high percentage of water-stable aggregates and are less susceptible to raindrop impact detachment. Conversely, soils with low OM tend to be less aggregated and more susceptible to rill erosion (Young and Onstad, 1978). Since a wide variability exists among water stable aggregate sizes, similar soils can potentially have different ESSDs depending on the percentage of OM.

ESSD-RUSLE RELATIONSHIPS

RUSLE OVERVIEW

Modeling conditions that can exist for a specific treatment combination requires that a sediment transport model be capable of estimating how the ESSD may change based on a variety of potential treatment and scale conditions. The following sections will describe how the RUSLE model is currently designed to estimate sediment delivery, with a specific emphasis on how the model calculates the size percentage and distribution of particles and aggregates in the sediment. How these aggregate/particle size classes are then used in subsequent detachment/deposition relationships with the transport capacity will be reviewed to get an idea of how the current approach is limited with respect to management and scale. The descriptive size class capabilities under the current approach are then addressed and a new method that removes size class limitations is introduced *(∆D value Description Section*).

RUSLE, or the Revised Universal Soil Loss Equation, quantifies erosion rates as a function of influential environmental conditions and user-defined management factors. RUSLE combines and accounts for both empirical and process-based observations from an extensive USLE database, including 10,000+ plot-years of field data and 2,000 plot-years of simulated rainfall data (Wischmeier and Smith, 1965, 1978). The intended application of the model is designed to capture the main effects of erosion while

enabling specific, user-defined, modeling capabilities. RUSLE therefore estimates soil loss using a large, robust data pool that accounts for the effects of implemented management factors.

RUSLE EQUATION STRUCTURE

RUSLE models erosion as a combined function of process-based and empirically derived parameters normalized to reflect a worst-case scenario for the desired climate, soil, and topography, and then applied management factors that reduce erosion when implemented. The RUSLE parameters model erosion as influenced by environmental conditions using the following relationship (USDA-ARS, 2008b):

$$A = R \times K \times LS \times C \times P$$

Where:

A = estimated average soil loss (or daily rates) (M L^{-2} T^{-1})

R = rainfall-runoff erosivity (energy based on max. 30 min intensity; (L^2 F L^{-2} T^{-2})

K = soil erodibility (describes soil ease of detachment; (M L^2 T L^{-4} F^{-1})

L = dimensionless slope length factor (slope length effects on erosion)

S = dimensionless slope steepness factor (slope angle effects on erosion)

C = dimensionless cover-management factor (accounts for routine management processes; e.g., no-till)

P = dimensionless support practice factor (accounts for practices that impact the runoff flow pattern; e.g., terraces)

The RUSLE modeling structure works as an interdependent hierarchical web, computing erosion rates based on the combined effects of individual sub-process as they interact with other processes. RUSLE uses this relationship to estimate the average sediment delivery from a defined area by performing an iterative calculation between the estimated eroded mass delivered off-site and the ESSD associated with that mass. The calculations reduce error by adjusting the transported mass values as the ESSD changes when sediment is deposited. The resulting values reflect the amount of sediment delivered to a defined location as a function of environmental conditions and management factors.

RUSLE TRANSPORT CALCULATIONS

Detachment is not modeled in RUSLE as a combination of separate detachment and transport processes, since it is rather an empirical relationship based on a fit to the measured 10,000+ plot-years of data. Sediment transport and how it is affected by various soil, management, and topographic conditions were not, however, represented in those data, so these are modeled in RUSLE using a more process-based approach. RUSLE models the transport of sediment as a function depending on both the sediment load and the transport capacity. The sediment load is described as a sediment concentration and varies both temporally and spatially. The most basic principle governing sediment load values is that the composition and amount of entrained sediment is a function of both the detachment processes and the available transport capacity of the runoff.

Transport capacity relationships in RUSLE are described by the following relationship (Foster and Meyer, 1972; Foster and Meyer, 1975; Nearing et al., 1989; Finkner et al., 1989):

$$T_c = K_T \zeta qs$$

Where:

T_c = transport capacity (M L^{-2})

s = sine of the slope angle

K_T = transport coefficient reflecting cover-management effects

ζ = coefficient that accounts for hydraulic resistance effects

q = runoff (L^2 T^{-1})

If the sediment load exceeds the transport capacity, deposition will occur, calculated in RUSLE using:

$$D_p = \left(\frac{\alpha_d V_f}{q} \right) T_c - g$$

Where:

D_p = deposition (M L^{-2})

α_d = calibrated deposition coefficient

V_f = fall velocity of the sediment in still water (L T^{-1})

q = overland flow (L^2 T^{-1})

T_c = transport capacity (M L^{-1} T^{-1})

g = sediment load (M L^{-1})

The density and geometry of the eroded sediment composition greatly affect the distance a particle travels before being deposited, where deposition is assumed to be governed by Stokes Law (Haan et al., 1994):

$$V_f = \frac{2}{9}\frac{r^2 g(\rho_p - \rho_f)}{\eta}$$

Where:

V_f = particle settling velocity (L T^{-1}); *vertically downwards if* $\rho_p > \rho_f$, *upwards if* $\rho_p < \rho_f$;

r = Stoke's radius of the particle (L); *all particles are assumed to be spherical*

g = gravitational acceleration (L T^{-2})

ρ_p = particle density (M L^{-3})

ρ_f = fluid density (M L^{-3})

η = (dynamic) viscosity (M L^{-1} T^{-1})

Note the importance of the radius (or diameter) on the settling velocity. If all things are equal except that one particle is twice as large as another, the larger particle will settle four times as fast. This effect is fundamentally significant for modeling sediment transport processes, especially when dealing with finer (clay) particles. The runoff energy available, coupled with particle density and geometry, result in a temporally and spatially dynamic sediment load. The resulting sediment load transported offsite is a function of both interrill and rill detachment rates and the flow energy.

The sediment load transported offsite is calculated based on a steady-state conservation of mass principle (USDA-ARS, 2008b):

$$g_{out} = g_{in} + \Delta x \, \bar{D}$$

Where:

g_{out} = sediment load leaving the lower end of a segment (M L^{-1})

g_{in} = sediment load entering the upper end of the segment (M L^{-1})

Δx = segment length (L)

$\bar{D}$ = net detachment or deposition within a segment (M * L^{-2})

As erosion processes occur, the equations shown in the next sections calculate values for each of five assumed sediment size classes, based on the initial size distribution and depositional-transport interactions. The different fall velocities associated with these sediment classes enable the depositional modeling of all sediment sizes, as well as any enrichment processes that occur as coarser particles are deposited faster than fines. RUSLE specifically calculates changes in the ESSD as a function of these factors interacting with transport capacity relationships. The resulting equation structure enables spatial and temporal modeling capabilities that estimates the ESSD of the sediment load transported offsite.

RUSLE ESSD-TRANSPORT CAPACITY RELATIONSHIPS

Once the sediment load has been estimated for a described segment, RUSLE assigns diameter sizes and corresponding mass estimates of particles and aggregates to the remaining sediment load (g_{in}), maintaining the sediment continuity equation. RUSLE does this based on equations discussed in the next sections, but it is important to note that RUSLE applies these relationships after a detached mass has been estimated for a given representative segment of sheet and rill erosion, using the

basic RUSLE empirical erosion relationships. This assumes that the values used to estimate the ESSD are representative of the scale related to the defined segment. The next sections will discuss the current methods used to determine the existing RUSLE relationships.

REVIEW OF CURRENT RUSLE PSD/ESSD RELATIONSHIPS

The initial ESSD is fundamental to subsequent transport estimate accuracy because depositional processes are modeled based on Stokes Law, which is very sensitive to sediment size. After deposition is calculated, the resulting sediment load is then used in the subsequent transport and deposition calculations in the next segment downslope, ultimately estimating the sediment delivery from a respective area along with the size distribution of that delivered sediment. Therefore, any error associated with this calculation of ESSD will directly affect the sediment delivery estimates.

RUSLE currently calculates the distribution of particles into five size classes, calling those sand, silt, small aggregate, clay, and large aggregate, and dividing them based on statistical relationships described in Foster (1985), which improved on findings described in Young (1980). The Young (1980) findings included relationships that described the ESSD diameter sizing, as well as the aggregate / primary particle density relationships, all based on the matrix soil description. These attempts at describing the ESSD of eroded sediment were limited because they included the aggregated fractions of eroded sediment along with the primary particle fractions in the analyses. Although the resulting analyses are limited, they provided valuable insights into observed texture, density, cover and slope relationships with the distribution of particles.

The findings described in Young (1980) supported later efforts by Foster (1985) in categorizing particle diameter values and primary particle statistical assumptions

(diameter increase with clay). Young (1980) reviewed and grouped 21 soils from existing literature into three textural categories:

High Sand (> 50% sand- 5 soils)

High Clay (>50% clay- 5 soils)

High Silt (> 33% silt- 11 soils)

Although the data associated with the 21 soils were obtained under either bare or bare fallow conditions, it is important to note that other influential test conditions were variable (e.g., various rainfall applications, plot lengths, sediment analyses, etc.).

Young described the un-dispersed size distribution of primary particles by relationship to the matrix primary particle size distribution (PSD). The study grouped soils separately by their matrix texture (3 groups: high sand, high silt, or high clay) and used the data of the matrix PSD with the ESSD to statistically develop relationships. The limited data for each soil textural group restricted extensive statistical analysis, but Young presented mathematical relationships that presumably captured general ESSD trends for each soil type. These relationships demonstrated significant correlations between eroded particle size percentages and the same sized particle percentage in soil matrix soil. These relationships only described 3 eroded particle size classes and were based only on matrix particle size considerations. The relationships described by Young (1980) are:

SANDY SOIL ESSD ** (r^2 values were not reported)*

$clay_s = 0.5\ clay_m$

$sand_s = sand_m$

$silt_s = 100 - sand_m - 0.5\ clay_m$

CLAY SOIL ESSD ** (r^2 values were not reported)*

$clay_s = 0.22\ clay_m$

$sand_s = 1.53 (silt_m - sand_m) – 14.91$

$silt_s = 100 – clay_s - sand_s$

SILT SOIL ESSD

$clay_s = 1.2 + 0.20\ clay_m$ n =15 r^2=0.49

$silt_s = 0.14 + 0.67\ silt_m$ n =14 r^2=0.55

$sand_s = 100 – clay_s - silt_s$

Where:

s = un-dispersed sediment portion (ESSD)

m = matrix soil portion (PSD)

*** *all soil portions expressed as a percentage*

Young (1980) also reviewed aggregate densities based on 43 measurements on 13 different soils from 4 different studies, and presented average density values for various size fractions of aggregates. Matrix silt content was the only factor taken into consideration and analyzed independently. A linear relationship was presented describing an inverse relationship between percent silt and aggregate density (r^2=0.86), but only six upper Midwest soils were used to form the statistical relationship.

Young (1980) also briefly discussed the effect of slope steepness on the distribution of eroded sediment. The research statistically analyzed 7 different soil types under various slopes (~0-20%) and concluded that an increased potential for transporting coarser material exists up to about a 10-15% slope, from where the percentage of sediment larger than 50 μm remains relatively constant with increasing slopes.

Since the statistical relationships formed by Young (1980) were limited (21 soils under various influential conditions and only three size classes described), further analyses were needed to 'refine' the mathematical relationships regarding the effects of cover, particle diameters, slope steepness, tillage, etc. on the size distribution of eroded sediment. Also, Young (1980) only related the PSD to particle size classes, and no attention was paid to individual aggregate size classes.

Foster (1985) derived equations that attempted to describe the ESSD as a function of the fractional primary particle composition of the matrix soil. Foster, building on the work done by Young (1980), incorporated two new aggregate size classes (small and large) into limited statistical relationships that described the ESSD. In addition, relationships defining the diameters of those classes were also formed. The data used to generate the statistical relationships were gathered from a literature survey, which included Alberts et al., 1980; Meyer et al., 1980; Young, 1980; Alberts et al., 1981; Fertig et al., 1982; and 'unreported data by Young R.A. and Neibling W.H.'.

PRIMARY CLAY

In the Foster (1985) analysis, primary clay was the only PSD particle class measured directly. From the combined data generated in the literature survey for that study, a regression analysis was used to describe the relationship of primary clay found in eroded sediment as a function of clay content in the matrix soil, resulting in

$$F_{cl} = 0.26\left(O_{cl}\right)$$

Where:

F_{cl} = fraction of the primary clay class in the sediment

O_{cl} = relative clay fraction in the matrix soil

SMALL AGGREGATE

The weakest derived relationship in the Foster (1985) approach is the size classification scheme used to determine the small aggregate class. The small aggregate eroded ESSD data were taken from a total of 16 soils and were generated under a broad range of test conditions (e.g., scale, management, etc.). The base data were the following:

- Fertig et al. (1982): 3 soils, lab scale (1.22m^2) under various slopes (0-15%) and under either cultivated or grassed conditions.
- Alberts et al. (1980): 1 soil, 8% slope, (0.6m * 0.6 m) field plots under simulated rainfall and plot was not tilled for a year.
- Alberts et al. (1981): 2 soils, field scale (3.7 wide * 10.7m long plots) under simulated rainfall and under 3 different tillage treatments: moldboard, chisel, and lightly disked.
- Meyer et al. (1980): 10 soils, interrill scale (0.9m^2) under simulated rainfall and in between crop rows (high slopes ~10-20%), slopes differed among soils with the exception of one soil. All other soils were continuously cropped cotton and all plots were freshly tilled just before testing.

In this analysis by Foster (1985), the proportion of the primary silt and small aggregate class was based upon the concept of primary silt enrichment occurring in the 4-63 μm range but not associated with silt-sized aggregates. Also, the ratio of silt to clay in the small aggregates was assumed to be identical to that in the matrix soil, assuming no detachment particle selectivity. Based on these assumptions, estimates of the fractions of primary silt and small aggregate were determined through an analysis of 16 soils where the particle composition of the 4-63 μm sediment class was known. The steps used to determine the small aggregate percentage of the ESSD were as follows:

- The % of sediment < 63 μm was multiplied by the % of clay in that class to determine the amount of clay in the < 63 μm size class.
- The amount of clay < 4 μm was subtracted from the above amount to determine the amount of clay in the small aggregate class (this amount is based on the total soil sample)
- Multiplying the previous value by the ratio of silt to clay in the matrix soil determine the amount of silt in the small aggregate class.
- The total primary silt in the 4-63 μm size class was determined by subtracting the silt in the small aggregate and the clay in the small aggregate from the (total) silt-sized class.
- The total fraction of the small aggregate class was determined by adding the amount of clay to the amount of silt in the small aggregate class.

The small aggregate fraction was then related to the clay content in the matrix soil through a linear regression analysis of 16 soils, based on previous work by Meyer et al. (1980), Alberts et al. (1980 and 1981), and Fertig et al. (1982). An increased distribution of larger aggregates as clay content increased was accounted for based on findings described by Young (1980), as follows:

$$F_{sg} = 1.8\left(O_{cl}\right) \qquad O_{cl} < 0.25$$

$$F_{sg} = 0.45 - 0.6\left(O_{cl} - 0.25\right) \qquad 0.25 \le O_{cl} \le 0.50$$

$$F_{sg} = 0.6\left(O_{cl}\right) \qquad O_{cl} > 0.50$$

Where:

F_{sg} = relative fraction of small aggregate

O_{cl} = relative clay fraction in the matrix soil

PRIMARY SILT

The Foster (1985) equations also assumed that the fraction of primary silt was equal to the combined amounts of primary silt and silt in the small aggregates. This condition enabled the fraction of eroded primary silt to be determined from the difference between the small aggregate fraction and the fraction of primary silt in the matrix soil. The relationship was examined for 20 soils, resulting in the following relationship:

$$F_{si} = O_{si} - F_{sg}$$

Where:

F_{sg} = relative fraction of small aggregate

O_{si} = relative silt fraction in the matrix soil

F_{si} = fraction of the primary silt class in the sediment

If F_{si} was negative, then F_{sg} was set to O_{si}, and F_{si} was set to zero.

PRIMARY SAND

In the Foster (1985) approach, the primary sand fractions of the un-dispersed sediment were assumed to be consistent with the amount of primary sand in the matrix soil. This assumption was based upon the concept of no particle selectivity processes involved in detachment processes. Foster based this assumption on a statistical analysis of ~20 soils where primary sediment size distribution data existed for both the matrix and eroded sediment. Foster observed non-significant interactions of particle selectivity at the 95% probability level. Based on the data from 24 soils, Foster (1985) developed the following relationship:

$$F_{sa} = O_{sa}\left(1 - O_{cl}\right)^{5}$$

Where:

O_{sa} = relative sand fraction in the matrix soil

O_{cl} = relative clay fraction in the matrix soil

F_{sa} = fraction of the primary sand class in the sediment

The exponent (5) was determined by back-calculating values for the exponent from the 24 soils. The back-calculated values were then averaged to get the exponent of 5, using the relationship:

$$Exponent = \frac{\ln\left(\frac{F_{sa}}{O_{sa}}\right)}{\ln\left(1 - O_{cl}\right)}$$

LARGE AGGREGATE

The mathematical relationships developed by Foster (1985) and listed above all described ESSDs as fractions. Since all the fractional distributions of the size classes must sum to 1, the fraction composed of large aggregates can be calculated from the other fractions, as shown in the following relationship. If the resulting value is negative, all other values are proportionately reduced to give $F_{lg} = 0$.

$$F_{\lg} = 1 - F_{cl} - F_{si} - F_{sg} - F_{sa}$$

Where:

F_{lg} = relative fraction of large aggregate

F_{cl} = relative fraction of primary clay in the sediment

F_{si} = relative fraction of primary silt in the sediment

F_{sg} = relative fraction of small aggregate in the sediment

F_{sa} = relative fraction of primary sand class in the sediment

AGGREGATE DIAMETERS

The current diameter classifications of both the large and small aggregates used in RUSLE2 were also described in Foster's 1985 paper. The diameter size grouping relative to the fraction of clay in the soil was justified by the findings of previous particle size composition research (Young, 1980). Young (1980) studied the compositions of various sized aggregates and how these aggregate diameter sizes change with varying clay percentages. No attention was paid to organic matter influences, and all plots were under bare/fallow conditions.

The Foster (1985) paper classified particle diameter based upon the relative percent of primary clay existing in the matrix soil as follows:

$$D_{\lg} = 2\left(O_{cl}\right) \quad \text{for} \quad O_{cl} > 0.15$$

$$D_{\lg} = 0.300 \quad \text{for} \quad O_{cl} \le 0.15$$

$$D_{sg} = 0.100 \quad \text{for} \quad O_{cl} > 0.60$$

$$D_{sg} = 0.2\left(O_{cl} - 0.25\right) + 0.030 \quad \text{for} \quad 0.25 \le O_{cl} \le 0.60$$

$$D_{sg} = 0.030 \quad \text{for} \quad O_{cl} < 0.25$$

Where:

0_{cl} = clay fraction in the matrix soil

D_{lg} = diameter of large aggregate (mm)

D_{sg} = diameter of small aggregate (mm)

CHAPTER II

JUSTIFICATION

As reviewed above, the limited data pool and highly variable test conditions associated with the Young (1980) and Foster (1985) work warrant a more specific revision to include data collected since the 1985 analysis, while attempting to isolate the effects of the variable influential management conditions. Presently, RUSLE2 models the ESSD at the point of detachment, but does not account for differences that affect the ESSD related to scale, residue, and tillage practices. Since the current relationships fail to accurately describe the impact of these important factors on the ESSD, the resulting sediment delivery estimates are flawed, especially since they are based on the very size-sensitive Stokes law based detachment-transport relationships. In addition to the above limitations, the accuracy of the sediment size distribution will ultimately affect modeled estimates, so the current five size class limit on descriptive capabilities is also probably inadequate.

OBJECTIVES

This thesis entailed development of a more robust RUSLE-compatible method of calculating the ESSD of nonpoint source, hillslope eroded sediment. The primary objectives of the newly developed set of RUSLE equations, outside the obvious goal of increased ESSD accuracy, were: (1) to develop predictive equations that enable users to define the ESSD using more than five size classes; (2) to develop predictive equations that account for the variable impacts of management practices on the ESSD; (3) to describe how these management practices impact or alter the ESSD depending on the scale considered; (4) to validate the accuracy of the new equations.

CHAPTER III

RESEARCH METHODS

To address the objectives with respect to the ESSD and the aforementioned concerns, various ESSDs were collected from peer reviewed literature. Once collected, various ANOVA models were tested with the output data to judge the various grouping of factors to ensure that all factors within a specific group respond similarly to treatments. Once ANOVA results were satisfactory, regression techniques were used to quantify these relationships with equations. After outliers were addressed, the equations producing the most significant results (strongest r^2 values) were validated against current RUSLE2 ESSD estimates to evaluate the strength of the approach. These methods are discussed in depth below, with specific emphasis on the conceptual reasoning behind how the groups were formed for scale, residue, and tillage practices. Afterwards, concepts of ΔD values are introduced to explain how and why ΔD values were analyzed as independent responses instead of regular D values.

