USE OF THE REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE) TO PREDICT EVENT SOIL LOSS

by

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A Thesis
submitted in partial fulfillment of the
requirements of the degree

MASTER OF SCIENCE

IN

Natural Resources

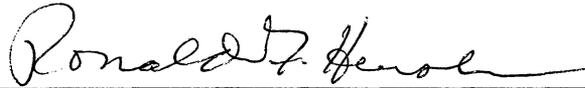College of Natural Resources

UNIVERSITY OF WISCONSIN-STEVENS POINT

Stevens Point, Wisconsin

May - 2002

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ABSTRACT

Soil erosion is an important environmental and economic problem. Information about soil loss from erosion by water may be used to assess ecosystem health and function. Erosion events can be expensive and potentially dangerous. The US Environmental Protection Agency (EPA) states that sediments are the largest pollutant of our Nation's water bodies on a volume basis. The average annual land development rate from 1992-1997 was 1.3 million hectares (3.2 million acres), which was more than double the average rate occurring over the previous ten years (Benson, 1999). Erosion control plans become more important with the increase of land disturbances. Much of the soil loss information for erosion control is based on the Revised Universal Soil Loss Equation (RUSLE). RUSLE, previously the Universal Soil Loss Equation (USLE), was developed to estimate average annual soil loss from agricultural fields. The equation reliably predicts soil loss on an annual basis, but there is a need to be able to accurately predict soil loss for durations of less than one year. This project evaluated whether RUSLE could be applied to accurately predict soil loss from single rainfall events by comparing measured soil loss values to values predicted by the equation. Event soil erodibility factors (RUSLE K factors) were back calculated and compared to published average annual K factor values to confirm the use of RUSLE to predict event soil loss. The equation was found to be a reliable predictor of event soil loss on loam and sandy loam soils, but not on the silty clay loam soil.

ACKNOWLEDGEMENTS

Many people have assisted me in various ways over the past three or so years. First and foremost, my family has provided me with support, confidence, and encouragement from day one. Thank you MOM, DAD, Laura, Dan, Kim, Andy, Jill, Aly, and Jake. I would also like to acknowledge the following people:

Graduate Committee

Dr. N.E. Spangenberg – University of Wisconsin-Stevens Point, Committee Chairman

Dr. Spangenberg devoted countless hours of his time to help me complete my course work and thesis. He taught me what it took to become a professional scientist.

Dr. Ronald Hensler – University of Wisconsin-Stevens Point

Dr. Hensler assisted with soil-related questions.

Dr. Robert Rogers - University of Wisconsin-Stevens Point

Dr. Rogers provided assistance with the statistical analyses.

Mr. Anthony Johnson – American Excelsior Company, Rice Lake, WI

I worked for Mr. Johnson for three summers at American Excelsior Company's ErosionLab™ while obtaining all my field data. Mr. Johnson helped me on both a technical and personal level.

Mr. Ryan Vavra – ErosionLab

Mr. Vavra assisted in most of the field-testing.

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INTRODUCTION

Initial Efforts

The development of erosion-prediction technology started with analyses that identified the major variables involved in the process of soil erosion by water. Renard et al. (1997) report that Cook presented three such variables in 1936: susceptibility of soil to erosion, potential erosivity of rainfall and runoff, and soil protection by plant cover. The first equation for calculating soil loss from a field was published by Zingg in 1940. The equation mathematically described the effects of slope length and steepness on erosion (Renard et al., 1997). The following year, Smith added support practice and cropping system factors to the equation, and included the concept of a specific annual soil loss limit. With the resulting equation, Smith developed a graphic method for selecting conservation practices under soil conditions common to the Midwest United States.

Slow Progress

In 1947, Browning and associates added to Smith's equation by including soil erodibility and management factors. The group also compiled more extensive tables of relative factor values for various slope lengths, different soil types, and different crop rotations (Renard et al., 1997). Smith and Whitt (1947) proposed an erosion-estimating equation in the form: A=C*S*L*K*P, which was believed to be applicable to the major soil types of Missouri. The majority of the equation's prediction capability was determined by the C factor, which was the average annual soil loss from claypan soils for a specific rotation, steepness, slope length, and row direction. The additional factors (S,L,K,P) for slope steepness, slope length, soil erodibility, and support practice were dimensionless. The additional factors were used to adjust the C value to fit other

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conditions. Similar erosion prediction work was being performed in other areas of the country at this time. Although this work was an advance in predicting soil loss, a rainfall factor needed to be incorporated to make the equation applicable across several states (Smith and Whitt, 1947).