ESSD ANALYSIS

All the data used in this analysis were from previously published sources. Because the ESSD is affected by various treatment combinations and scales, efforts to represent specific conditions are thus restricted where data are lacking, and certain treatment combinations might be limited by those incomplete data sets, but a later discussion in the ANOVA and Regression Analysis sections will address these issues.

An extensive search and review of available data produced studies of varying relevance. Some 200+ papers were reviewed for data. Only 42 of those studies were found to contain data suitable for further analysis, and ultimately only 16 different studies were ultimately deemed acceptable and subsequently analyzed. These 16 different studies included work on ~45 different soils.

Because the aim of this research was to evaluate various treatment responses for RUSLE-based modeling applications, certain studies were incompatible and excluded from the subsequent analysis. Incompatible data were weeded out based on the criteria listed below:

- Must report both PSD (dispersed matrix) and ESSD (un-dispersed sediment) for sizes up to 2 mm.
- Plot size must be larger than $1m^2$ and smaller than $1000m^2$.
- Must be under normal rain-fed field conditions, with no added inflow.
- The plot conditions must be clearly defined in the report, including especially scale, pre-test disturbances/ tillage treatments, residue cover, and slope.

The data, once accepted, were entered into a spreadsheet. To analyze factors that result in similar treatment responses, groups were formed based on the responses identified by the literature review, which were later checked using ANOVA procedures as described below**.** The following factors were identified by the literature as being significant to the ESSD: scale, tillage intensity, residue (type and cover) and matrix clay percentage. Since these factors were initially deemed significant, data groupings were needed to analyze the response of similar and different levels of each treatment and determine any outliers. The following sections discuss the grouping methodology used after the data were initially collected, followed by a description of how these groups were assigned and evaluated as compared to current models.

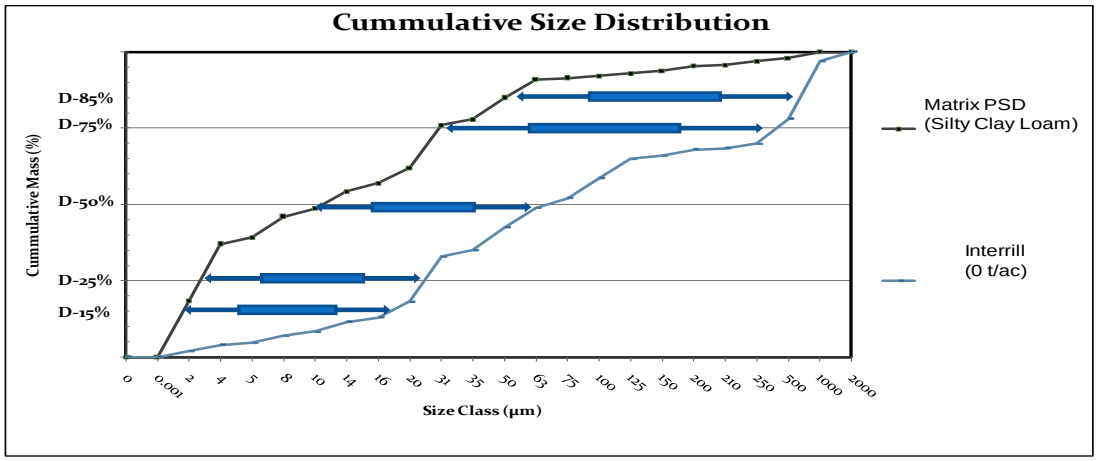
Δ D-VALUE DESCRIPTION

Once the scales and treatments were identified, independent response factors needed to be defined before ANOVA, regression, and validation efforts could be carried out. This required that all the responses be analyzed under similar conditions. To achieve this, ESSDs were interpolated so that similar D-values could be used. Once obtained, D-values were compared to the same D-values for the matrix PSD, since this represents the dispersed native soil and clearly has a controlling impact on the ESSD. The implicit primary assumption is that without any aggregation or selective transport the ESSD should be equal to the matrix PSD. Therefore, if we calculate how an ESSD D-value changes from the same matrix D-value we can characterize the degree of aggregation (or lack of) by the difference in D-values which we will call a ΔD value. This means that, for any D-value we choose, we can calculate a ΔD value, which will define how the ESSD differs from the PSD at that point. A positive ΔD value reflects the presence and general extent of aggregation. Conversely, a negative ΔD value for large ΔD size classes indicates a transport limiting condition where larger sediment is deposited and enrichment of finer sediment results. A negative ΔD value for smaller ΔD size classes indicates conditions where increased proportions of larger sized sediment are transported. In other words, negative ΔD values for smaller ΔD size classes (i.e., ΔD-15) result from the relative increased proportion of larger sized sediment, which increasingly offsets the slope of the line used to indicate the D values.

For statistical modeling considerations, ΔD values were analyzed (using ANOVA and linear regression) as independent factors, defined as:

$$\Delta D \text{ value} = [(\text{ESSD D-value}) - (\text{Matrix PSD D-value})]$$

ΔD values represent how the ESSD differs or is altered from the PSD (Figure 6) without having to define a specific size class or bin, as was done for the current



Treatment (residue t/ac)	ΔD-15 (µm)	ΔD-25 (µm)	ΔD-50 (µm)	ΔD-75 (µm)	ΔD-85 (µm)
Interrill (0 t/ac)	17	**26***	64	458	825

Example Calculation: ΔD-25 = [ESSD D-25 (**26µm***) – Matrix PSD D-25 (**3 µm**)] = **23µm**

Figure 6: ΔD value Introduction and Example Calculation.

RUSLE2 approach. This helps to remove error associated with having to define treatment responses associated with various soils. Since matrix texture (the PSD) obviously has a significant influence on the ESSD, any additional consideration that can potentially remove or identify variability will benefit the accuracy of the model. Specifically, developing models that evaluate the response of treatments with respect to how the mass of eroded particles is different from the matrix soil at various size classes can reduce variability, by in effect averaging this variability over the range of Δ D-values associated with specific matrix clay percentages. While this approach can describe any number of response trends (curves), it is limited by the strength of the fit described using the available data.

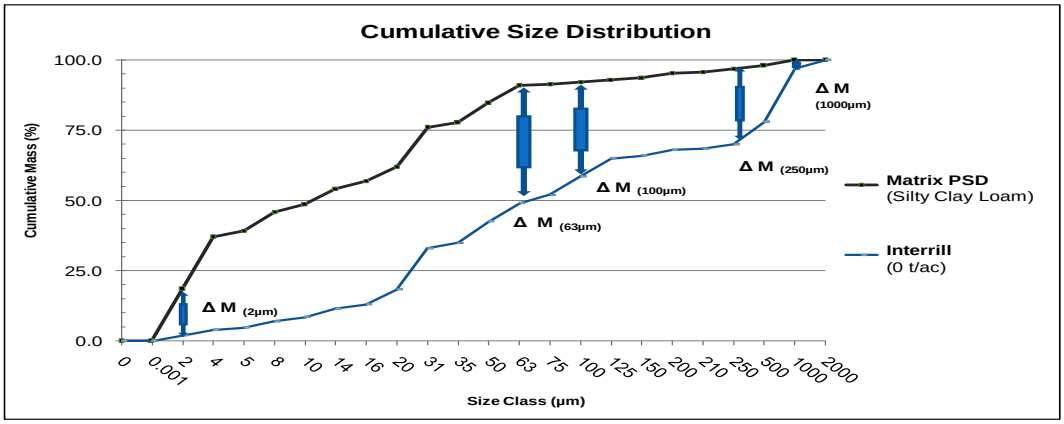
Specific ΔD-values were selected to address the areas where responses were most notable. Five ΔD values were analyzed: ΔD-15, ΔD-25, ΔD-50, ΔD-75, and ΔD-85 (Figure 6). These were selected based on visual observation of grouped separations in

specific regions of the cumulative S-distributions (*Appendix A-1*). A similar study that attempted to compare s-curves from various treatments was also helpful in selecting ΔD-15 and ΔD-85 as important ΔD values (Gilley, 1986). One of the key goals of this project, therefore, is to develop relationships between ΔD values and the desired management parameters, such as tillage intensity and biomass additions. Following the work of Foster (1985), these ΔD relationships will be analyzed against a soil's matrix clay fraction, as that appears to be a controlling factor in aggregation.

Another way to analyze ESSD responses would be to use ΔMass values instead of ΔD values (Figure 7). This approach was briefly investigated, but it was ultimately decided that using ΔD values would be more appropriate since D values are already accepted and widely used to describe the ESSD. Additionally, (Δ) D-values were thought to be theoretically more applicable because they allow the ESSD to be described using set intervals of the total mass as opposed to specific size classes that contain variable amounts of mass. Therefore, describing the ESSD using set mass intervals instead of at specific classes reduces potential errors associated with highly variable mass distributions. ΔM values are defined as:

$$\Delta M \text{ value} = [(\text{ESSD M-value}) - (\text{Matrix PSD M-value})]$$

To achieve ΔD value modeling objectives, a valid grouping scheme needed to be implemented that accounts for and distinguishes between various management practices and scales. This approach was initially evaluated using ANOVA. ANOVA methods were used to determine the most appropriate grouping separation of the data, which were ultimately used to develop separate, group-specific predictive equations. These ANOVA methods are discussed in the following section.



Treatment (residue t/ac)	M% (@ 2 µm)	M% (@ 63 µm)	M% (@ 100 µm)	M% (@ 250 µm)	M% (@ 1000 µm)
Interrill (0 t/ac)	3%	**48%***	59%	68%	78%

Example Calculation: ΔM% $_{(63\ \mu m)}$ = [ESSD M%$_{(63\ \mu m)}$ **(48%*)** – Matrix PSD M%$_{(63\ \mu m)}$ **(89%)**] = **- 41%***

Figure 7: ΔM value Introduction and Example Calculation

ANOVA METHODS

Analysis of Variance (ANOVA) tests were used to initially determine a grouping system that explains the greatest amount of variation in mean ΔD values. This presupposes that once an optimal grouping system is formed, these groups can then be used in a regression analysis to develop/fit predictive equations. ANOVA used ΔD values as the independent variables and ordered groups as fixed, explanatory variables in a Complete Randomized Design (clay = covariate for Scale_Rill). A completion of these tests provided insight regarding which factors were potentially significant model parameters by determining which variables (clay, scale, residue, or tillage) were the most effective in describing the variation. Additionally, specific grouping arrangements were tested to validate the most applicable arrangement.

Typical output for the ANOVA tests indicates significant factors, levels of probability for that significance, and tests for equal variance and normality. If equal

variance and/or normality concerns existed, then the groups were reevaluated based on qualitative theories supported by the literature analysis to determine if the exclusion/inclusion of additional data was necessary. Satisfactory values for acceptance were defined as follows: significant factor *p-value* < *(0.050)*, equal variance (Levene's test) > *(0.050)* and normality values (Shapiro-Wilk Normality test statistic) > *(0.700 - 0.900)*.

ANOVA tests therefore enabled a comparison of various terms to help distinguish between significant and non-significant groups that affected the ESSD. Terms were grouped into classes to isolate and analyze their significance. Four terms were analyzed: Matrix Clay %, Residue Cover, Tillage Intensity, and Scale. Once groups were defined based on findings supported by the literature, they were analyzed with ANOVA to determine their significance to the model as currently tested. ANOVA was used to compare multiple grouping schemes to evaluate which grouping approach was the most appropriate. To evaluate which ANOVA model identified the most appropriate grouping approach and should therefore be evaluated in the subsequent regression analyses, a typical series of tests would be carried out as follows:

- The variables were either defined as scaled or ordinal fixed factors.
    - Clay (for Scale_Interrill) and all ∆D values were set as scaled factors to account for interval values associated with these types of variables
    - Tillage, residue, and clay (for Scale_Rill) were fixed factors ordered based on increasing intensity.
- A model was then designed to test a specific condition (e.g., small vs. large plot ESSD differences). Models were designed to test all main effects and 2-way interactions, as well as a 3-way interaction. Generally, a large data set was initially tested and then both visible and logical outliers were removed until satisfactory results were achieved.

- The standardized residuals were saved and plotted for normality testing and a homogeneity test was run to test equal variance requirements.
- The output was then evaluated.
    - Shapiro-Wilk Normality test statistic must be ≤ 0.900 to be acceptable.
    - Levene's test of equal variances must be ≥ 0.050 to be acceptable.
- If notable output concerns were present, any identified outliers were reviewed and (potentially) removed.
- Grouping categories were reconsidered to address equal variance concerns.
- The data set was then retested using the same ANOVA approach after adjustments were made for the output issues.

All series of logical combinations (based on the literature) and scales were evaluated and the successful grouping of factors and scales was determined based on which grouping approach produced the most significant model with the greatest amount of variation explained. Once the parameters and strength of the relationships were identified using ANOVA, regression analyses were applied to confirm the strength and validity of the relationships for modeling applications, and to define the form of the relationships.

REGRESSION METHODS

Regression analysis techniques were used to develop predictive equations that could calculate the ESSD based on how various management practices and scales affected the distribution of transported sediment. The goal of this task was to improve the current ESSD modeling capabilities of RUSLE, so the success of the regression analysis cannot be judged solely on the strength of the fitted relationships (i.e., r^2).

Instead, a successful result was evaluated on how well the new model predicted the ESSD relative to current RUSLE estimates. In other words, if the revised equations are closer to the actual values than are current RUSLE estimates, then the project objectives have been met, regardless of the r^2 values for the regression relationships. This standard requires that the equations be validated against real and independent data to be fully accepted.

To get to a point where equations could be fit, the data were first plotted. ΔD-values were plotted against matrix clay content for each size class (i.e., ΔD-15 through ΔD-85). Once plotted, trends and outliers were visually evaluated and then potentially removed. After the plotted ΔD-values were evaluated, linear regression lines were fit to the data, without passing through zero. The equation that described that line and the r^2 value were then taken from that plotted relationship to be used (once validated) as a predictive equation for said tillage, residue, scale combination for that specific ΔD-value. This regression analysis approach was used for all ΔD-values, so five (∆D-15, ∆D-25, ∆D-50, ∆D-75, and ∆D-85) separate equations were needed to calculate each ESSD from the underlying matrix soil PSD.

VALIDATION METHODS

Validation of the improved accuracy of the new equations was needed to confirm the value of this research. To achieve this, the ESSD was first calculated using both the current and new equations. ΔD-values were calculated from the current RUSLE equations by calculating the predicted diameter and mass percentage of primary particles then distributing the mass of the two aggregate size classes (small and large) equally over the potential diameter size range of each aggregate size class, so for example a small aggregate calculation of 18% mass for a 70 µm small aggregate size would have that 18% mass equally distributed across the high end of the small aggregate size range; i.e., 70-100 µm. Once the masses were totally distributed for

each aggregate size class, the current RUSLE ESSDs were linearly interpolated and resulting ΔD-values were calculated. The true, independent data (not used in developing the regression relationships) were also linearly interpolated to get the D-values and resulting ΔD-values, which were defined as “truth”. The ΔD-values for the new equations were simply calculated using the developed equations. Root Mean Square Error values (RMSE) were then calculated for each ΔD-value size class (15%, 25%, 50%, 75%, and 85%) as well as for the overall ESSD for each soil. In other words, the validity of the current RUSLE or new relationships to calculate an ESSD was defined by how well the calculated ΔD values fit the “truth” ΔD values, with the quality of fit defined by the minimum RMSE.

CHAPTER IV

RESULTS & DISCUSSION

DATABASE INVENTORY AND DESCRIPTIVE STATISTICS

RESIDUE GROUPING

ANOVA tests indicated more significant models that explained more variation when multiple ordered residue groups were used as compared to only using two groups (grouped as either residue or no-residue). Additionally, the lack of treatment combinations limited any direct usage of specific values, instead ordered categories were have formed to subsequently analyze ESSD relationships. The various residue types studied were ordered into three groups based on the specific loading rate values of each study. The loading rate is defined as the amount of residue mass per unit area, but when a study expressed residue in terms of a fractional surface cover, the RUSLE conversion factors for each residue type (Renard et al., 1997, p. 169) were used to convert percent coverage values to a loading rate (mass/area). No distinctions were made between incorporated or surface applied residue differences because not enough data were available.

Due to the highly variable physical nature of various residues, an ordered fixed factor was used to characterize the effects of various residue treatments. Residue treatments included in the study included corn grain, soybean, sorghum, sugar beets, cotton, erosion control mats, grass, shrubland, rye, and no residue (Table 1). These various treatments were split into three ordered residue groups based on loading rate: Res_None = no residue, Res_Low = low residue (≤500 lbs ac^{-1}) and Res_High = high residue (>500 lbs ac^{-1}).

Table 1: Collected residue types and corresponding loading rates. (N)-values refer to the number of associated ESSD measurements existing in our dataset (e.g., 5 ESSDs were able to be analyzed for Rye residue cover treatments with 1962 lbs/acre). Some Studies did not report values; instead only qualitative data was reported and used to group the treatment.

Residue Type	Loading Rate (lbs/acre)	N
Corn Established	Not Reported (Res_Low)	**1**
Cornstalk	80	**3**
Cornstalk	219	**3**
Cornstalk	500	**3**
Cornstalk	587	**3**
Cornstalk	654	**3**
Cornstalk	864	**3**
Cornstalk	1340	**1**
Cornstalk	2240	**10**
Cornstalk	3400	**3**
Cornstalk	6720	**5**
Cornstalk	13460	**5**
Cotton Established	Not Reported (Res_Low)	**1**
Erosion Control Mats	Not Included in Analysis	**8**
Grassed	Not Reported (Res_Low)	**9**
Rye	1963	**5**
Shrubland	Not Reported (Res_Low)	**1**
Sorghum	1680	**8**
Sorghum	3360	**8**
Sorghum	6720	**8**
Sorghum	13460	**8**
Soybean	1680	**8**
Soybean	3360	**8**
Soybean	6720	**8**
Soybean	13460	**8**
Sugar Beets Established	Not Reported (Res_Low)	**1**
No Residue Cover / Bare		*141*
Total		**273**

TILLAGE INTENSITY BASED GROUPING

Tillage practices were divided into four intensity-scaled groups based on common distinctions accepted in the literature and then evaluated with ANOVA and regression analyses (discussed later). The assignments of unique practices to specific groups were meant to characterize similar tillage operations based on the present level of soil disturbance or un-consolidation: (Till_None = no tillage, Till_Low = low tillage, Till_Medium = medium tillage, Till_High = high tillage; Table 2). Till_None contained plots that were undisturbed for an extended period before the tests. Disked and chisel plowed treatment conditions were grouped into Till_Low because these do not disturb much of soil surface and subsurface areas compared to other practices. The Till_Medium (or Till_Med) group contained more destructive tillage operations that disturb a greater amount of the soil surface and subsurface areas as compared to Till_Low. Treatments entered in Till_Medium included conventional-moldboard and chisel+disked practices. Till_High contained soils that were highly disturbed, including freshly tilled soils, some combination of intense treatments (moldboard+disked), and lab tested soils (transported, sieved, then packed). Table 3 presents a data inventory of the collected RUSLE compatible ESSDs that were included in the analyses. Notice that limited combinations of certain variables exist for each scale. While the relative distribution of data within each Tillage group was skewed, enough data were available for a general evaluation of tillage vs. no tillage management conditions on the ESSD.

Tillage intensity rating was meant to characterize the degree of un-consolidation associated with soil disturbance activities. This grouping focused on tillage-related ESSD responses and was not intended to address other aggregation-controlling factors such as freeze-thaw and wet-dry cycles, Organic Matter %, Iron Oxide%, moisture content, Calcium Carbonate %, PH, etc. Grouping tillage practices assumes that all soils were under the same conditions prior to the disturbance activity. This we know to be untrue, so it is accounted for by grouping freshly-tilled soils into the highest disturbance category (Till_High) regardless of the tillage disturbance. All other soils that

Table 2: Collected tillage practices. (N)-values refer to the number of associated ESSD measurements existing in our dataset (e.g., 8 ESSDs were able to be analyzed for chisel tillage treatments). Some Studies did not report values; instead only qualitative data was reported and used to group the treatment.

Reviewed Tillage Practice	Assigned Tillage Group	N
None	Till_None	59
No-Till	Till_None	7
Chisel	Till_Low	8
Disked	Till_Low	6
'Conventional'	Till_Medium	17
Moldboard	Till_Medium	16
Chisel + Disked	Till_Medium	2
Moldboard + Disked	Till_High	12
Disked + Rototilled	Till_High	68
Plowed, Disked, + Rototilled	Till_High	8
Freshly Tilled Soils	Till_High	21
Highly Disturbed/Lab	Till_High	49
	Total	**273**

Table 3: Grouped data inventories for both scales. Each number corresponds to the number of valid, RUSLE-compatible ESSDs that were obtained.

Scale_Interrill	Res_None	Res_Low	Res_High	Total
Till_None	8	-	-	***8***
Till_Low	-	-	-	***-***
Till_Med	15	-	-	***15***
Till_High	31	-	19	***58***
Total	***54***	***-***	***19***	***73***
Scale_Rill	**Res_None**	**Res_Low**	**Res_High**	**Total**
Till_None	12	-	6	***18***
Till_Low	1	3	10	***14***
Till_Med	29	3	4	***36***
Till_High	21	-	42	***62***
Total	***63***	***6***	***62***	***131***

were tilled but then exposed to precipitation at least once prior to testing were grouped according to their tillage treatment alone. A single precipitation event prior to testing was assumed to homogenize soil moisture, help settle the soil, and smooth surface roughness conditions.

ANOVA OVERVIEW AND ANALYSIS

ANOVA methods were applied to determine which specific management factors contributed to statistically different mean ΔD values, so for which factors it would be useful to apply regression relationships. ANOVA methods did this using ΔD values as independent variables and ordered groups as fixed, explanatory variables in a Complete Randomized Design (with a covariate for Scale_Rill). This provides insight regarding which factors are potentially significant model parameters by determining which variables (clay, scale, residue, or tillage) were the most effective in describing the variation. Typical output for the ANOVA tests indicates a list of significant factors, levels of probability of that significance, and equal variance and normality checks. If equal variance and/or normality concerns existed, then the groups were reevaluated based on qualitative theories supported by the literature analysis to determine if the exclusion/inclusion of additional data was necessary.

The most effective / significant model was ultimately determined by selecting the model and parameters that, when analyzed, explained the greatest amount of the variation in the mean with the most significant variables identified and minimal equal variance and normality concerns. This approach was run to justify the clay, scale, tillage, and residue grouping approach so that the best groups are defined to reveal the strongest relationships in the regression analysis.

ANOVA OUTPUT CONCERNS

Questions were encountered in the ANOVA analysis due to concerns with normality and equal variance requirements. A satisfactory normality will have a Shapiro-Wilk value ≥ 0.900, and a satisfactory equal variance will have a Levene P value ≥ 0.050. Failing to satisfy normality and equal variance assumptions raises concerns regarding the validity of the associated identified significant factors (i.e., the significance of the hypothesis test and p-value). Whether these model parameters are significant or not could be a result of problems associated with outliers and/or meta-data issues. Outliers and meta-data issues were therefore evaluated to determine how much concern deviations from equal variance and normality requirements might impose, if any.

Conceptual outliers were initially evaluated, followed by examination of statistical outliers. Conceptual outliers are data that in some way fail to meet the desired theoretical criteria to be included in the analysis, as described below. Statistical outliers were values that were conceptually valid but were identified in post hoc tests (box-plots) as being outliers. Statistical outliers were included in the ANOVA analysis, but were subsequently evaluated in the regression analysis.

The following were identified as conceptual outliers and removed from the dataset prior to the ANOVA analysis:

- If the size classes reported were too broad or contained substantial data outside the preset assumed allowable range of 0-2000 microns, the dataset was removed. For example, for one study of erosion control mats (Ziegler, 1998), the largest size class was defined as ranging from 250-4000 µm. This was unacceptable because when linearly interpolated the larger values (closer to 4,000) were larger than acceptable values.

- The Weakly (1962) data were removed as an outlier because the largest size class measured was down to 50 μm. This offset the ESSD and prevented any analysis/comparisons with larger size classes.

- Data collected under added inflow conditions (Polyakov, 2003) was removed because the introduction of clean water to the top of the plot could unduly modify the results.

- Splash/wash values are not conceptually applicable for Scale_Interrill. The resulting ∆D values suggest that the detached materials are not being transported by mechanisms similar to those affecting the other data in Scale_Interrill, meant to characterize near-scale field conditions. For example, raindrop impact has the energy to splash very large particles onto the small-scale box-plot sidewalls, so those are counted as splash and wash even though they might be far too heavy to actually be transported by shallow surface flow.

Outliers were also identified statistically using post-hoc Box-plot analyses. If statistical outliers had been removed before the ANOVA analysis the equal variance and normality assumptions might have improved, but data removal could also have reduced the overall significance of our model and prevented significant variables from being identified. Also, if interpolation errors existed, then for one ∆D value the data might contain significant errors and be questionable, but another ∆D value closer to a non-interpolated value might be completely valid. This could result in the erroneous removal of data that are significant for some ∆D values but not others. Because of these issues, the statistically identified outliers, which if removed might have resolved the equal variance and normality issues, were included in the ANOVA analysis and then later addressed in the regression analysis.

Some other possible problems associated with meeting the ANOVA assumptions can arise from difficulties using meta-data due to both intrinsic variations associated with separate research plots and also with trying to unify the dataset for unbiased

analyses. The following issues were also evaluated in the regression analysis with ΔD relationships, especially ΔD relationships that showed signs of normality and equal variance concerns:

Interpolation Procedures

- Linear interpolation of size classes can introduce error because the shape of the distribution between size classes is unknown and any estimation will result in some error.
- Additional error is introduced by using unequal PSD size classes to linearly extrapolate D-values and compute ΔD values. The extent of this error is still unclear, but this method proved to be acceptable when confronted with the other available options.

Grouping Errors (Clay, Residue, and Tillage)

- If factors were grouped incorrectly the resulting analysis will contain error and fail to describe significant relationships. Inappropriately grouped factors will ultimately generate a less significant model with more equal variance and normality concerns.

Analyzing Incomplete Populations

- Some treatments were not represented well enough in the reported literature to make detailed analyses specific to that treatment and scale over various ranges in matrix clay content (Table 3).

Working with a limited meta-dataset reduced the probability of satisfying the ANOVA assumptions for each ΔD value model. This limit was noted in several deviations from the accepted normality and equal variance assumptions. As outliers were removed, normality and equal variance assumptions generally improved, but the number of terms in the model and the overall significance were reduced. Since the

error that possibly contributes to equal variance and normality concerns cannot be proven to be associated with either the statistical outliers or the meta-data/interpolation error, the outliers were included in the ANOVA analysis and later investigated in the regression analysis.

ANOVA MATRIX CLAY RELATIONSHIPS

Current RUSLE equations take advantage of the strong relationship between the matrix clay content of a soil and the ESSD. This can be seen in the current RUSLE equation structure (Chapter I; *Review of Current RUSLE PSD/ESSD Relationships*), where the size composition of the ESSD is based solely on an equation related to soil matrix clay content. While this relationship is explicit in the literature and has been accepted in current modeling approaches, it has not been validated for modeling ΔD value responses to management practices and variable scales.

The following ANOVA modeling were therefore run treating clay as both a covariate and a fixed factor (as seen separately in each table below), to determine if the significance of clay on the ESSD relative to influential management factors is linearly related (covariate) or whether ESSD responses to matrix clay content is only significant for soils within a certain matrix clay content range (fixed factor). This was evaluated by comparing and accepting the model associated with the (either fixed or covariate) clay variable that explained the most variation.

Although clay was shown to be a significant variable, treating the variable (clay) as a fixed factor or covariate depended on the scale considered.

SCALE_INTERRILL CLAY:

Based on the ANOVA output, clay was modeled as a covariate for Scale_Interrill and fixed factor for Scale_Rill. ANOVA treats a covariate as a continuous explanatory variable that is unaffected by treatments and has a somewhat linear relationship to the response. A covariate term is fitted first, then other primary explanatory variables and

interactions are added and their additional effect is statistically assessed. While the relationship might not be linear over the entire clay range for Scale_Interrill, treating the relationships as such identified the most additional significant terms in the Scale_Interrill model. Clay appeared to be strongly related to all ΔD values in Scale_Interrill and should therefore be modeled correspondingly.

SCALE_RILL CLAY:

Treating clay as a covariate for Scale_Rill failed to identify any significant terms for smaller ΔD values, meaning that fitting the clay first overwhelmed the impact of the other variables. On the other hand, for Scale_Rill modeling clay as a fixed factor with groups identified significant terms for smaller ΔD values and proved to be a better model.

Matrix clay was categorized into 4 groups: Clay_ Low = 0-15%, Clay_Med = 15-30%, Clay_High = 30-50%, and Clay_Very_High ≥ 50% matrix clay content. These values were grouped based on typical ranges expressed in the literature and on the distribution of values within the dataset population. Since Clay was modeled as a covariate for Scale_Interrill, separate equations should be investigated in the regression analysis for limited application over discrete ranges in matrix clay content**.** Note the difference in the significant variables described in each model based on whether clay was treated as a covariate or fixed factor (*Appendix; A-3*). Specifically, notice how for scale, treating clay as a covariate resulted in a more significant mode for Scale_Interrill but not Scale_Rill.

SCALE GROUPING APPROACH:

As was described above, scale was split into 2 groups based on the various detachment/transport mechanisms described by Kinnell (2005) and the general ESSD responses identified by the literature for both interrill and rill scales (Figure 1). The first scale, called Scale_Interrill, contained sediment data collected at or near the point of

detachment (<15 m), which would be dominated by raindrop detachment with shallow overland flow transport mechanisms. In other words, the (measured) sediment represented by this group is from the interrill scale and at or near transport-limiting conditions, but it is assumed that none of the sediment has been deposited once detached.

To define the most appropriate scale for Scale_Interrill, ANOVA tests were first run on a larger scale. The outliers were then evaluated and finally, the scale was decreased to see if a better model resulted. When ANOVA output was evaluated for conditions where all the ESSDs from plots <15m were analyzed together it was apparent that equal variance and normality concerns were present (below Table 4). This suggests that some data may not be applicable and another grouping approach might provide a better model with more of the variation explained with all the output concerns satisfied.

One possibility for the weak model described for scales <15 m is that the scale is too large and that flow detachment is occurring and causing the equal variance and normality concerns. The following output in Table 5 checks that possibility and represents ESSDs generated from even smaller scales, including just sizes <5 m. Table 5 evaluates the possibility of whether or not removing the ESSD data for scale >5 m would remove a substantial amount of variation or if another grouping approach should be tested. When re-running ANOVA for smaller plots to see if the large plot size affects the model, no significant improvements were noticed as indicated by the lack of significant variables identified and equal variance and normality concerns.

Another possibility for the weak model could result from the inclusion of splash / wash data that is generated on a very small scale and is generally larger in size than ESSDs generated from typical interrill scales. The ANOVA output in Table 6 is generated from scales <5 m with no splash / wash data included.

Table 4: ANOVA test of significant variables on all data < 15 m including splash and wash. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale: All data < 15m • Covariate = Clay • Fixed = Residue, Tillage.	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	Tillage (0.070) Till*Clay (0.064)	0.007	0.443
∆D-25	Tillage (0.066) Till*Clay (0.087)	0.005	0.396
∆D-50	None	0.009	0.517
∆D-75	None	0.379	0.78
∆D-85	None	0.029	0.922

Table 5: ANOVA test of significant variables on all data < 5 m including splash and wash. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= All data < 5m (including splash/wash) • Covariate = Clay • Fixed = Residue, Tillage	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	None	0.017	0.5
∆D-25	None	0.012	0.448
∆D-50	None	0.024	0.584
∆D-75	None	0.267	0.728
∆D-85	None	0.09	0.828

Table 6: ANOVA test of significant variables on data < 5 m excluding splash and wash. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= All data < 5m (excluding splash/wash) • Covariate = Clay • Fixed = Residue, Tillage	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	Tillage (0.098) Till*Clay (0.067)	0.088	0.429
∆D-25	Tillage (0.076) Till*Clay (0.064)	0.064	0.378
∆D-50	Tillage (0.097) Till*Clay (0.048)	0.078	0.568
∆D-75	None	0.323	0.782
∆D-85	Till*Clay (0.029)	0.09	0.864

When removing splash/wash data and larger plots, some significant terms were identified for the covariate model (Table 5 and 6), but ANOVA (normality) output concerns still existed. Because the overall significance of the model improved when both splash / wash values were removed, it was possible that small scale wash values still might be applicable.

ANOVA was then used to test how the significance changed when only splash plots were removed and wash remained. When only splash data were removed for small scale plots <15 m, a more significant model was generated that indentified more significant terms (with fewer output concerns) and ultimately described more of the variance in the model (Table 7). Although removing splash data from Scale_Interrill analyses resulted in a more significant model, output concerns still existed for both equal variance and normality assumptions.

Further (ANOVA post-hoc) evaluation of the skewed data/outliers indicated that both small scale splash / wash related data were not acceptable for RUSLE modeling capabilities. Removal of the splash / wash data for plots <15 m resulted in the most

Table 7: ANOVA test of significant variables on data < 15 m including wash but not splash. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= All data < 15m (including wash/ no splash) • Covariate = Clay • Fixed = Residue, Tillage	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	Till*Clay (0.073)	0.042	0.385
∆D-25	Till (0.097) Till*Clay (0.092)	0.049	0.317
∆D-50	None	0.111	0.432
∆D-75	Clay (0.097)	0.606	0.734
∆D-85	None	0.03	0.908

significant terms identified out of all other applicable Scale_Interrill combinations (Table 8) and is assumed to be the most applicable scale to be analyzed with regression analysis techniques.

When compared to the previous Tables (4-8), modeling clay as a covariate provides a more significant model (e.g., more significant variables identified) and describes a greater amount of the variation compared to modeling clay as a fixed factor for Scale_Interrill (*Appendix; A-3*). This clay=covariate relationship suggests that these ∆D value treatment responses for this scale are possibly linearly related to matrix clay content, but this relationship needs to be further evaluated using regression analyses.

The second scale (Scale_Rill) contains the data for studies in which there is potential detachment of soil by flow, which primarily includes those study areas that are large enough to produce rills. While Scale_Interrill is intended to describe the resulting ESSD under raindrop-detachment transport-limiting conditions, Scale_Rill is intended to describe the resulting ESSD under flow-detachment limiting conditions, which generally provide plenty of energy to carry the sheet-eroded sediment. In other words, Scale_Rill

Table 8: ANOVA test of significant variables on data <15 m excluding both splash and wash. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= All data < 15m (excluding splash/wash) • Covariate = Clay • Fixed = Residue, Tillage	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	Tillage (0.046) Till*Clay (0.010)	0.163	0.406
∆D-25	Tillage (0.000) Till*Clay (0.000)	0.035	0.538
∆D-50	Till*Clay (0.040)	0.075	0.534
∆D-75	Clay (0.056)	0.582	0.742
∆D-85	Clay (0.044) Till*Clay (0.042)	0.003	0.941

is meant to contain data that are predominately influenced by runoff mechanisms and the ESSD is generated under supply-limited conditions.

The grouping of data in these two separate scales is meant to isolate the dominant acting forces responsible for eroding a specific size class with respect to the various significant management factors implemented. Scale_Rill represents larger scales, where detachment-transport mechanisms are dominated by runoff flow processes. Accurately specifying the break between Scale_Interrill and Scale_Rill is difficult, but was necessary for meaningful data analyses.

Since it is difficult to distinguish between ESSDs that are defined by either (RD-FT) or (FD-FT) mechanisms as the scale is increased, the remaining data that are >15 m were grouped and assumed to be under Scale_Rill conditions. ANOVA methods were used to help identify whether a similar model can be applied to Scale_Rill as in Scale_Interrill (i.e., an expected linear ∆D response to treatments based on matrix clay

content modeled as a covariate), or if other models are more appropriate to describe the Scale_Rill ΔD responses to treatments for specific fixed clay content ranges. This was evaluated by comparison of both clay = fixed and clay = covariate models to determine which model is more significant (e.g., more significant variables identified) and describes a greater amount of the variation (*Appendix- A3*; Table 9). After ANOVA comparisons were run for both clay = fixed and clay = covariate models, it was determined that modeling clay = fixed is a more appropriate method for Scale_Rill.

In summation, the individual scales were intended to capture effects of processes that are primarily influenced by either small scale, raindrop (transport limiting/ supply dominated) or large scale, flow dominated (supply limited / transport dominated) mechanisms. This does not argue a mutually exclusive representation of the conditions, merely a broad grouping of scales where one could expect processes that are dominated by either mechanism/process. As mentioned above, RUSLE2 already contains a means of estimating the degree to which the hillslope erosion is dominated

Table 9: ANOVA test of significant variables on all data >15 m. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= all data > 15m • Covariate = Fixed • Fixed = Residue, Tillage	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
ΔD-15	Till (0.000) Residue (0.000) Clay (0.000) Till*Clay (0.000) Till*Residue(0.002)	0.049	0.955
ΔD-25	Till (0.012) Till*Clay (0.000)	0.361	0.609
ΔD-50	Residue (0.000)	0.331	0.533
ΔD-75	Clay (0.017)	0	0.935
ΔD-85	Till (0.000) Till*Residue (0.009)	0	0.987

by interrill or rill processes, which could be useful in determining where in this spectrum the situation actually lays.

MANAGEMENT FACTOR GROUPING APPROACH

ANOVA was also used to determine the most appropriate way to model treatment responses for various management factors that for certain combinations of tillage and residue are scarcely represented. For instance, only one study reported Chisel*Disked tillage combinations, therefore any attempts to analyze the effect of this treatment will require that other tillage groups that have similar impacts on the ESSD are categorically grouped based on an intensity rating. For example, Chisel*Disked tillage operations can be grouped with similar, multi-process high intensity tillage practices such as moldboard*disked operation. But before this rated grouping approach is justified, it needs to be determined that these treatments (regardless of the intensity or loading rate) do in fact significantly influence ΔD values. To evaluate whether or not management groups significantly influence the ESSD, a presence or absence condition was assigned for each treatment and evaluated at both scales as seen below (Table 10).

Using only 2 management intensity treatment groups identified three significant Scale_Interrill relationships. Multiple intensity-ordered treatment levels were therefore accepted and used in the Scale_Interrill model because they identify more significant relationships (seven) in effect, describing a greater amount of the variation as indicated by comparative evaluations of the ANOVA output (Table 8 vs. 10).

These finding were consistent with the treatment grouping relationships seen in the Scale_Rill analysis. When only 2 treatment groups were used to model Scale_Rill relationships (Table 11), some variables were significant, but not as many as were defined using multiple intensity-ordered treatment levels (Table 9). While a similar number of output concerns were noted for both models, more serious equal variance concerns were found when the model using only 2 treatment groups was analyzed.

Table 10: ANOVA test of significant variables on unordered management factors for Scale_Interrill. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= Interrill (All data < 15m excluding splash/wash) • Covariate = Clay • Fixed = Residue (2 groups) Tillage (2 groups)	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	None	0.1	0.491
∆D-25	Clay (0.077)	0.031	0.578
∆D-50	Clay (0.017)	0.074	0.466
∆D-75	Clay (0.000)	0.817	0.723
∆D-85	Clay (0.000)	0.1	0.923

Table 11: ANOVA test of significant variables on unordered management factors for Scale_Rill. Note: unacceptable values were red-highlighted for models that failed to satisfy acceptable output assumptions. Acceptable equal variance values must be ~> 0.05 and acceptable normality values must be ~> 0.900 to satisfy the output assumptions.

Model Design: • Scale= Rill (All data >15m) • Covariate = Clay • Fixed = Residue (2 groups) Tillage (2 groups)	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	Till (0.002) Residue (0.050) Clay (0.012) Residue*Clay (0.001) Till*Clay (0.001)	0	0.79
∆D-25	Till*Clay (0.063)	0.005	0.697
∆D-50	None	0.73	0.515
∆D-75	Clay (0.078)	0.156	0.954
∆D-85	Tillage (0.057)	0	0.975

For both scales, using more than 2 levels for each treatment group generates a more significant model. Therefore, multiple levels were used to describe each treatment group based on a categorical ordered intensity rating.

REGRESSION ANALYSIS; SCALE_INTERRILL

The goal of the regression analysis was to develop predictive equations that account for variable protective and destructive management practices (residue and tillage practices), as well as the eroded sediment size differences that occur due to variable scales. Although the data were limited, several equations were found for each scale that could be validated against real data. The following equations in Table 12 were developed for Scale_Interrill using regression analysis techniques.

The regression analyses for Scale_Interrill were limited by the small amount of available data. Although a wide range of soil types were studied, the data set only contained seven Scale_Interrill compatible studies, so few treatment combinations were represented (see descriptive statistics, Table 3). This lack of data restricts the regression analysis to only those treatments that were represented in the data set.

Notice the N/A values in the above table where equations were not able to be described. Although this is the case for most of the treatment combinations, equations were able to be described for three different treatment combinations (Till_Med/Res_None, Till_High/Res_None, and Till_High/Res_High). These equations were developed by fitting regression lines to the observed plotted response trends and reflect the general findings suggested in the literature review (i.e., residue cover reduced the transport of larger sediment, tillage destroys aggregates and releases primary particles, etc.).

Tillage practices tended to increase the proportion of finer particles in the ESSD. More specifically, increasing tillage intensity was shown (Figures 8, 9) to increase the size percentage of eroded particles compared to less intense disturbances. This tendency for more intensely disturbed tillage practices to increase the percentage of

Table 12: Scale_Interrill regression equations (y = ΔD value µm and x = soil matrix clay percentage). (r^2) values and the source of the data are also presented as well as the (N) number of ESSDs that were used in each analysis. N/A listings are present where there were not enough data to fit an equation.