<u>Corn Belt and Musgrave Equations</u>

The United States Department of Agriculture – Soil Conservation Service (USDA-SCS) office in Milwaukee, Wisconsin, recognized the value of a soil loss prediction equation to the region's plentiful farmlands. The Milwaukee USDA-SCS teamed with local scientists to derive the slope-practice method of estimating soil loss. The slope-practice method was applicable throughout the corn belt region.

At a 1946 conference, erosion specialists from around the United States met to alter the slope-practice equation so it could be applied outside of the corn belt. (Renard et al., 1997). The conference attendees reviewed soil-loss data from around the country, reevaluated previous known erosion prediction technology, and incorporated a rainfall factor to produce the Musgrave equation, which included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length, soil characteristics, and vegetal cover effects (Musgrave, 1947).

<u>The National Equation</u>

Efforts to develop a national equation began after the benefit of the Musgrave equation and other state and regional erosion predicting equations were recognized. The Agricultural Research Service (ARS) established the National Runoff and Soil Loss Data Center at Purdue University in 1954. The Data Center was to serve as a clearinghouse for all existing erosion data from around the country. The effort yielded 10,000 plot-years of

runoff and soil-loss data from 49 locations throughout the United States. The data would be used to develop a national soil loss equation.

A conference held at Purdue University in 1956 brought scientists and potential users of the national equation together. The purpose of the conference was to create a "universal" equation that could be applied to areas where no rainfall erosion measurements existed, while considering all the previous knowledge that had been collected on soil erosion prediction. The resulting equation contained seven factors consisting of crop rotation, management, slope steepness, slope length, conservation practice, soil erodibility, and previous erosion. The conference members concluded that there was not enough data to add a rainfall factor to the National Equation at that time (Renard et al., 1997).

The Universal Soil Loss Equation (USLE)

Wischmeier, Smith, and others developed the Universal Soil Loss Equation (USLE) following the 1956 conference, and following further analyses of the data compiled by the Data Center. USLE's three main goals were:

1) That each factor contributing to soil erosion by water could be represented by a single value.

2) Each factor could be estimated from meteorological, soil, or erosion research data for the specific location.

3) The equation would contain no geographical constraints.

USLE considered six factors that are involved in soil erosion caused by water in the form of A=RKLSCP, where:

A=Average annual soil loss

R=Rain fall erosivity

K=Soil erodibility

LS= Slope length and steepness

C=Cover management factor

P=Support conservation practices

The USLE factors will be discussed in detail in the section on *RUSLE's Factors*.
USLE was said to be applicable where the equation's factors could be evaluated and
where specific conditions of the equation were met. Examples of specific conditions of
the equation include slope steepness less than 22% and maximum slope length of 305m
(1000ft) (Foster et al., 1999).

Although the USLE was similar to previous equations, it incorporated many
changes and improvements. Six major improvements with USLE (Renard et al., 1997)
included :

1) More complete separation of factor effects so that changes in one or more
   factors in the equation could be predicted more accurately.

2) An erosion index which included more accurate, localized estimates of the
   erosive potential of rainfall and its associated runoff.

3) A quantitative soil erodibility factor that was derived from research data without
   reference to an arbitrary set value.

4) A nomograph and equation for determining the soil erodibility factor for many
   soils.

5) The interaction effects between management and cropping parameters.

6) The incorporation of the effects of local rainfall characteristics during the year and
   specific cropping conditions in the cover factor.

USLE was not immediately published. The equation was introduced and utilized at regional workshops on soil loss prediction from 1959-1962. The equation was modified and improved as a result of the preliminary applications. It was not until 1965 that USLE was presented to the public by Wischmeier and Smith in Agriculture Handbook No. 282.

The Revised Universal Soil Loss Equation (RUSLE) is Born

The USLE has been updated periodically with improvements based on continued experience and additional research. Agriculture Handbook No. 537 reported vast improvements to USLE, causing the equation to be renamed the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The major differences between USLE and RUSLE are summarized in Table 1.

RUSLE was first released for widespread use in late 1992 in a computerized format termed RUSLE 1.02. Since 1992, improvements have been made to the equation resulting in additional computerized versions of RUSLE. The computerized RUSLE programs were DOS based programs until the release of RUSLE 2.0 in 2001. RUSLE 2.0 is a windows based revision of RUSLE based on a graphical user interface, which gives the program a modern look and feel. An option between US customary units and SI units is also available in RUSLE 2.0 (USDA-Agriculture Research Service, 2001; Updated Computer…, 2002).