Tillage Treatment	Residue Treatment	ΔD-15	ΔD-25	ΔD-50	ΔD-75	ΔD-85	Number of ESSDs Reported	Number of Studies	Other
Till_None	**Res_None**	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	**8**	**1**	*N/A*
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	Res_High	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
Till_Low	**Res_None**	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	Res_High	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
Till_Med	**Res_None**	**y = -0.093x + 8.125 (r^2 = 0.029)**	**y = 0.287x + 4.295 (r^2 = 0.224)**	**y = 1.939x - 15.23 (r^2 = 0.543)**	**y = 9.504x - 94.83 (r^2 = 0.719)**	**y = 22.22x - 247.4 (r^2 = 0.796)**	**15**	**2**	(Meyer 1992, Meyer 1980)
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	Res_High	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
Till_High	**Res_None**	**y = 0.330x + 1.383 (r^2 = 0.437)**	**y = 0.774x - 5.325 (r^2 = 0.832)**	**y = 2.064x - 27.39 (r^2 = 0.715)**	**y = 17.64x - 252.3 (r^2 = 0.588)**	**y = 30.90x - 430.8 (r^2 = 0.526)**	**31**	**6**	(Cogo 1983, Meyer 1980, Fertig 1982, Alberts 1983, Gilley 1986, Gilley 1987)
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	***Res_High**	**y = 0.306x - 5.205 (r^2 = 0.249)**	**y = 0.663x - 12.91 (r^2 = 0.399)**	**y = 1.308x - 20.48 (r^2 = 0.235)**	**y = 8.631x - 81.25 (r^2 = 0.077)**	**y = 12.39x + 209.0 (r^2 = 0.060)**	**19**	**2**	*Weak r^2 possibly due to residue loading rate. (Gilley 1986, Gilley 1987)

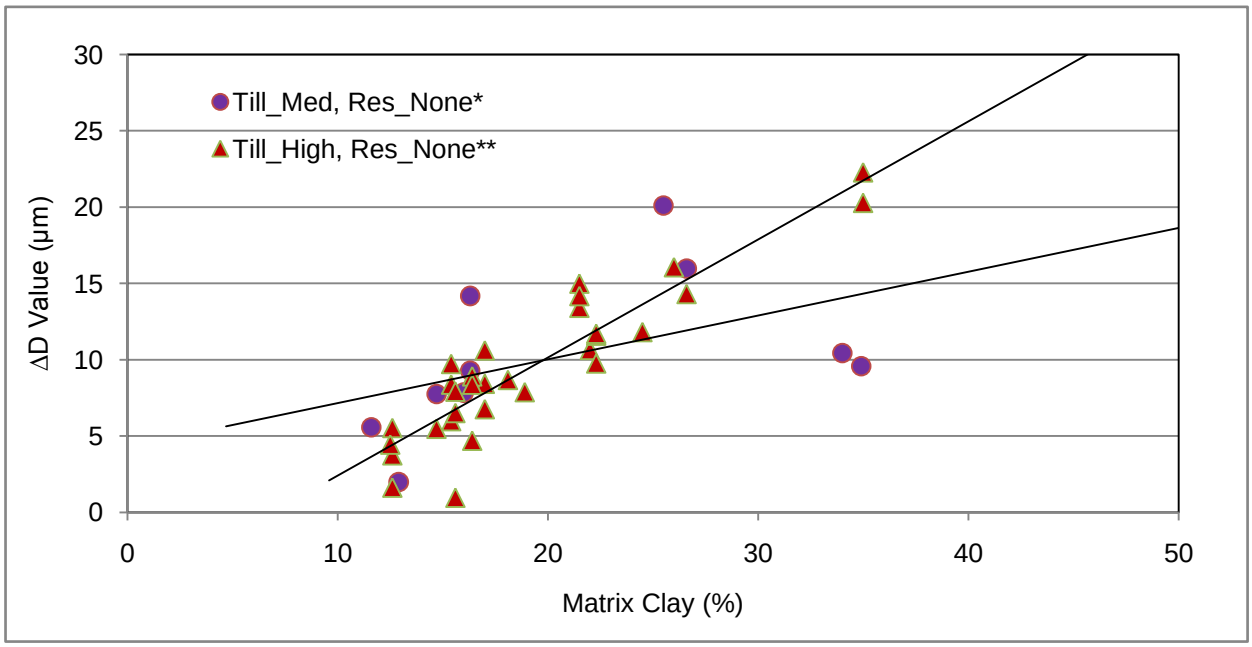


Figure 8: Scale_Interrill ΔD-25 values under no residue / variable tillage treatments. *y = 0.287x + 4.295 (r^2 = 0.22), ** y = 0.774x – 5.325 (r^2 = 0.83).

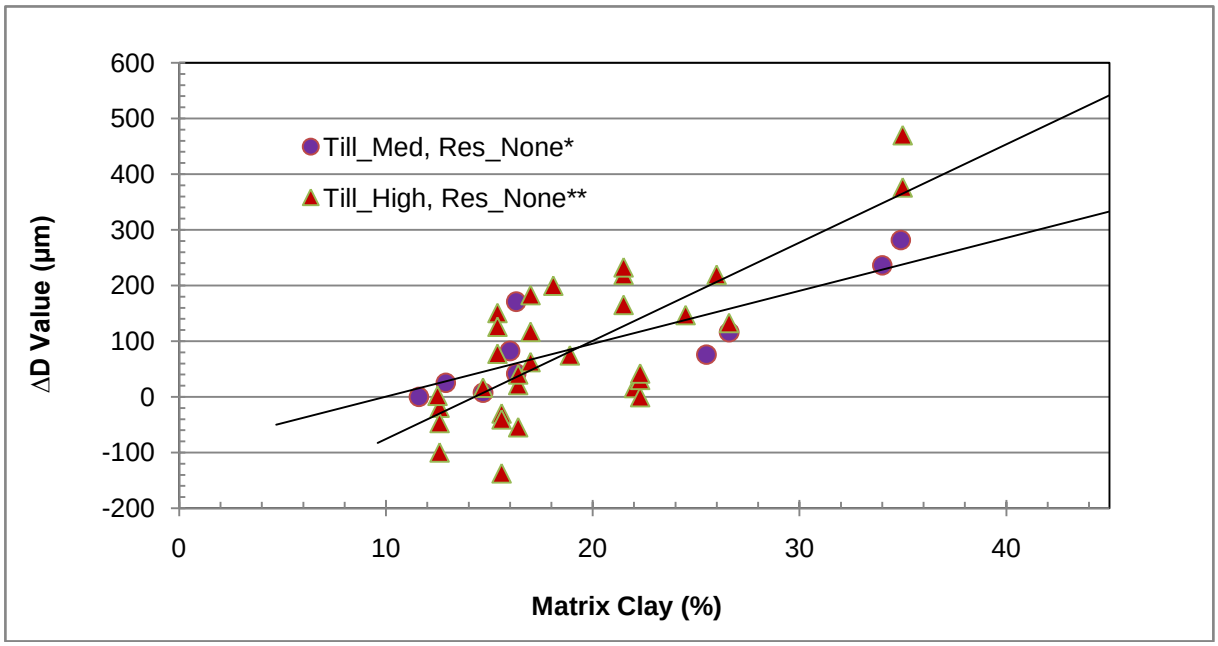


Figure 9: Scale_Interrill ΔD-75 values under no residue / variable tillage treatments. *y = 9.503x - 94.82 (r^2 = 0.72), **y = 17.64x - 252.2 (r^2 = 0.59).

sediment was noticeable for both the small and large sized sediment sizes (Figures 8, 9) as indicated by a weak (r^2) relationship between increased tillage and increased ΔD values.

While tillage intensity appeared to be affect the size and percentage of eroded particles, ESSD responses for residue treatments were variable. For Till_High/Res_High treatments the size percentage of eroded particles was lower as compared to similar treatments under no residue coverage (i.e., ΔD values were comparatively larger for Till_High/Res_None treatments), but this response was not as clear for the different ΔD size classes (Figures 10 - 12). Notice for larger ΔD values, the significant relationship between high residue coverage and reduced ΔD values is not as distinct as compared to smaller ΔD size classes (i.e., ΔD-25).

Although some of these residue cover relationships appear to be weakly correlated, it is suggested that residue loading rate has a significant effect on the ESSD, but the response appears spurious due to the wide range of ΔD values associated with Res_High treatments, the two distinct data groups, and the unequal variance values associated with the corresponding ANOVA output (Table 8). While this correlation is strong for the smaller size classes (Figure 10), the scatter associated with residue treatments in Figures (11) and (12) suggests either spurious results or more likely, other factors such as residue loading rate might cause the variability. Although loading rate as a variable is significant, it was not possible due to the limited dataset to develop predictive equations based on loading rate. Therefore, the equations were left as is and this effect of residue on reducing the amount of larger sediment delivered as compared to no residue was noted and suggested to be addressed in future research efforts.

The removal of ESSDs associated with very high/ low matrix clay soils, as initially suggested in the ANOVA analysis, was also supported by the regression analysis. When high/low clay ΔD values were plotted it was apparent that our linear regression analysis was only valid over a linear response range, which was not the case for high/low clay soils. Therefore, these soils were removed from the dataset for subsequent development of equations using regression analysis.

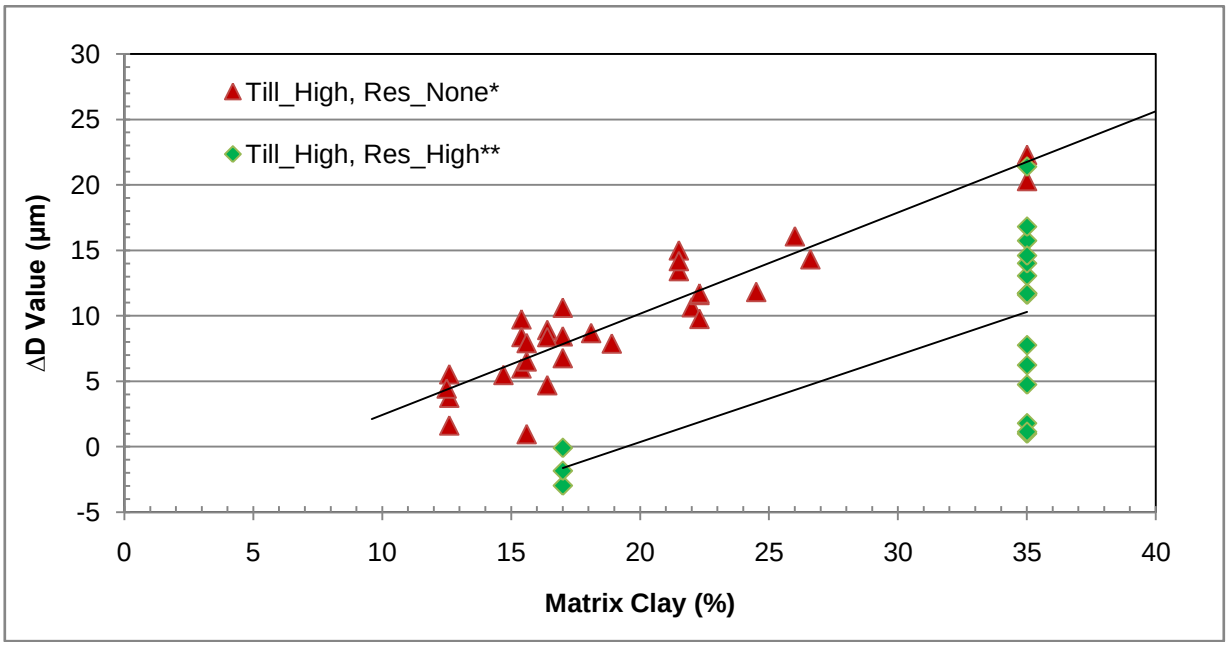


Figure 10: Scale_Interrill ΔD-25 values under high tillage / no- vs. high- residue treatments. * y = 0.774x – 5.325 (r^2 = 0.83), **y = 0.663x – 12.90 (r^2 = 0.40).

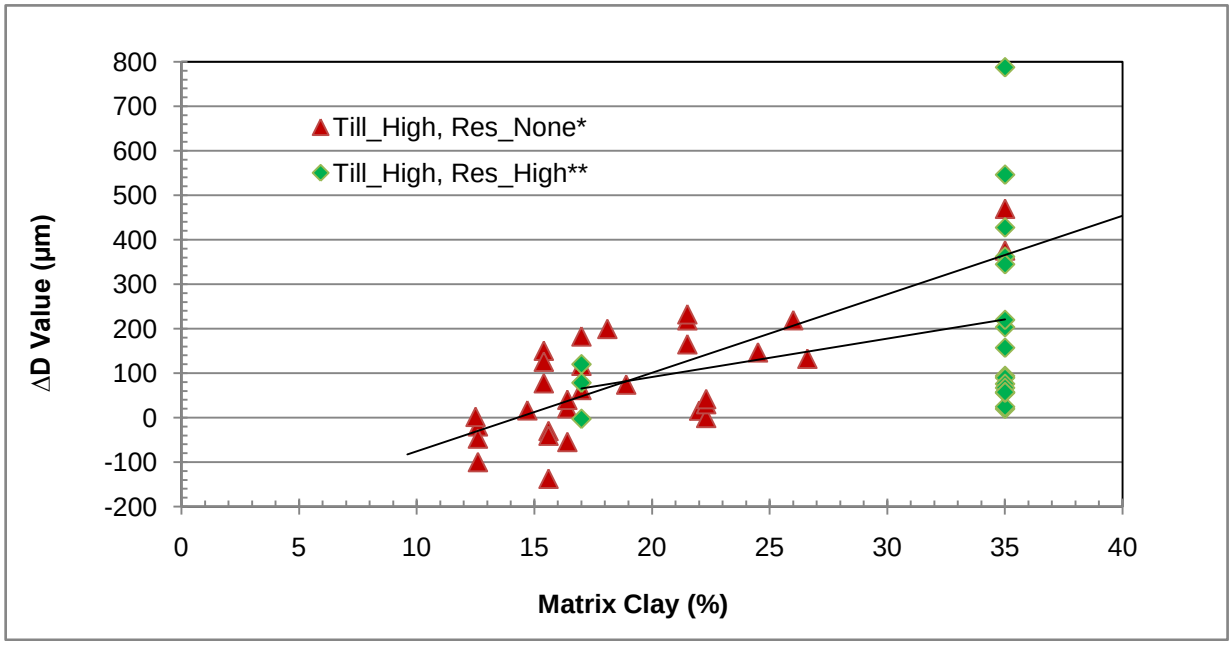


Figure 11: Scale_Interrill ΔD-75 values under high tillage / no- vs. high- residue treatments. *y = 17.64x - 252.2 (r^2 = 0.59), ** y = 8.630x - 81.24 (r^2 = 0.08).

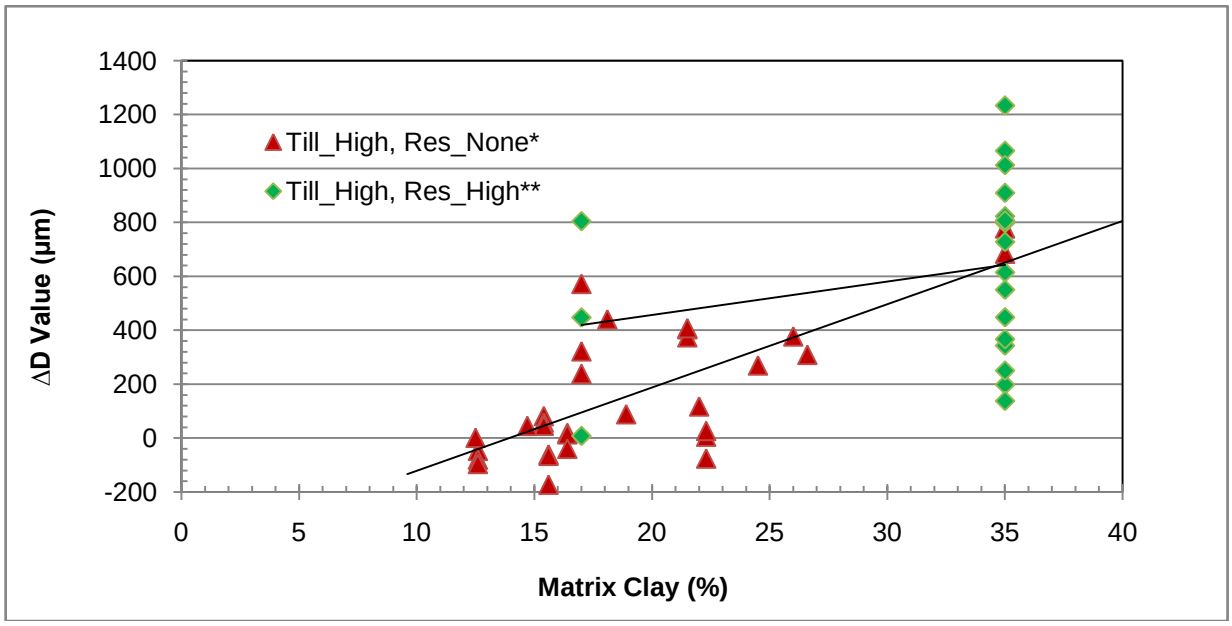


Figure 12: Scale_Interrill ΔD-85 values under high tillage / no- vs. high- residue treatments. *y = 30.9x - 430.7 (r^2 = 0.53), **y = 12.38x + 209.0 (r^2 = 0.06)

REGRESSION ANALYSIS; SCALE_RILL

The regression analysis for Scale_Rill was also limited by the small amount of available data. Although more treatment combinations were studied as compared to Scale_Interrill, the data set was still limited by the few compatible treatment combinations that were represented (see descriptive statistics; Table 3). Because numerous soils with variable clay contents are needed to develop predictive equations, the resulting analysis is limited for any treatment combination where few variable clay contents were represented. For these relationships, some of the analysis is limited to qualitative reasoning.

Rill detachment mechanisms do not always affect Scale_Rill ESSDs similarly, because as more variability exists as the plot size increases, other factors become more significant (i.e., increased slope increases the runoff rate and velocity). Additionally, interrill detachment/transport mechanisms can still predominate in Scale_Rill for periods when the runoff flow energy is below the critical rill detachment energy. Therefore the resulting ESSDs for Scale_Rill will exhibit more variability, which needs to be

considered as predictive equations are developed to model this scale. There are two options that can address this issue; either more data are needed to better describe the extent of this variability using more variables, and/or several equations can be fit to describe the maximum and minimum ΔD value possibilities. The minimum ΔD value equations should reflect no rill contributions to the ESSD. Therefore the ESSD for the minimum rill scale is strictly a function of the contributing interrill ESSDs. The maximum ΔD value equations should reflect ESSDs that are dominated by rill contributions to the sediment load where the resulting ESSD is a combined weighted ratio of the maximum rill detachment ESSD and the contributing interrill ESSDs.

The following regression analysis (Table 13) only fit one set of equations for each Scale_Rill treatment combination because not enough data were available to develop maximum and minimum equations. This regression technique was aimed at identifying any dominant trends that can be used as either a qualitative basis to focus future research or for general predictive estimates, depending on the strength of the analysis.

Scale_Rill no tillage treatment soils were studied for both no-residue and high residue conditions, which enabled the effects of residue on Till_None soils to be evaluated. It appears from the plotted values that there is no difference between the ESSD generated for high and no residue for Till_None treatments regardless of the size class considered (Figures 13, 14). Whether this is a true result that can be expected for all soils (within the acceptable clay range) or simply the result of using a very limited data set is unclear and needs to be further evaluated with additional data before any conclusive decisions can be made.

Till_Low data were not able to be rigorously evaluated against the influences of variable residue cover because only 10 Res_High ESSDs and only a few Res_None (N=1) and Res_Low (N=3) ESSDs were represented. From the limited studies, it was demonstrated that Res_High ΔD values were lower than Res_Low values (Figures 15, 16). That is, for low tillage practices the size of the particles in the ESSD is reduced under high residue coverage as compared to under less residue coverage.

Table 13: Scale_Rill regression equations. (r^2) values and the source of the data are also presented as well as the (N) number of ESSDs that were used in each analysis. N/A listings are present where there was not enough data to fit an equation. (y = ΔD value µm and x = soil matrix clay percentage)

Tillage Treatment	Residue Treatment	ΔD-15	ΔD-25	ΔD-50	ΔD-75	ΔD-85	Number of ESSDs Reported	Number of Studies	Other
Till_None	Res_None	y = 0.172x + 2.962 (r^2 = 0.065)	y = -0.011x + 18.24 (r^2 = 5E-06)	y = -1.092x + 63.53 (r^2 = 0.003)	y = 5.521x + 44.55 (r^2 = 0.016)	y = -9.537x + 388.1 (r^2 = 0.016)	12	3	(Cogo 1983, Armstrong 1996, Martinez-Mena 1999)
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	Res_High	y = -0.125x + 10.42 (r^2 = 0.051)	y = -0.117x + 18.08 (r^2 = 0.003)	y = -0.032x + 16.09 (r^2 = 3E-04)	y = -27.46x + 1165 (r^2 = 0.155)	y = -57.27x + 1749 (r^2 = 0.159)	6	3	(Cogo 1983, Diezman 1987, Martinez-Mena 1999)
Till_Low	Res_None	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	1	1	(Cogo 1983)
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	3	1	(Alberts & Moldenhauer 1981; same soil measured)
	Res_High	y = -1.186x + 28.78 (r^2 = 0.908)	y = -1.173x + 27.91 (r^2 = 0.781)	y = -4.429x + 88.32 (r^2 = 0.255)	y = 34.25x - 870.9 (r^2 = 0.798)	y = -11.66x - 512.0 (r^2 = 0.175)	10	2	(Alberts & Moldenhauer 1981; Cogo 1983)
Till_Med	Res_None	y = 0.75x - 7.404 (r^2 = 0.351)	y = 1.901x - 25.19 (r^2 = 0.173)	y = 5.801x - 90.73 (r^2 = 0.047)	y = 13.64x - 76.89 (r^2 = 0.048)	y = 29.99x - 191.6 (r^2 = 0.075)	29	4	(Cogo 1983, Armstrong 1996, Diezman 1987, Swanson 1967)
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	3	1	(Alberts & Moldenhauer 1981; same soil measured)
	Res_High	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	4	2	(Cogo 1983, Alberts & Moldenhauer 1981; same soil measured)
Till_High	Res_None	y = 0.484x - 2.932 (r^2 = 0.349)	y = 0.817x - 5.606 (r^2 = 0.397)	y = 3.779x - 47.25 (r^2 = 0.471)	y = 5.772x + 241.3 (r^2 = 0.011)	y = 2.883x + 549.6 (r^2 = 0.001)	21	5	(Young 1978, Cogo 1983, Gilley 1986, Alberts 1983, Gilley 1987)
	Res_Low	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	***N/A***	***N/A***	*N/A*
	*Res_High	y = 0.363x - 5.385 (r^2 = 0.363)	y = 0.697x - 11.09 (r^2 = 0.444)	y = 2.387x - 34.72 (r^2 = 0.179)	y = 5.152x + 205.7 (r^2 = 0.022)	y = 0.768x + 729.4 (r^2 = 2E-04)	42	3	*Weak r2 possibly due to residue loading rate. (Cogo 1983, Gilley 1986, Gilley 1987)

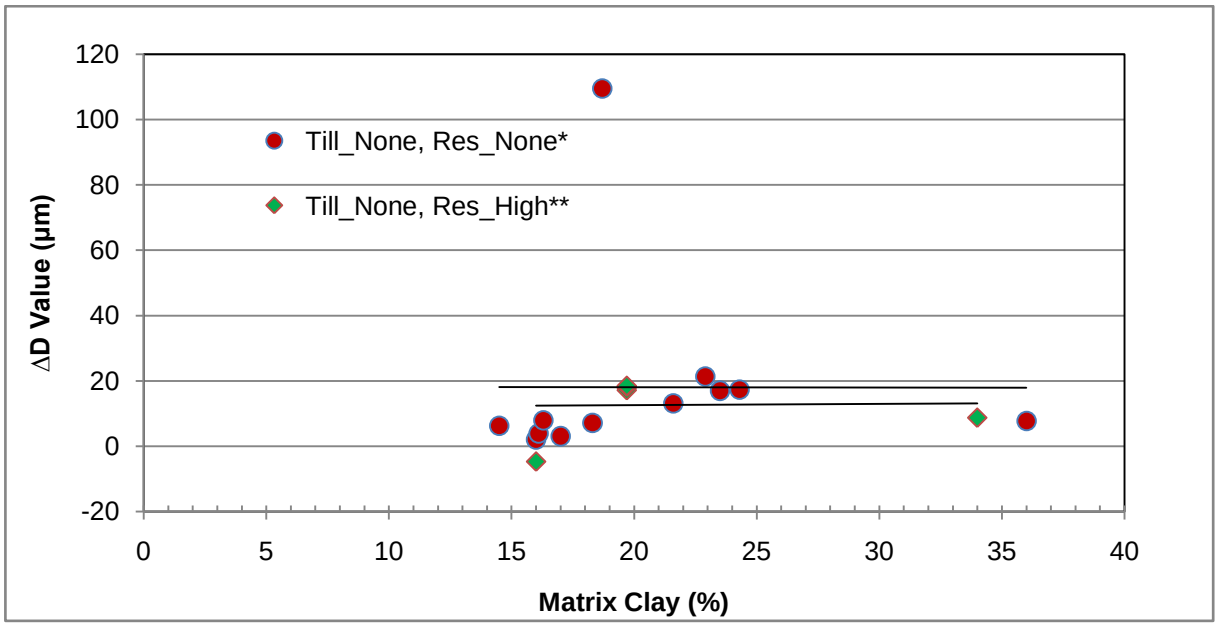


Figure 13: Scale_Rill ΔD-25 values under no tillage / no- vs. high- residue treatments. * y = -0.010x + 18.24 (r^2 = 5E-06), **y = 0.041x + 11.70 (r^2 = 0.000).

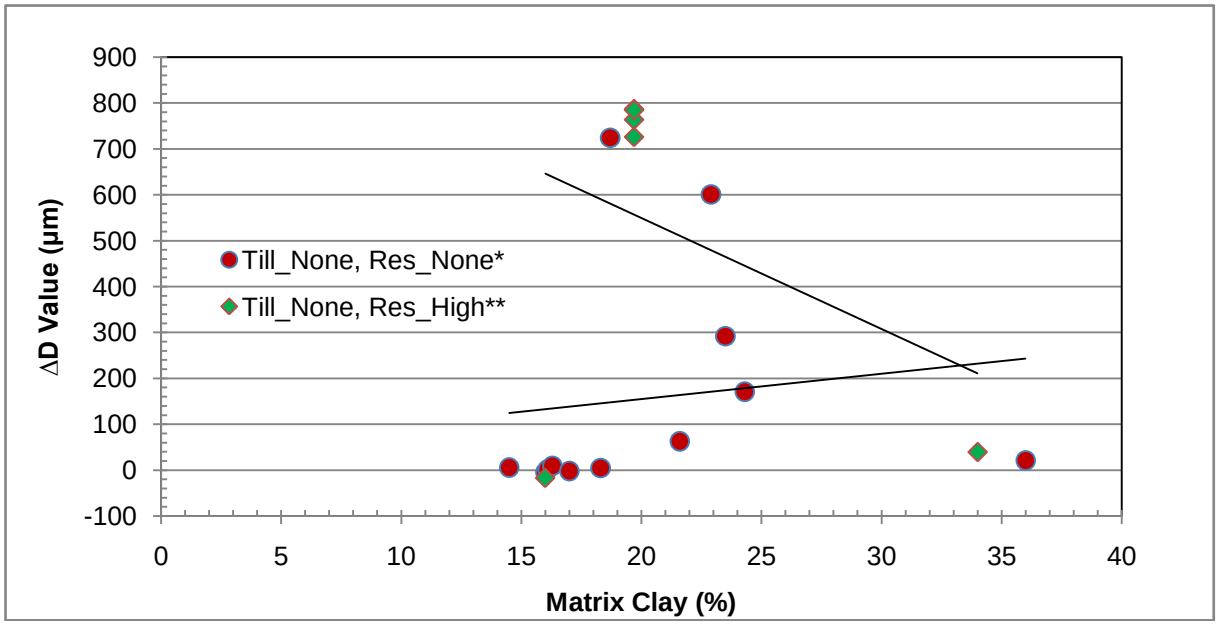


Figure 14: Scale_Rill ΔD-75 values under no tillage / no- vs. high- residue treatments. *y = 5.521x + 44.54 (r^2 = 0.016), **y = -24.17x + 1033 (r^2 = 0.153).

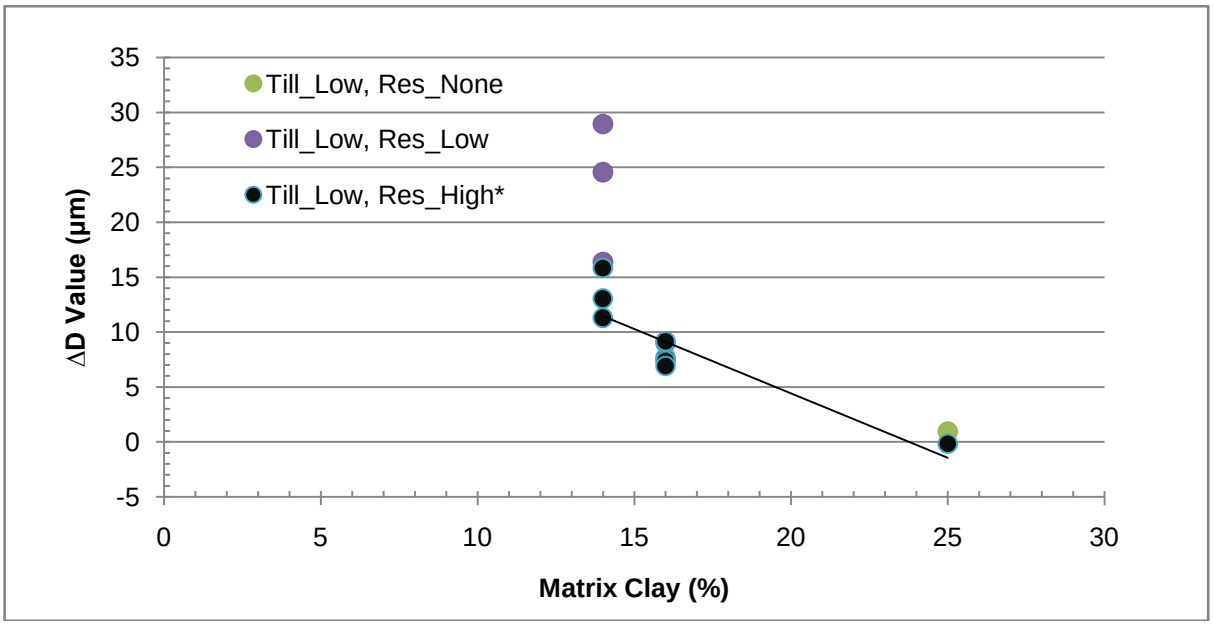


Figure 15: Scale_Rill ΔD-25 values under low tillage / no-, low-, and high- residue treatments. *y = -1.173x + 27.905 (r^2 = 0.78).

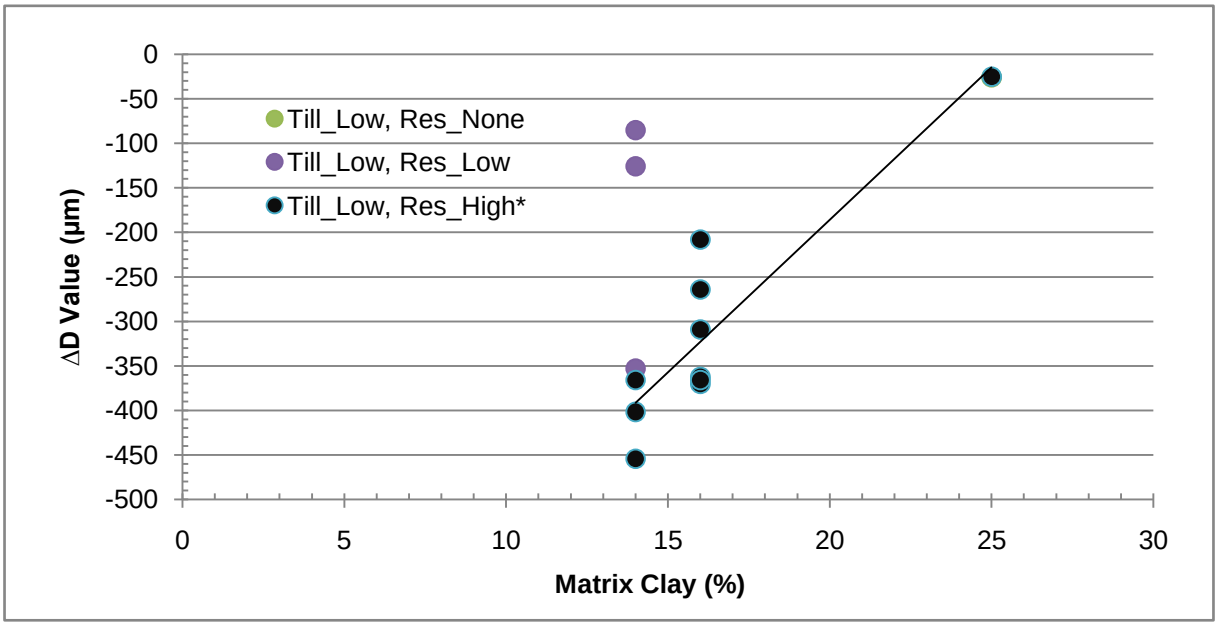


Figure 16: Scale_Rill ΔD-75 values under low tillage / no-, low-, and high- residue treatments. *y = 34.24x - 870.92 (r^2 = 0.80).

This ΔD value reduction was more apparent for larger sediment classes, as can be seen comparatively in Figures 15 and 16, where ΔD values are negative for larger size classes, indicating a transport limiting condition that results from residue coverage. The extent of this reduction may be related to residue loading rate, but it is still unclear how these treatment responses compare to Till_Low/Res_None treatments due to the lack of data.

Only one data point existed for Till_Low/Res_None treatments, and the values were more similar to ones seen for Till_Low/Res_High than seen for Till_Low/Res_Low treatments (Figure 15, 16). The resulting analysis on the effects of residue on Till_Low soils was not described for Res_Low and Res_High treatments until more data can be collected and analyzed for Res_None treatments.

Till_Med treatments were evaluated against residue coverage treatments, but only one treatment combination (Till_Med/Res_None) had enough measured clay content variation to fit a regression line (Figures 17, 18). Till_Med/Res_None treatments had a more linear ΔD value response at smaller size classes (ΔD-25), but ΔD variability increased as larger size classes were described (ΔD-75). This suggests that factors other than the tillage treatment were responsible for the variability.

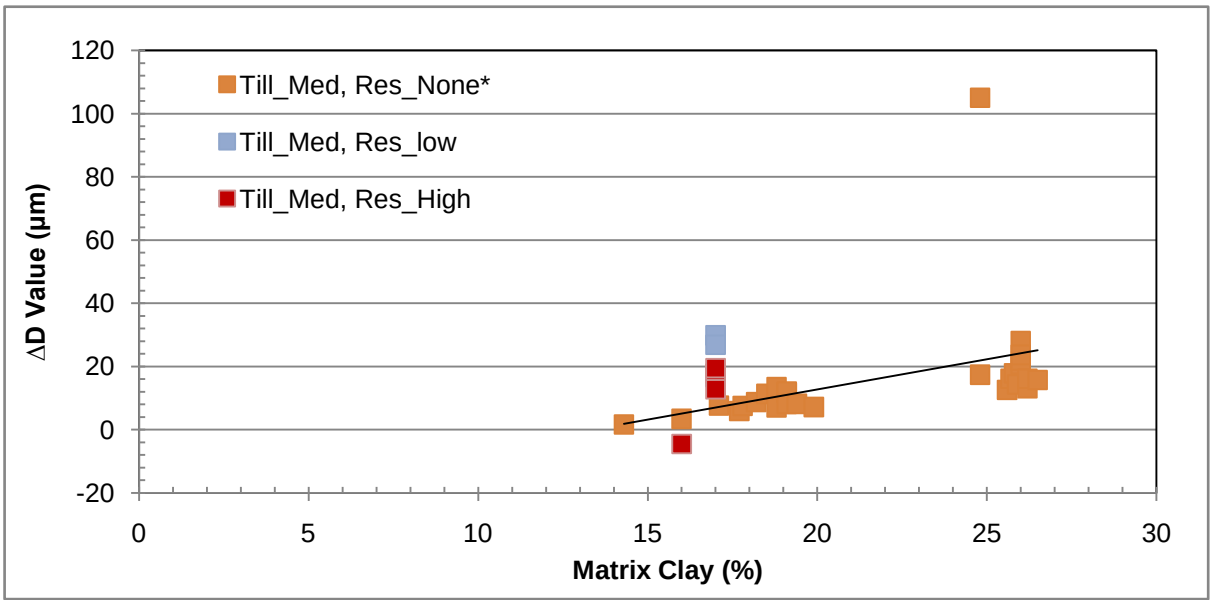


Figure 17: Scale_Rill ΔD-25 values under medium tillage / no-, low-, and high-treatments. *y = 1.908x - 25.39 (r^2 = 0.174).

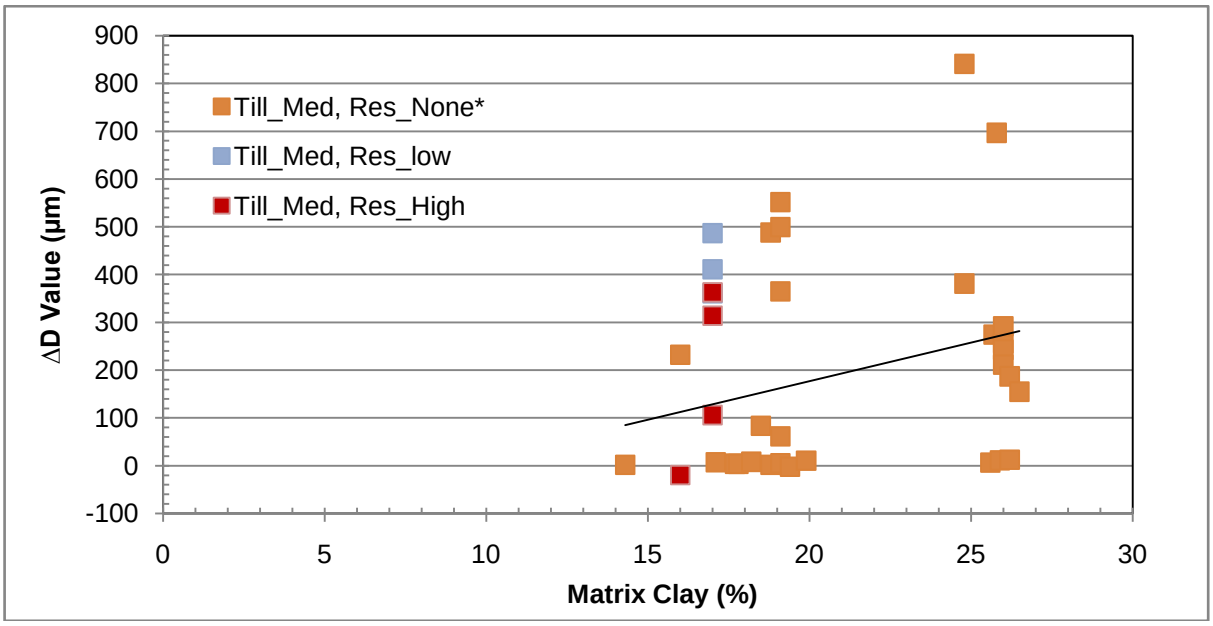


Figure 18: Scale_Rill ΔD-75 values under medium tillage / no-, low-, and high-treatments. *y = 16.10x - 145.0 (r^2 = 0.08).

Till_High soils were evaluated against high- and no-residue treatments (Figures 19, 20). Data were not available to evaluate Res_Med treatments.

While there appeared to be a significant difference in residue treatment responses for the smaller size classes (ΔD-25; Figure 19), this was not as clear for the larger size classes (ΔD-75; Figure 20). It appears that for smaller size classes (ΔD-25) any loading rate associated with High residue cover tends to generate smaller ΔD values as a result, but not for larger size classes (e.g., ΔD-75). Spurious results were suggested by the unnaturally high variability associated with Res_High plotted values. This condition was initially indicated by the unacceptable equal variance values in the associated ANOVA output (Table 9). Interestingly, the ANOVA equal variance concerns for Scale_Interrill were not as bad as for Scale_Rill (Table 8 and 9). This suggests that other factors than loading rate (as it is currently defined) have a significant effect on the variability of data, especially for larger size classes, and this response seems to increase with scale.

For larger size classes (ΔD-75), there appears to be no difference between ΔD values for Res_None and Res_High treatments, unless we take the residue loading rate

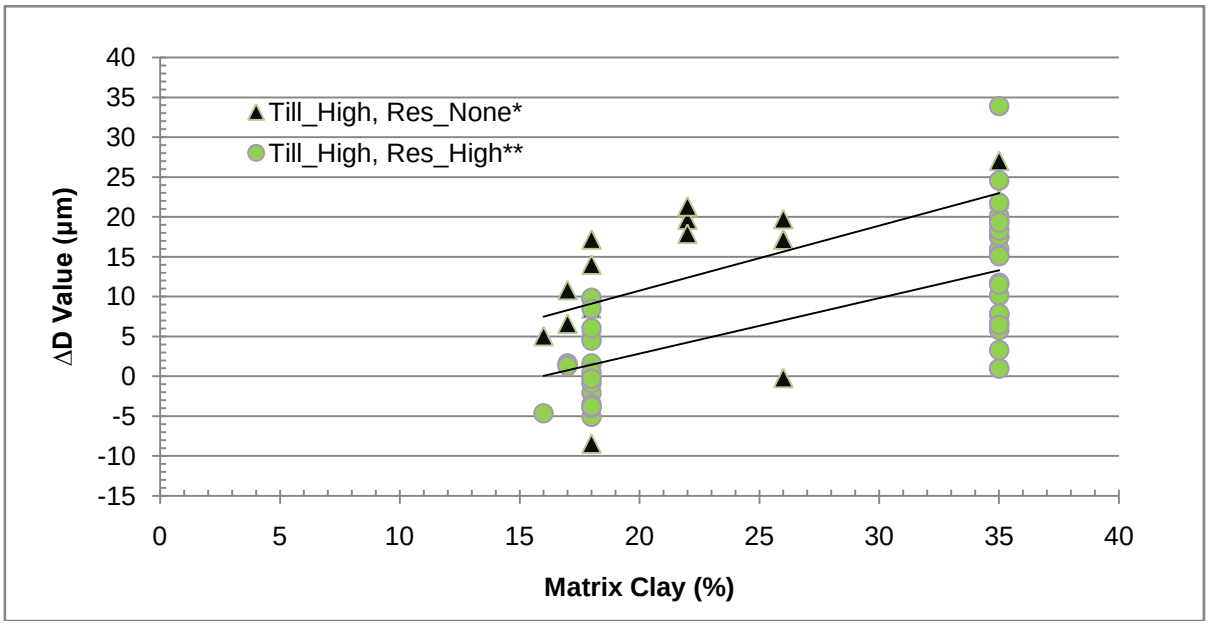


Figure 19: Scale_Rill ΔD-25 values under high tillage / no- and high- residue treatments. * y = 0.817x - 5.606 (r^2 = 0.397), **y = 0.697x - 11.08 (r^2 = 0.44).

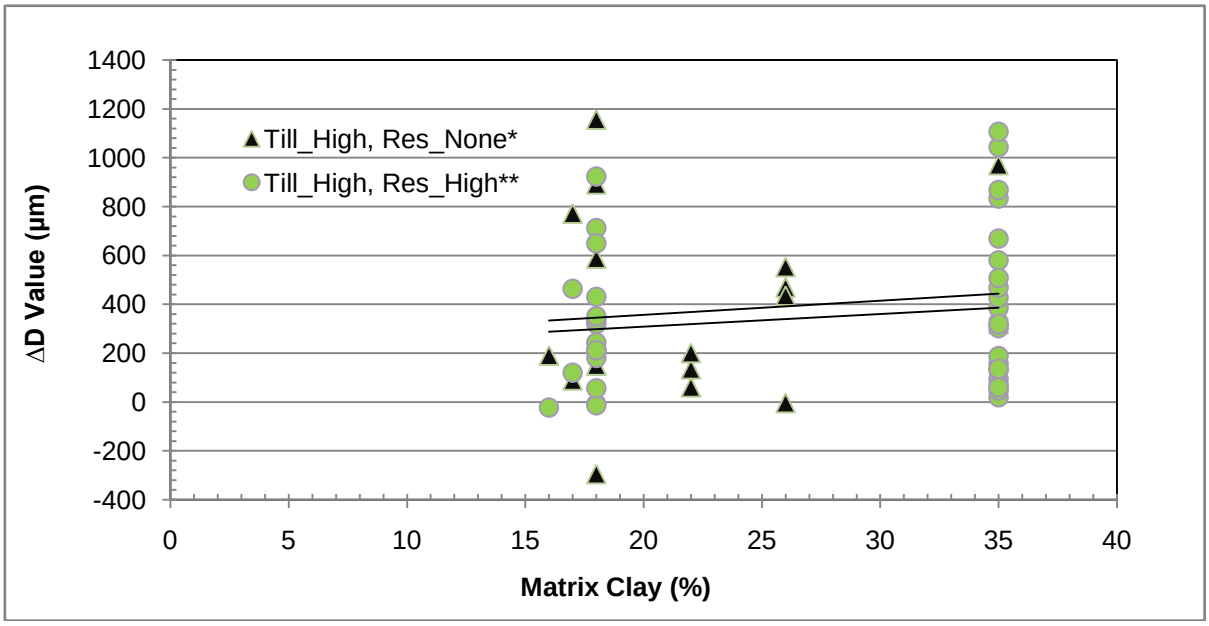


Figure 20: Scale_Rill ΔD-75 values under high tillage / no- and high- residue treatments. * y = 5.772x + 241.3 (r^2 = 0.011), **y = 5.151x + 205.6 (r^2 = 0.02).

into consideration. Therefore, for highly disturbed (tilled) soils, high residue has a significant effect on reducing the amount of finer sediment, but this relationship is not as clear for larger-sized sediment, which suggests that other factors are significant.

When loading rate is considered (Figure 21), it can be seen that the significance of the loading rate varies depending on which size class is considered. For example, no differences exist due to loading rate for ΔD-15, but at ΔD-75 very distinct differences exist. At larger ΔD values (i.e., ΔD-75 and ΔD-85), larger ΔD values are observed for low residue coverage treatments as compared to high coverage. In other words, at larger ΔD values, increased residue loading rate tends to reduce the erosion of larger sized sediment and results in erosion of particles more similar to the matrix PSD. Interestingly, residue type also appears to have a slight effect on ΔD values. For example, larger ΔD values were generally observed for soybean as compared to sorghum residue treatments, but this effect was not clear for every loading rate, and there were not really enough data available to follow this up further.

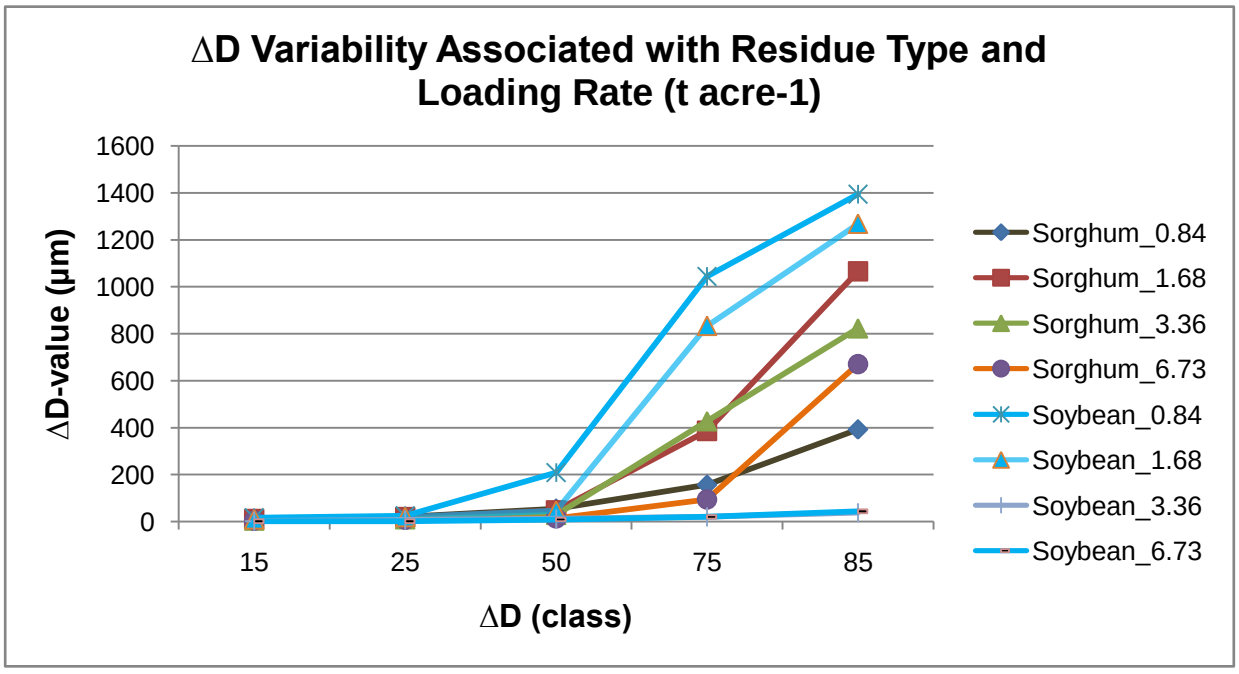


Figure 21: The effects of residue type and cover on various ΔD values. Averaged Scale_Rill ΔD-values associated with residue cover (2 residue types and 4 loading rates represented by the numbers above in tons acre^{-1}) for each cumulative ΔD size class.

Applications of regression techniques accomplished two main objectives. First, regression techniques were used to validate the ANOVA suggested groupings using statistical support (i.e., strong r^2 values). Secondly, predictive equations were able to be defined for those conditions that showed a relationship. These equations were defined for each of the 5 ΔD-values for each available treatment combination. The resulting set of equations could then be used to estimate the ESSD generated by a specific combination of soil, management practice, and scale. The main goal of the regression analysis was to derive or identify equations that ultimately are more accurate than the current RUSLE equations, partially because these newly-derived equations will include tillage and residue practices. Therefore a weak r^2 is not as important as a more accurate overall predictive estimate, which must be validated against real, independent data.

VALIDATION

A comparison of the predictive accuracies of the current RUSLE equations against the proposed (regression generated) equations were used to validate which method comes closer to 'true' estimates and should therefore be accepted. Root mean squared error (RMSE) calculations were used as an unbiased estimator to describe how close an equation comes to predicting the actual ESSD.

RMSEs were found by comparison of the predictive estimates of ΔD values calculated for both the current and proposed RUSLE equations to ΔD values associated with independent data. The ΔD values that were calculated using the newly-proposed RUSLE equations did so using corresponding equations developed for the specific soil texture, scale, and management practices associated with independent data. The ΔD values that were calculated using the current RUSLE equations did so using the specific soil texture associated with the independent data, since that is the only parameter that currently used to calculate the ESSD (and resulting ΔD values). The ΔD values associated with the independent ESSD data was then used as a true standard and basis to calculate RMSEs for the two sets of ΔD values.

RMSEs were calculated first for each individual ΔD value to get an indication of the accuracies associated with specific size ranges, and then also for the total ESSD (i.e., combined ΔD values) to evaluate how accurate the equations are at describing the entire ESSD. A smaller RMSE indicates an estimate closer to the actual independent/ true standard value, so is more accurate than larger RMSEs. These calculations therefore provide an unbiased comparison of the accuracy of the current RUSLE equations against the proposed equations.

The following Tables 14 and 15 display the comparative accuracies of the two sets of equations to independent data. The independent data consists of Till_Med/Res_None treatment combinations for 4 soils ranging from 15-46% matrix clay (Meyer, 1992).

Notice in the above tables (14, 15) that the RMSEs for the ΔD value size classes associated with the new equations are typically smaller, so these are more accurate than the current RUSLE2 equations. These smaller RMSE values are not better for all the ΔD value size classes for each soil, but when all the soils RMSEs are averaged, the RMSEs for the new equations are significantly better except for ΔD-75 (Table 16).

Table 14: RMSE ΔD values for each soil generated using the current RUSLE equations. The red-highlighted values indicate worse RMSEs as compared to the new equations (Meyer 1992).

Current RUSLE Equations	Soil Type and Matrix Clay (%)	Loring Silt Loam (15%)	Monona Silty Clay Loam (27%)	Atwood Silty Clay Loam (30%)	Leeper Clay (46%)	*Averaged RMSE*
	ΔD-15 (μm)	96.0	249.6	900.0	259.2	19.4
	ΔD-25 (μm)	295.8	912.0	1288.8	5169.6	43.8
	ΔD-50 (μm)	745.3	1428.8	134909.3	285.6	185.3
	ΔD-75 (μm)	1714.0	36442.8	133663.4	4303.4	209.8
	ΔD-85 (μm)	98658.8	852852.3	48136.4	242753.3	557.3

Table 15: RMSE ΔD values for each soil generated using the new equations. In this case the Till_Med/Res_None equations, which best represent the validation data conditions. The red-highlighted values indicate worse RMSEs as compared to the current RUSLE equations (Meyer 1992).

Revised Equation (Till_Med / Res_None)	Soil Type and Matrix Clay (%)	Loring Silt Loam (15%)	Monona Silty Clay Loam (27%)	Atwood Silty Clay Loam (30%)	Leeper Clay (46%)	*Averaged RMSE*
	ΔD-15 (μm)	20.3	15.2	12.3	7.8	3.7
	ΔD-25 (μm)	31.4	15.2	5.8	252.8	8.7
	ΔD-50 (μm)	265.7	739.8	0.25	10485.8	53.6
	ΔD-75 (μm)	2959.4	11257.2	368570.4	98910.3	347.0
	ΔD-85 (μm)	7344.5	26146.9	624100.0	4395.7	406.8

Table 16: Averaged RMSE of the four (validated) soils for both the current RUSLE2 and the new equations. The red-highlighted values indicate RMSEs that were worse for the new equations than for the current RUSLE equations.

Analysis Method	Current RUSLE RMSEs	New Equations (Till_Med/Res_None) RMSEs
ΔD-15 (μm)	19.4	3.7
ΔD-25 (μm)	43.8	8.7
ΔD-50 (μm)	185.3	53.6
ΔD-75 (μm)	209.8	347.0
ΔD-85 (μm)	557.3	406.8

A possible reason for the consistently less accurate ΔD-75 estimates with the new approach might be interpolation errors associated with trying to fit a line over larger gaps. Interpolation error is more likely to occur over large size differences (as opposed to small gaps) because the variability between gaps is unknown and averaged out, introducing error for areas where interpolation over- or under-estimates true values. In addition, in establishing the Small Aggregate values, the Foster (1985) approach focused specific attention to fitting the data within the size range usually falling near the D-75 value, so it should be expected to have a reasonably good fit there.

The RMSEs for all soils combined were better for the new approach than for the current RUSLE2 approach for every size class except the ΔD-75 size class (Table 16). While this exception is significant, the comparative difference is overshadowed by the overall significance of the RMSEs for the complete ESSD. For example, if we compare the summed RMSE's for the complete ESSD (all ΔD size classes), it can be seen that the new equations generate a lower overall RMSE (RUSLE RMSE=1016 µm, new RMSE=820 µm). Additionally, the improved accuracies are most notable for the smaller size classes, which tend to be disproportionally associated with negative sediment impacts.

Because these new equations account for management practices and generate a more accurate set of predictive equations, it is suggested that these equations be in contention with the current RUSLE equations, if not altogether replace those.

RUSLE APPLICATIONS OF THE NEW EQUATIONS

Assuming accurate equations are developed, the ESSD can be calculated for individual scales using RUSLE and information on the soil matrix clay content, residue loading rate, and tillage operation. RUSLE can use the interrill equations to calculate the ESSDs in the sediment load coming from the interrill areas based on the user-defined contributing area as well as the matrix clay content and specific management (tillage and residue) practice. In order for RUSLE to calculate the ESSD over entire hillslopes, rill scale ESSDs need to be appropriately accounted for based on specific

conditions. More specifically, it needs to be determined how to calculate rill scale ESSDs for various flow conditions (e.g., no-rill detachment to high rill detachment). Having two sets of equations for Scale_Rill could be used to weight the ESSD based on predominating conditions. For example, a typical Scale_Rill plot could be 20m long on a 1% slope or 20m long on a much steeper slope (~25%) and these two sets of equations could be used separately for each representative Scale_Rill contributing plot to adjust for the increased rill erosion rate.

Scale-weighted equations to describe the ESSD based on the relative contributing scales should be considered, much like the current use of interrill/rill ratios used by RUSLE to account for the different detachment rates characteristic of each scale[1]. Although RUSLE uses an interrill/rill ratio to calculate total mass detachment rates based on the relative plot conditions, this suggested use of several equations to 'weight' the ESSD equations has not been proven to generate valid results and should be tested once more data are obtained, tested, and validated. Additionally, the size standards for qualifying specific scales as well as conditions that either increase or decrease rill detachment rates (slope, runoff rate, etc.) need to be defined and evaluated so that RUSLE can appropriately calculate the hillslope ESSD relative to the ratio of interrill / rill contributing scales.

[1] RUSLE calculates the interrill/rill ration as a function of slope steepness, rill to interrill soil erodibility characteristics, and how cover-management conditions affect rill erosion different from interrill erosion (USDA-ARS, 2008b).

CHAPTER IV

CONCLUSIONS

Based on the results of our analyses, residue cover and tillage management practices significantly impact the ESSD depending on the contributing scale. The revisions made to quantitatively model these impacts generally improved ESSD estimates compared to the current RUSLE approach, which estimates the ESSD in five size classes based solely on soil clay content.

Since the size distribution of soil particles as detached by raindrop impact and concentrated flow erosive forces is different, spatial relationships as they affect the ESSD were defined to aid RUSLE2 in modeling correlations between the resulting sheet and rill ESSD when either scale predominates. ESSD data were collected for 73 Scale_Interrill and 131 Scale_Rill treatment combinations. While there were insufficient data to evaluate every treatment combination, several predictive equations were successfully developed. Specifically, Till_Med / Res_None equations proved to be more accurate at predicting the ESSD than the current methods, when validated against real data.

This study found that the proposed revisions to these equations better describe the size distribution of hillslope detached particles for four (Scale_Interrill) independent data sets (avg. RMSE = 182.5 µm) than does the current approach (RMSE = 208.4 µm), partially by including the previously unaccounted management factors. When validated against independent data, these new equations were notably more accurate (i.e., had smaller RMSEs) at predicting smaller sediment size classes, which tends to be the size range most associated with negative impacts.

Additional improvements to the approach make use of ΔD values, which enables the user to completely define the ESSD based on deviation from the dispersed matrix particle size distribution (PSD), with that deviation defined by the regression relationships described above. Once the ESSD has been defined, users may divide the

ESSD into specific size classes in any way they desire, because using ΔD values allows the entire ESSD to be defined more precisely.

Since the strength of the aforementioned approach is ultimately tied to the data used to develop relationships, additional research is needed to account for ΔD relationships not able to be described by this project due to lack of data. To address these limitations encountered during the research, the following subjects need to be further investigated:

- Update / develop equations for more treatment combinations and soils as data become available.
    - Revise proposed equations.
        - Develop equations for Scale_Rill.
        - Develop more specific residue equations to better account for type and loading rate effects.
        - Validate all treatments combinations for both scales.
- Develop a method to determine the primary particle composition of the aggregates and the overall sediment. In other words, once the ESSD of the delivered sediment is known, can the dispersed particle size distribution of that sediment be estimated? This is important in determining the ability of the aggregates to carry attached chemicals. Some work on this has already been done based on the non-selectivity approach described by Foster (1985), but the approach is still incomplete.
- Evaluate error caused by the linear interpolation between sparse data points to develop the ESSD, especially for the lower D-values.
    - Other applicable interpolation procedures should be tried (spline, asymptotic, etc.) and compared to fine-resolution ESSD data to determine which approach fits best. Developing a better interpolation approach may

reduce the error associated with some of the fits, perhaps allowing more significant effects and better fits.

- Standards need to be developed that objectively define the desired spatial scales (e.g., size dimensions, flow rates, etc.).
- Evaluate the potential applicability of using ΔM values instead of ΔD values as more data become available.
- Evaluate potential chemical transport applications

While this study did not find enough data to develop a fully comprehensive hillslope model, the approach contained within this document was shown to be an improved, valid approach. The above issues need to be addressed and new results validated to provide a model that can account for common soil management practices and can distinguish between hillslope (interrill and rill) scale differences. The increased accuracy and applicability of the resulting product ultimately will provide a robust tool to help address and mitigate erosion related impacts and concerns. Because these equations account for management practices and generate a more accurate set of predictive equations, they should be seriously considered to replace the existing RUSLE equations as they are developed.

BIBLIOGRAPHY

Abu Hammad, A., H. Lundekvam, and T. Borresen. 2005. Adaptation of RUSLE in the eastern part of the Mediterranean region. Abu Environmental Management. 34(6): 829-841.

Ackerman, F.G., and H.E. Myers. 1943. Some factors influencing aggregation of claypan soils. Soil Science 55(1): 405-413.

Alberts, E.E., G.E. Schuman, and R.E. Burwell. 1978. Seasonal runoff losses of nitrogen and phosphorus from Missouri valley loess watersheds. Journal of Environmental Quality 7(2): 203-208.

Alberts, E.E., W.C. Moldenhauer, and G.R. Foster. 1980. Soil aggregates and primary particles transported in rill and inter rill flow. Soil Science Society of America Journal 44: 590-595.

Alberts, E.E, and W.C. Moldenhauer. 1981. Nitrogen and phosphorus transport by eroded soil aggregates. Soil Science Society of America Journal 45: 391-396.

Alberts, E.E., W.H. Neibling, and W.C. Moldenhauer. 1981. Transport of sediment nitrogen and phosphorus in runoff through cornstalk residue strips. Soil Science Society of America Journal 45: 1177–1184.

Alberts, E.E., R.C. Wendt, and R.F Piest. 1983. Physical and chemical-properties of eroded soil aggregates. Transactions of the American Society of Agricultural and Biological Engineers 26(2): 465-471.

Alberts, E. E., and W. H. Neibling. 1994. Influence of crop residues on water erosion. In Managing Agricultural Residues, 19-39. P.W. Unger, ed. Chelsea, Mich.: Lewis Publishers.

Aldurrah, M.M., and J.M. Bradford. 1982(a). Parameters for describing soil detachment due to single water-drop impact. Soil Science Society of America Journal 46(4): 836-840.

Aldurrah, M.M., and J.M. Bradford. 1982(b). The mechanism of raindrop splash on soil surfaces. Soil Science Society of America Journal 46(5): 1086-1090.

Ali, S., and V.N. Shard. 2005. Evaluation of the universal soil loss equation (USLE) in semi-arid and sub-humid climates of India. Applied Engineering in Agriculture 21(2): 217-225.

Annaba, M., S. Hoot, C. Francou, M. Poitrenaud, and Y. Le Bissonnais. 2007. Soil aggregate stability improvement with urban composts of different maturities. Soil Science Society of America Journal 71: 413-423.

Arduino, E., E. Barberis, and V. Boero. 1989. Iron oxides and particle aggregation in B horizons of some Italian soils. Geoderma. 45(3-4): 319-329.

Arshad, M., J. Ryan, and R.C. Paeth. 1980. Influence of organic matter, free iron and calcium carbonate on soil particle size distribution. Agrochimica 24(5-6): 470-477.

Armstrong, S.M., and O.R. Stein. 1996. Eroded aggregate size distributions from disturbed lands. Transactions of the American Society of Agricultural and Biological Engineers. 39(1): 137-143.

Baneejee, S.P., P. Pande, R.C. Pant, R.K. Subi, and K.C. Bodala. 1981. Free iron oxide in relation to aggregation in lateritic soils of East Midnapur Forest Division, West Bengal. Indian. 107(1): 24–29.

Barberis, E., F. Ahimone Marsan, V. Boero, and E. Arduino. 1991. Aggregation of soil particles by iron-oxides in various size fractions of soil B-horizons. Journal of Soil Science. 42(4): 535-542.

Borggaard, O.K. 1983. Iron oxides in relation to aggregation of soil particles. Acta Agriculturae Scandinavica (Sweden) 33: 257-260

Bradford, J. M., J. E. Ferris, and P.A. Remley. 1987(a). Interrill soil-erosion processes. 1. effect of surface sealing on infiltration, runoff, and soil splash detachment. Soil Science Society of America Journal 51(6): 1566-1571.

Bradford, J. M., J. E. Ferris, and P.A. Remley. 1987(b). Interrill soil-erosion processes. 2. relationship of splash detachment to soil Properties. Soil Science Society of America Journal 51(6): 1571-1575.

Brown, L. C., and L. D. Norton 1994. Surface residue effects on soil-erosion from ridges of different soils and formation. Transactions of the American Society of Agricultural and Biological Engineers 37(5): 1515-1524.

Chaplot, V. A. M., and Y. Le Bissonnais. 2000. Field measurements of interrill erosion under different slopes and plot sizes. Earth Surface Processes and Landforms 25: 145.

Chaplot, V. A. M., and Y. Le Bissonnais. 2003. Runoff features for interrill erosion at different rainfall intensities, slope lengths, and gradients in an agricultural loessial hillslope. Soil Science Society of America Journal (3): 844-851.

Chesters, G., O.J. Attoe, and O.N. Allen. 1957. Soil aggregation in relation to various soil constituents. Soil Science Society of America Proceedings 21: 272-277.

Clean Water Act. 33 U.S.C. 1251 et seq 1977

Cogo, N.P., W.C. Moldenhauer, and G.R. Foster. 1983. Effect of crop residue, tillage-induced roughness, and runoff velocity on size distribution of eroded soil aggregates. Soil Science Society of America Journal 47: 1005-1008.

Deizman, M.M., S. Mostaghimi, V.O. Shanholtz, and J.K. Mitchell. 1987. Size

distribution of eroded sediment from two tillage systems. Transactions of the American Society of Agricultural and Biological Engineers 30(6): 1642-1647.

De Ploey, J., and J. Savat. 1968. Contribution to the study of splash erosion (In French) Z. Geomorphology 12: 174-193.

De Ploey, J. 1981. Crusting and time-dependant rainwash mechanisms on loamy soils. Soil Conservation-Problems and Prospects. (Morgan R.P.C. editor), 139-152. J Wiley & Sons, Chichester.

Deshpand, T.L., Greenlan D.J., and J.P. Quirk. 1968. Changes in soil properties associated with removal of iron and aluminium oxides. Journal of Soil Science 19(1): 108-122.

Durnford, D., and J.P. King. 1993. Experimental study of processes and particle-size distributions of eroded soil. Journal of Irrigation and Drainage Engineering-ASCE 119(2): 383-398.

Duiker, S.W., F.E. Rhoton, J. Torrent, N.E. Smech, and R. Lan. 2003. Iron (hydr)oxide crystallinity effects on soil aggregation. Soil Science Society of America Journal 67(2): 606-611.

Ekwue, E.I. 1991. The effects of soil organic matter content, rainfall duration and aggregate size on soil detachment. Soil Technology 4(3): 197-207.

Farenhorst, A., and R.B. Bryan. 1995. Particle size distribution of sediment transported by shallow flow. Cantena 25: 47-62.

Farmer, E.E. 1973. Relative detachability of soil particles by simulated rainfall. Soil Science Society of America Proceedings 37: 629-633.

Fertig, L.H., E.J. Monke, and G.R. Foster. 1982. Characterization of eroded soil particles from interrill areas. ASAE. Paper No. 82-2038, ASAE. St. Joseph, MI. 49085.

Finkner, S.C., J.E. Gilley, and G.E. Varvel. 1986. Size distribution of sediment as affected by sorghum and soybean residue. American Society of Agricultural Engineers Paper No. 86-2536, ASAE. St. Joseph, MI 49085.

Finkner, S.C., M.A. Nearing, G.R. Foster, and J.E. Gilley. 1989. A simplified equation for modeling sediment transport capacity. Transactions of American Society of Agricultural Engineers 32(5):1545-1550.

Foot, K., and R.P.C. Morgan. 2005. The role of leaf inclination, leaf orientation and plant canopy architecture in soil particle detachment by raindrops. Earth Surface Processes and Landforms 30:1509-1520.

Foster, G.R., and L.D. Meyer. 1972. Transport of soil particles by shallow flow. Transactions of the American Society of Agricultural Engineers 15(1): 99-102.

Foster, G.R., and L.D. Meyer. 1975(a). Soil erosion and sedimentation by water-an overview. Proc. Nat. Symp. Soil Erosion and Sedimentation by Water. ASAE 4(77): 1-13.

Foster, G.R., and L.D. Meyer. 1975(b). Mathematical simulation of upland erosion by fundamental erosion mechanics. *In:* Present and Prospective Technology for Predicting Sediment Yields and Sources. ARS-S-40 U.S. Department of Agriculture. pp. 190-204.

Foster, G.R., C.B. Johnson, and W.C. Moldenhauer. 1982. Critical slope lengths for unanchored cornstalk and wheat straw residue Transactions of the American Society of Agricultural and Biological Engineers. 25(4): 935-939, 947.

Foster, G.R., R.A. Young, and Neibling W.H. 1985. Sediment composition for nonpoint source pollution analyses. Transactions of the American Society of Agricultural Engineers 28(1): 133-139, 146.

Franti, T.G., J.M. Laflen, and D.A. Watson. 1999. Predicting soil detachment from high-discharge concentrated flow. Transactions of the American Society of Agricultural and Biological Engineers 42(2): 329-335.

Frere, M.H., D.A. Woolhiser, J.H. Caro, B.A. Stewart, and W.H. Wischmeier. 1977. Control of nonpoint water pollution from agriculture: some concepts. Journal of Soil and Water Conservation 32: 260-264.

Freebairn, D.M., D.M. Silburn, and R.J. Loch. 1989. Evaluation of soil erosion models for clay soils. Australian Journal of Soil Research 27: 199-211.

Furbish, D.J., K.K. Hamner, M. Schmeeckle, M.N. Borosund, and S.M. Mudd. 2007. Rain splash of dry sand revealed by high-speed imaging and sticky paper splash targets. Journal of Geophysical Research-Earth Surface 112(F1): Art. No. F001001

Gabriels, D., and W.C. Moldenhauer. 1978. Size distribution of eroded material from simulated rainfall: effect over a range of soil texture. Soil Science Society of America Proceedings 42(6): 954-958.

Gabriels, D. 1999. The effect of slope length on the amount and size distribution of eroded silt loam soils: short slope laboratory experiments on interrill erosion. Geomorphology 28(1-2): 169-172.

Gale, W.J., C.A. Cambardella, and T.B. Bailey. 2000. Root-derived carbon and the formation and stabilization of aggregates. Soil Science Society of America Journal 64: 201-207.

Ghadiri, H., and D. Payne. 1988. The formation and characteristics of splash following raindrop impact on soil. Journal of Soil Science 39(4): 563-575.

Gilley, J.E., S.C. Finkner, and G.E. Varvel. 1986a. Runoff and erosion as affected by

sorghum and soybean residue. Transactions of the American Society of Agricultural and Biological Engineers 29(6): 1605-1610.

Gilley, J.E., S.C. Finkner, R.G. Spomer, and L.N. Mielke. 1986b. Size distribution of sediment as affected by corn residue. Transactions of the American Society of Agricultural and Biological Engineers 29(5): 1273-1277.

Gilley, J.E., S.C. Finkner, and G.E. Varvel. 1987(a). Slope length and surface residue influences on runoff and erosion. Transactions of the American Society of Agricultural and Biological Engineers 30(1): 148-152.

Gilley, J.E., S.C. Finkner, and G.E. Varvel. 1987(b). Size distribution of sediment as affected by surface residue and slope length. Transactions of the American Society of Agricultural and Biological Engineers 30(5): 1419-1424.

Gulser, C. 2006. Effect of forage cropping treatments on soil structure and relationships with fractal dimensions. Geoderma (131): 33-44.

Haan, C.T., B.J. Barfield, and J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego. p. 204-212

Hairsine, P. B., and C. W. Rose. 1992. Modeling water erosion due to overland-flow using physical principles. 2. rill flow. Water Resources Research 28(1): 245-250.

Hillel, D. 1998. Environmental Soil Physics. Academic Press, Inc., San Diego, CA.

Khanbilvardi, R.M., and A.S. Rogowski. 1986. Modeling soil-erosion, transport and deposition. Ecological Modeling 33(2-4): 255-268.

Kinnell, P.I.A. 1990. The mechanics of raindrop-induced flow transport. Australian Journal of Soil Research 28(4): 497-516.

Kinnell, P.I.A. 1991. The effect of flow depth on sediment transport induced by raindrops impacting shallow flows. Transactions of the American Society of Agricultural and Biological Engineers 34: 161-168.

Kinnell, P. I. A., and D. Cummings. 1993. Soil slope gradient interactions in erosion by rain-impacted flow. Transactions of the American Society of Agricultural and Biological Engineers 36: 381-387.

Kinnell, P.I.A. 2000. The effect of slope length on sediment concentrations associated with side-slope erosion. Soil Science Society of America Journal 64: 1004-1008.

Kinnell, P.I.A. 2005(a). Raindrop-impact-induced erosion processes and prediction: a review. Soil Science Society of America Journal 19(14): 2815-2844.

Kinnell, P.I.A. 2005(b). Sediment transport by medium to large drops impacting flows at subterminal velocity. Soil Science Society of America Journal 69(3): 902-905.

Lattanzi, A.R., L.D. Meyer, and M.F. Baugardner. 1974. Influences of mulch rate and

slope steepness of interrill erosion. Soil Science Society of America Proceedings 38: 946-950.

Le Bissonnais, Y. 1996. Aggregate stability and assessment of soil crustability and erodibility: I theory and methodology. European Journal of Soil Science 47: 425-437.

Le Bissonnais, Y., H. Benkhadra, V. Chaplot, D. Fox, D. King, and J. Daroussin. 1998. Crusting, runoff and sheet erosion on silty loamy soils at various scales and upscaling from m^2 to small catchments. Soil and Tillage Research 46: 69.

Legout C., S. Leguedois, and Y. Le Bissonnais. 2005(a). Aggregate breakdown dynamics under rainfall compared with aggregate stability measurements. European Journal of Soil Science 56(2): 225-537.

Legout, C., S. Leguedois, Y. Le Bissonnais, and O. Malam Issa. 2005(b). Splash distance and size distributions for various soils. Geoderma 124(3-4): 279-292.

Leguedois, S., O. Planchon, C. Legout, and Y. Le Bissonnais. 2005. Splash projection distance for aggregated soils: theory and experiment. Soil Science Society of America Journal 69(1): 30-37.

Loch, R.J., D.M. Silburn, and D.M. Freebairn. 1989. Evaluation of the CREAMS model. II. use of rainulator data to derive soil erodibility parameters and prediction of field soil losses using derived parameters. Australian Journal of Soil Research 27(3): 563-576.

Loch, R. J., and J. L. Foley. 1994. Measurement of aggregate breakdown under rain-comparison with tests of water stability and relationships with field-measurements of infiltration. Australian Journal of Soil Research 32(4): 701-720.

Luk, D.H., A.D. Abrahams, and A.J. Parsons. 1993. Sediment sources and sediment transport by rill flow on a semiarid piedmont slope, southern Arizona. Cantena 20(1-2): 93-111.

Maguire, R.O., A.C. Edwards, and M.J. Wilson. 1998. Influence of cultivation on the distribution of phosphorus in three soils from NE Scotland and their aggregate size fractions. Soil Use and Management 14: 147-153.

Malam Issa, O., Y. Le Bissonnais, O. Planchon, D. Favis-Mortlock, N. Silvera, and J. Wainwright. 2006 Soil detachment and transport on field- and laboratory-scale interrill areas: erosion processes and the size-selectivity of eroded sediment. Earth Surface Processes and Landforms 31: 929-939.

Martinez-Mena, M., J. Alvarez Rogel, J. Albaladejo, and V.M. Castillo. 1999. Influence of vegetal cover on sediment particle size distribution in natural rainfall conditions in a semiarid environment. Cantena 38: 175-190.

McCool, D.K., L.C. Brown, G.R. Foster, C.K. Mutchler, and L.D. Meyer. 1987. Revised

slope steepness factor for the universal soil loss equation. Transactions of the American Society of Agricultural and Biological Engineers 30(5): 1387-1396.

McCool, D.K., G.R. Foster, C.K. Mutchler, and L.D. Meyer. 1989. Revised slope length factor for the universal soil loss equation. Transactions of the American Society of Agricultural and Biological Engineers 32(5): 1571-1576.

Mermut, A. R., S.H. Luk, M.J.M. Romkens, and J.W.A. Poesen. 1997. Soil loss by splash and wash during rainfall from two loess soils. Geoderma 75 : 203.

Merten, G. H., M. A. Nearing, and A.L.O. Borges. 2001. Effect of sediment load on soil detachment and deposition in rills. Soil Science Society of America Journal 65(3): 861-868.

Meyer, L.D., C.B. Johnson, and G.R. Foster. 1972. Stone and woodchip mulches for erosion control on construction sites. Journal of Soil and Water Conservation 27(6): 264-269.

Meyer, L.D., G.R. Foster, and S. Nikolov. 1975a. Effect of Flow rate and canopy on rill erosion. Transactions of the American Society of Agricultural and Biological Engineers 18(5): 905-911.

Meyer, L.D., G.R. Foster, and M.J.M. Romkens. 1975b. Source of soil eroded by water from upland slopes. Proceedings of the 1972 Sediment Yield Workshop, Oxford, MS, ARS-S-40:177-189.

Meyer, L.D., W,C, Harmon, and L.L. McDowell. 1980. Sediment sizes eroded from crop row sideslopes. Transactions of the American Society of Agricultural and Biological Engineers 26(4): 891-898.

Meyer, L. D. 1981. How rain intensity affects interrill erosion. Transactions of the American Society of Agricultural and Biological Engineers 24(6): 1472-1475.

Mikha, M.M., and C.W. Rice. 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Science Society of America Journal (68): 809-816.

Morgan, R.P.C., J.N. Quinton, R.E. Smith RE, G. Govers, J.W.A. Poesen, K. Auerswald, G. Chisci, D. Torri, and M.E. Styczen. 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms 23(6): 527-544.

Moss, A.J., and P. Green. 1983. Movement of solids in air and water by raindrop impact- effects of drop-size and water depth variations. Australian Journal of Soil Research 21(3): 257-269.

Moss, A.J. 1991a. Rain-impact soil crust. 1. formation on a granite-derived soil. Australian Journal of Soil Research 29: 271 – 289.

Moss, A.J. 1991b. Rain-impact soil crust. 2. Some effects of surface slope, drop size, and soil variation. Australian Journal of Soil Research 29: 291 – 309.

Mutchler, C.K. 1967. Parameters for describing raindrop splash- knowledge of raindrop splash geometry is a prerequisite to splash erosion control. Journal of Soil and Water Conservation 22(3): 91.

Mutchler, C.K., and R. A. Young. 1975. Soil detachment by raindrops, present and prospective technology for predicting sediment yield and sources. USDA Annual Report, pp. 5–40.

Nearing, M.A., L.T. West, and L.C. Brown. 1988. A consolidation model for estimating changes in rill erodibility. Transactions of the American Society of Agricultural and Biological Engineers 31(3): 696-700.

Nearing, M.A., G.R. Foster, L.J. Lane, and S.C. Finkner. 1989. A process-based soil erosion model for USDA Water Erosion Prediction Project technology. Transactions of American Society of Agricultural Engineers 32(5):1587-1593.

Nearing, M. A., J. M. Bradford, and S.C. Parker. 1991. Soil detachment by shallow flow at low slopes. Soil Science Society of America Journal 55(2): 339-344.

Nearing, M. A., L. D. Norton, D.A. Bulgakov, G.A. Larionov, L.T. West, and K.M. Dontsova. 1997. Hydraulics and erosion in eroding rills. Water Resources Research 33(4): 865-876.

Nearing, M. A., J. R. Simanton, L.D. Norton, S.J. Bulygin, J. Stone. 1999. Soil erosion by surface water flow on a stony, semiarid hillslope. Earth Surface Processes and Landforms 24(8): 677-686.

Oades, J.M. 1967. Carbohydrates in some Australian soils. Australian Journal of Soil Research 5: 103-115.

Owoputi, L.O. 1994. A physically based study of the mechanism of sediment detachment in the soil erosion process. Ph.D.diss.Univ.of Saskatchewan, SK, Canada.

Owoputi, L. O., and W. J. Stolte. 1995. Soil detachment in the physically-based soil-erosion processes- a review. Transactions of the American Society of Agricultural and Biological Engineers 38(4): 1099-1110.

Palis, R.G., G. Okwach, C.W. Rose, and P.G. Saffigna. 1990. Soil erosion processes and nutrient loss. II The effect of surface contact cover and erosion processes on enrichment ratio and nitrogen loss in eroded sediment. Australian Journal of Soil Research 28: 623-639.

Palmer, R.S. 1964. The influence of a thin water layer on drop impact forces. I.A.H.S. publ. 65: 141-148.

Parsons, A. J., A. D. Abrahams, and J. Wainwright. 1996. Responses of interrill runoff and erosion rates to vegetation change in southern Arizona. Geomorphology 14(4): 311-317.

Parsons, A. J., S. G. L. Stromberg, and M. Greener. 1998. Sediment-transport competence of rain-impacted interrill overland flow. Earth Surface Processes and Landforms 23(4): 365-375.

Parsons, A.J., and P.M. Stone. 2006. Effects of intra-storm variations in rainfall intensity on interrill runoff and erosion. Cantena 67: 68-78

Podmore, T.H., and G.E. Merva. 1971. Silt transport by thin film flow. Transactions of the American Society of Agricultural and Biological Engineers 14(6): 1065-1067, 1072.

Poesen, J., and J. Savat. 1981. Detachment and transportation of loose sediments by raindrop splash. part II: detachability and transportability measurements. Catena 8:19–41.

Polyakov, V.O., and M.A. Nearing. 2003. Sediment transport in rill flow under deposition and detachment conditions. Catena 51(1): 33-43.

Proffitt, A.P.B., and C.W. Rose. 1991. Soil erosion processes. I. the relative importance of rainfall detachment and runoff entrainment. Australian Journal of Soil Research 29, 671-683.

Quansah, C. 1981. The effect of soil type, slope, rain intensity and their interactions on splash detachment and transport. European Journal of Soil Science 32(2): 215–224.

Rauws, G., and G. Govers. 1988. Hydraulic and soil mechanical aspects of rill generation on agricultural soils. Journal of Soil Science 39(1): 111-124.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404pp.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas, and P.E. Rasmussen. 1995. Soil orgainic-matter changes resulting from tillage and biomass production. Journal of Soil and Water Conservation 50(3): 253-261.

Riezebos, H.T., and G.F. Epema. 1985. Drop shape and erosivity; Part II splash detachment, transport and erosivity indices. Earth Surf. Processes Landforms 10:69–74.

Savat, J., and J. Poesen. 1981. Detachment and transportation of loose sediments by raindrop splash. part I: the calculation of absolute data on detachability and transportability. Catena 8:1–17.

Shainberg, I., G.J. Levy, P. Rengasamy, and H. Frenkel. 1992(a). Aggregate stability and seal formation as affected by drops impact energy and soil amendments. Soil Science 154 (2):113-119.

Shainberg, I., D. Warrington, and J.M. Laflen. 1992(b). Soil dispersibility, rain Properties, and Slope Interaction in Rill Formation and Erosion. Soil Science Society of America Journal 56(1): 278-283.

Sharma, P.P., S.C. Gupta, W.J. Rawls. 1991. Soil detachment by single raindrops of varying kinetic-energy. Soil Science Society of America Journal 55(2): 301-307.

Sharma, P.P. 1996. Interrill Erosion. Soil Conservation and Rehabilitation, Menachem A (ed.) Marcel Dekker: New York; 125-152.

Silburn, D.M., and R.J. Loch. 1989. Evaluation of the CREAMS model. 1. sensitivity analysis of the soil-erosion sedimentation component for aggregated clay soils. Australian Journal of Soil Research 27(3): 545-561.

Slburn, D. M. and D. M. Freebairn. 1992. Evaluations of the Creams Model. II. Simulation of the hydrology of vertisols. Australian Journal of Soil Research 30:547-64.

Six J., E.T. Elliot, and K. Paustian. 2000a. Soil Macroaggregate Turnover and Microaggregate Formation: A mechanism for C sequestration under no-tillage agriculture. Soil Biology and Biochemistry 32:2099-2013.

Six, J., K. Paustian, E.T. Elliot, and C. Combrink. 2000b. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. Soil Science Society of America Journal 64(2): 681-689.

Sutherland, R.A., Y. Wan, C.T. Lee, and A.D. Ziegler. 1996a. Aggregate enrichment ratios for splash and wash transported sediment from an Oxisol. Cantena 26: 187-208.

Sutherland, R. A., Y. Wan, A.D. Ziegler, C.T. Lee, and S.A. El-Swaify. 1996(b). Splash and wash dynamics: an experimental investigation using an Oxisol. Geoderma 69(1-2): 85-103.

Sutherland, R. A., R.L. Watung, and S.A. El-Swaify. 1996(c). Splash transport of organic carbon and associated concentration and mass enrichment ratios for an Oxisol, Hawaii. Earth Surface Processes and Landforms 21(12): 1145-1162.

Swanson, N.P., Dedrick A.R., and H.E. Weakly. 1965. Soil particles and aggregates transported in runoff from simulated rainfall. Transactions of the American Society of Agricultural and Biological Engineers 8(3): 437, 440.

Swanson, N.P., and A.R. Dedrick. 1967. Soil particles and aggregates transported in water runoff under various slope conditions using simulated rainfall. Transactions of the American Society of Agricultural and Biological Engineers 10(2): 246-247.

Terry, J.P., 1998. A rainsplash component analysis to define mechanisms of soil detachment and transportation. Australian Journal of Soil Research 36: 525 -542.

Tisdall, J.M., and J.M. Oades. 1982. Organic matter and water-stable aggregates in soil. Journal of Soil Science 33: 141-163.

Tiwari, A.K., L.M. Risse, and M.A. Nearing. 2000. Evaluation of WEPP and its comparison with USLE and RUSLE. Transactions of the American Society of Agricultural and Biological Engineers 43(5): 1129-1135.

Torri, D., M. Sfalanga, and M. Del Sette. 1987. Splash detachment: runoff depth and soil cohesion. Catena 14:149-155.

Torri, D., and J. Poesen. 1992. The effect of soil surface slope on raindrop detachment. Catena 19(6): 561-578.

Toy, T.J., Foster G. R., and Renard K.G. Soil erosion: processes, prediction, measurement, and control. New York: John Wiley & Sons, c2002.

Truman, C.C., and Bradford J.M. 1990. Effect of antecedent soil moisture on splash detachment under simulated rainfall. Soil Science 150: 787 – 798.

USDA-ARS. 2008(a). Draft User's Reference Guide. Revised Universal Soil Loss Equation Version 2 (RUSLE). U.S. Dept. of Agriculture, Agricultural Research Service. Available at: http://www.ars.usda.gov/Research/docs.htm?docid=6028. Accessed 6 June 2009.

USDA-ARS. 2008(b). Draft Science Documentation. Revised Universal Soil Loss Equation Version 2 (RUSLE). U.S. Dept. of Agriculture, Agricultural Research Service. Available at: http://www.ars.usda.gov/Research/docs.htm?docid=6028. Accessed 6 June 2009.

Uson, A., and M.C. Ramos. 2001. An improved rainfall erosivity index obtained from experimental interrill soil losses in soil with a Mediterranean climate. Cantena 43(4): 293-305.

Wagner, S., S.R. Cattle, and T. Scholten. 2007. Soil-aggregate formation as influenced by clay content and organic-matter amendment. Journal of Plant Nutrition and Soil Science 170(1): 173-180.

Wan, Y., and S.A. El-Swaify. 1998. Characterizing interrill sediment size by partitioning splash and wash processes. Soil Science Society of America Journal 62(2): 430-437.

Weakly, H.E. 1962. Aggregation of Soil Carried in Runoff from Simulated Rainfall. Soil Science Society of America Proceedings 26: 511-512.

Whalen, J.K., and C. Chang. 2002. Macroaggregate characteristics in cultivated soils after 25 annual manure applications. Soil Science Society of America Journal (66): 1637-1647.

Williams, J.D., D.E. Wilkins, C.L. Douglas, and R.W. Rickman. 2000. Mow-plow crop residue management influence on soil erosion in North-Central Oregon. Soil & Tillage Research 55(1-2): 71-78.

Wischmeier, W.H., and D.D. Smith. 1965. Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains. Guide for Selection Practices for SWC. Agricultural Handbook No. 282, May.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. USDA Agriculture Handbook No. 537.

Yong, R.N., and B.P. Warketon. 1966. Introduction to soil behavior. Macmillan Co.

Young, R.A., and J.L. Wiersma. 1973. The role of rainfall impact in soil detachment and transport. Water Resources Research 9(6): 1629-1636.

Young, R.A., and C.A. Onstad. 1976. Predicting particle-size composition of eroded soil. Transactions of the American Society of Agricultural and Biological Engineers 19(6): 1071-1075.

Young, R.A. and C.A. Onstad. 1978. Characterization of rill and interrill eroded soil. Transactions of the American Society of Agricultural and Biological Engineers 21: 1126-1130.

Young, R. A. 1980. Characteristics of eroded sediment. Transactions of the American Society of Agricultural and Biological Engineers 23(5): 1139-1142, 1146.

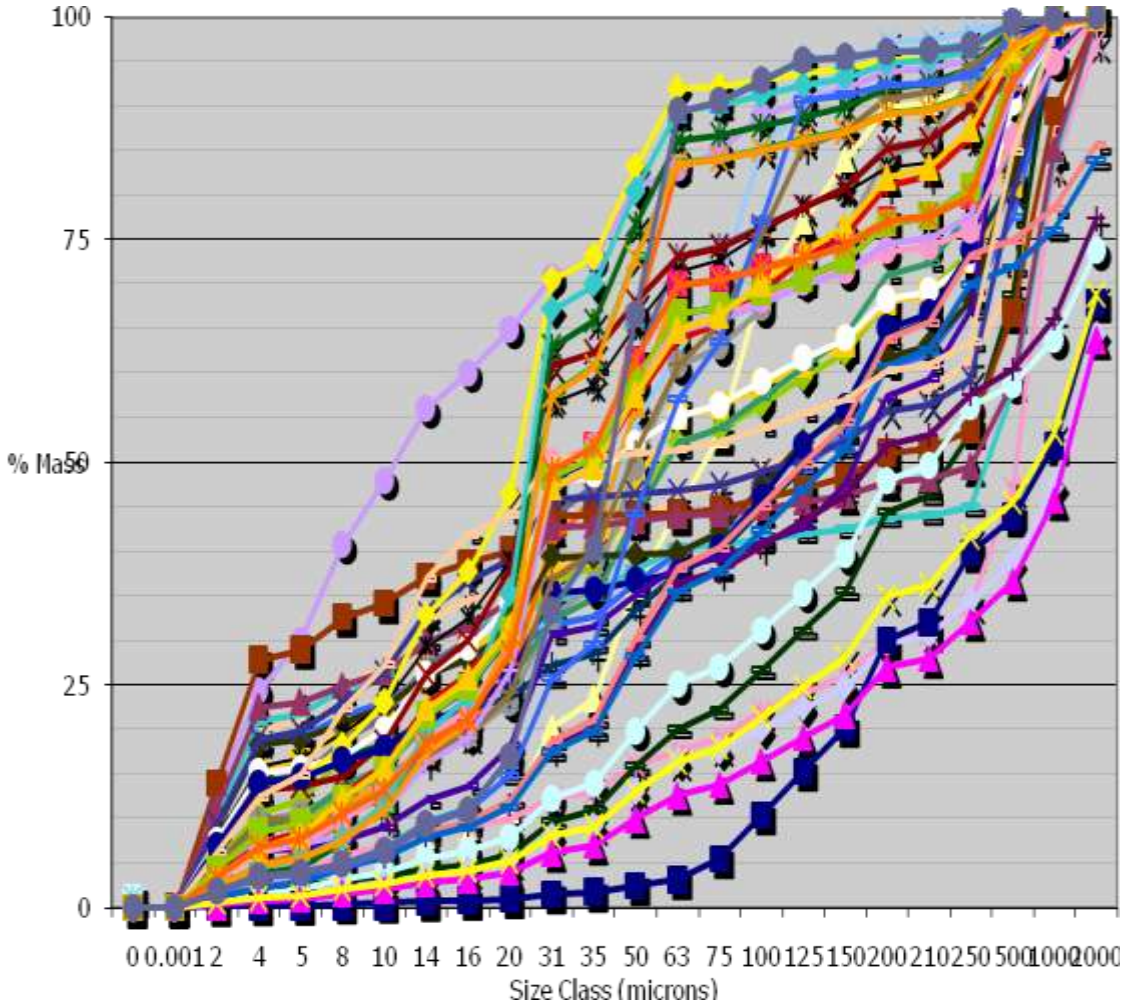
Zhang, G. H., B. Y. Liu, M.A. Nearing, C.H. Huang, and K.L. Zhang. 2002. Soil detachment by shallow flow. Transactions of the American Society of Agricultural and Biological Engineers 45(2): 351-357.

Zhang, G., Liu B., Liu G., He X., and M.A. Nearing. 2003. Detachment of undisturbed soil by shallow flow. Soil Science Society of America Journal (67): 713-719.

Ziegler, A.D., and R.A. Sutherland. 1998. Reduction in interrill sediment transport by rolled erosion control systems. Soil and Tillage Research 45(3-4): 265-278.

APPENDIX

A-1: Variable Scale_Interrill ESSDs. (*Note:* Grouped values around D-15, D-25, D-50, D-75, and D-85%).



A-2a: Scale_Interrill Descriptive Statistics and ANOVA Output

	Tillage Groups (1-4)	Residue Groups (1 3)	Mean	Std. Deviation	N
ΔD-15	1	1	12.4	1.9	8
		Total	12.4	1.9	8
	3	1	5.7	4.8	15
		Total	5.7	4.8	15
	4	1	7.8	3.3	36
		3	4.6	4.1	19
		Total	6.7	3.9	55
	Total	*1*	*7.9*	*4.1*	*59*
		3	*4.6*	*4.1*	*19*
		Total	*7.1*	*4.3*	*78*

	Tillage Groups (1-4)	Residue Groups (1 3)	Mean	Std. Deviation	N
ΔD-25	1	1	20.7	3.2	8
		Total	20.7	3.2	8
	3	1	11.0	7.2	15
		Total	11.0	7.2	15
	4	1	12.6	14.5	36
		3	8.4	7.1	19
		Total	11.2	12.5	55
	Total	*1*	*13.3*	*12.3*	*59*
		3	*8.4*	*7.1*	*19*
		Total	*12.1*	*11.4*	*78*

	Tillage Groups (1-4)	Residue Groups (1 3)	Mean	Std. Deviation	N
ΔD-50	1	1	31.0	20.7	8
		Total	31.0	20.7	8
	3	1	60.2	85.3	15
		Total	60.2	85.3	15
	4	1	35.7	73.4	36
		3	21.6	18.2	19
		Total	30.8	60.4	55
	Total	*1*	*41.3*	*72.0*	*59*
		3	*21.6*	*18.2*	*19*
		Total	*36.5*	*63.7*	*78*

	Tillage Groups (1-4)	Residue Groups (1 3)	Mean	Std. Deviation	N
ΔD-75	1	1	269.5	150.9	8
		Total	269.5	150.9	8
	3	1	221.9	232.0	15
		Total	221.9	232.0	15
	4	1	134.0	194.3	36
		3	196.3	209.2	19
		Total	155.5	199.8	55
	Total	*1*	*174.8*	*203.4*	*59*
		3	*196.3*	*209.2*	*19*
		Total	*180.0*	*203.6*	*78*

	Tillage Groups (1-4)	Residue Groups (1 3)	Mean	Std. Deviation	N
ΔD-85	1	1	17.5	179.7	8
		Total	17.5	179.7	8
	3	1	347.0	321.9	15
		Total	347.0	321.9	15
	4	1	212.7	284.2	36
		3	607.3	340.9	19
		Total	349.1	356.3	55
	Total	*1*	*220.4*	*295.8*	*59*
		3	*607.3*	*340.9*	*19*
		Total	*314.7*	*347.9*	*78*

A-2b: Scale_Rill Descriptive Statistics and ANOVA Output

	Tillage Groups (1-4)	Residue Groups (1-3)	Mean	Std. Deviation	N
ΔD-15	1	1	6.8	2.9	12
		3	4.9	2.0	6
		Total	6.2	2.7	18
	2	1	.1	-	1
		2	19.3	3.8	3
		3	9.4	4.0	10
		Total	10.9	6.3	14
	3	1	7.7	6.0	29
		2	18.4	4.1	3
		3	10.8	5.9	4
		Total	8.9	6.5	36
	4	1	7.6	5.9	20
		3	6.1	5.3	42
		Total	6.5	5.5	62
	Total	*1*	*7.4*	*5.4*	*62*
		2	*18.8*	*3.6*	*6*
		3	*6.8*	*5.1*	*62*
		Total	*7.6*	*5.8*	*130*

	Tillage Groups (1-4)	Residue Groups (1-3)	Mean	Std. Deviation	N
ΔD-50	1	1	10.9	6.8	12
		3	8.4	7.9	6
		Total	10.1	7.1	18
	2	1	-7.2	-	1
		2	198.6	75.9	3
		3	16.1	28.1	10
		Total	53.6	87.5	14
	3	1	45.6	125.2	29
		2	217.9	147.3	3
		3	61.0	68.4	4
		Total	61.7	128.4	36
	4	1	34.1	54.1	20
		3	36.6	39.9	42
		Total	35.8	44.5	62
	Total	*1*	*34.3*	*91.2*	*62*
		2	*208.2*	*105.3*	*6*
		3	*32.2*	*39.8*	*62*
		Total	*41.3*	*80.5*	*130*

	Tillage Groups (1-4)	Residue Groups (1-3)	Mean	Std. Deviation	N
ΔD-25	1	1	10.4	5.5	12
		3	7.7	6.5	6
		Total	9.5	5.8	18
	2	1	1.0	-	1
		2	23.3	6.4	3
		3	8.8	4.2	10
		Total	11.3	8.1	14
	3	1	17.7	26.0	29
		2	24.4	6.9	3
		3	11.3	11.0	4
		Total	17.6	23.7	36
	4	1	11.8	10.1	20
		3	10.6	8.5	42
		Total	11.0	9.0	62
	Total	*1*	*14.1*	*19.0*	*62*
		2	*23.9*	*6.0*	*6*
		3	*10.1*	*7.9*	*62*
		Total	*12.6*	*14.6*	*130*

	Tillage Groups (1-4)	Residue Groups (1-3)	Mean	Std. Deviation	N
ΔD-75	1	1	153.1	254.1	12
		3	264.9	241.2	6
		Total	190.4	248.7	18
	2	1	-25.7	-	1
		2	-187.9	144.2	3
		3	-312.7	122.6	10
		Total	-265.5	145.4	14
	3	1	229.6	294.5	29
		2	419.5	63.2	3
		3	190.9	178.8	4
		Total	241.1	274.7	36
	4	1	301.8	335.4	20
		3	402.2	301.7	42
		Total	369.8	313.8	62
	Total	*1*	*234.0*	*300.7*	*62*
		2	*115.8*	*347.2*	*6*
		3	*260.0*	*371.2*	*62*
		Total	*240.9*	*336.9*	*130*

	Tillage Groups (1-4)	Residue Groups (1-3)	Mean	Std. Deviation	N
ΔD-85	1	1	304.2	434.5	12
		3	461.2	862.8	6
		Total	356.5	589.0	18
	2	1	-798.6	-	1
		2	-420.2	75.3	3
		3	-702.0	88.9	10
		Total	-648.5	149.4	14
	3	1	406.4	484.6	29
		2	-35.0	62.9	3
		3	-339.1	301.9	4
		Total	286.8	511.3	36
	4	1	554.0	515.8	20
		3	782.5	441.8	42
		Total	708.8	475.0	62
	Total	*1*	*414.8*	*507.6*	*62*
		2	*-227.6*	*219.9*	*6*
		3	*439.6*	*729.6*	*62*
		Total	*397.0*	*628.2*	*130*

A-3: ANOVA Output

Model Design: • 2 groups- No Splash/Wash • Scale = Interrill • Fixed = Clay, Tillage, Residue	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	No Significant Terms	0	0.46
∆D-25	No Significant Terms	0	0.579
∆D-50	No Significant Terms	0.206	0.511
∆D-75	Residue (0.072) Clay (0.000)	0.375	0.712
∆D-85	Tillage (0.041) Clay (0.000)	0.056	0.914

Model Design: • No Splash/Wash • Scale = Interrill • Fixed = Clay, Tillage, Residue	Significant Terms	Equal Variance (*Levene P*)	Normality (*Shapiro Wilk*)
∆D-15	No Significant Terms	0	0.418
∆D-25	No Significant Terms	0	0.512
∆D-50	No Significant Terms	0.193	0.52
∆D-75	Clay (0.000)	0.391	0.717
∆D-85	Clay (0.000)	0.021	0.916

A-3: ANOVA Output (*continued*)

Model Design: • All No Splash • Scale = Interrill • Fixed = Clay, Tillage, Residue	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	No Significant Terms	0	0.382
∆D-25	No Significant Terms	0.001	0.338
∆D-50	No Significant Terms	0.004	0.531
∆D-75	Clay (0.000)	0.467	0.76
∆D-85	Clay (0.000)	0.174	0.929

Model Design: • No <15m and no splash-wash Scale = Interrill • Fixed = Clay, Tillage, Residue	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	No Significant Terms	0.015	0.4
∆D-25	No Significant Terms	0.021	0.349
∆D-50	No Significant Terms	0.058	0.608
∆D-75	Clay (0.000)	0.023	0.766
∆D-85	Clay (0.000)	0.058	0.883

A-3: ANOVA Output (*continued*)

Model Design: • All > 15m • Scale = Rill • Fixed = Clay, Tillage, Residue	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	None	0	0.504
∆D-25	None	0	0.472
∆D-50	None	0	0.666
∆D-75	Clay (0.000)	0.169	0.774
∆D-85	Clay (0.000)	0.083	0.898

Model Design: • All (splash +wash + <15m) • Scale = Interrill • Fixed = Clay, Tillage, Residue	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	None	0	0.44
∆D-25	None	0	0.409
∆D-50	None	0	0.594
∆D-75	Clay (0.000)	0.217	0.799
∆D-85	Clay (0.000)	0.099	0.945

A-3: ANOVA Output (*continued*)

Model Design: • All (except no <15m) • Scale = Rill • Fixed = Tillage, Residue • Covariate = Clay	**Significant Terms**	**Equal Variance (*Levene P*)**	**Normality (*Shapiro Wilk*)**
∆D-15	No Significant Terms	0.001	0.655
∆D-25	No Significant Terms	0.216	0.626
∆D-50	No Significant Terms	0.193	0.556
∆D-75	Till (0.010) Residue (0.004) Clay (0.000) Till*Clay (0.027) Till*Residue(0.016) Residue*Clay(0.002) Till*Res*Clay(0.010)	0.001	0.93
∆D-85	Till (0.079)	0	0.978

VITA

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