Table 1. Differences between USLE and RUSLE

Factor	USLE	RUSLE
R – Rainfall Erosivity	Based on long-term average rainfall conditions for geographic areas in the U.S.	Generally the same as USLE in the Eastern U.S. Values for western states (Montana to New Mexico and west) are based on data from more weather stations and thus are more precise for any given location RUSLE computes a correction to R to reflect the effect of raindrop impact for flat slopes striking water ponded on the surface.
K – Soil Erodibility	Based on soil texture, organic matter content, permeability, and other factors inherent to soil type.	Same as USLE but adjusted to account for seasonal changes such as freezing and thawing, soil moisture, and soil consolidation.
LS – Slope Length and Steepness	Based on length and steepness of slope, regardless of land use.	Refines USLE by assigning new equations based on the ratio of rill to interrill erosion, and accommodates complex slopes.
C – Cover Management	Based on cropping sequence, surface roughness, and canopy cover, which are weighted by the percentage of erosive rainfall during the six crop stages. Lumps these factors into a table of soil-loss ratios, by crop and tillage scheme.	Uses these subfactors: prior land use, canopy cover, surface roughness, and soil moisture. Refines USLE by dividing each year in the rotation into 15-day intervals, calculating the soil-loss ratio every time a tillage operation changes one of the subfactors. RUSLE provides improved estimates of soil-loss changes as they occur throughout the year, especially relating to surface and near-surface residue and the effects of climate on residue decomposition.
P – Support Practice	Based on installation practices that slow runoff and thus reduce soil movement. P factor values change according to slope ranges with some distinction for various ridge heights.	P factor values are based on hydrologic soil groups, slope, row grade, ridge height, and the 10-year, single storm erosion index value. RUSLE computes the effect of stripcropping based on the transport capacity of flow in dense strips relative to the amount of sediment reaching the strip. The P factor for conservation planning considers the amount and location of deposition.

Taken From: Troeh et al., 1999.

RUSLE's Factors

Although some of the factors in RUSLE have been altered from the factors previously used in USLE, the basis of the two equations is the same. RUSLE takes the

form of A=RKLSCP, where A is the average annual soil loss in tons per acre per year. The six factors of the equation are explained in detail in the following paragraphs.

R Factor

The R factor represents the climatic erosivity of a location. The R factor includes the two most important storm characteristics. These characteristics are the amount of rainfall and the peak intensity of the storm. RUSLE R factors can be calculated for a specific location based on rain gauge readings and storm duration (Renard et al., 1997). The product of the total kinetic energy (E) times the 30-minute maximum intensity (I_{30}) for a particular storm equals the R factor for that event. Average annual RUSLE R factors values are also presented in isoerodent maps. R factors from the isoerodent maps represent average EI_{30} values over many years. R factor values vary greatly from location to location. In the state of Michigan, for example, R ranges from 75 to 135 (US customary units) annually (Michigan State University, 2001). Rainfall erosivity factors have dimensions of LFL/L^2T and units of MJ*mm/ha*h*y (hundreds of foot*tonf *inch/ acre*h*yr) {See Appendix D for an explanation of all units used}.

K Factor

K is defined as the rate of soil loss per unit of rainfall erosion index for a soil cultivated in continuous fallow on a standard plot having a slope length of 22.1m (72.6ft) and a slope of 9% (Wischmeier and Smith, 1978). The K factor represents both susceptibility of soil to erosion and the rate of runoff. The soil erodibility factor can be extrapolated from the soil erodibility nomograph when soil organic matter content is 4% or less (Wischmeier and Smith, 1978). K factors for other soils can be determined from equations found in Agriculture Handbook No. 703 (Renard et al., 1997). The nomograph

considers texture, structure, and permeability in addition to organic matter. In RUSLE, factor K considers the whole soil body, while factor Kf considers only the fine-earth fraction. The fine earth fraction is all the material less than two millimeters in diameter. K=Kf for most soils. A K factor may need to be adjusted by a qualified soil scientist in situations where the subsoil is exposed, the soil's organic matter content has been depleted, soil structure has been altered, or where soil compaction has decreased permeability (Michigan State University, 2001). Soil erodibility factors have dimensions of ML^2T/L^2LFL and units of t*ha*h/ha*MJ*mm (ton*acre*hr/hundreds of acre*foot*tonf*inch).

LS Factor

Slope and length are combined into the LS factor in RUSLE. L is the slope length factor, which is the ratio of soil loss from the slope length measured in the field to that from a 22.1m (72.6ft) length on the same soil type and gradient. Slope length is the distance from the start of overland flow to the point where concentrated flow or deposition occurs. The most accurate method of determining slope length is to measure the distance on the ground (Michigan State University, 2001). Slope lengths greater than 305m (1000ft) should not be used in RUSLE because concentration usually occurs before the end of segments of this distance. (Michigan State University, 2001; Renard et al., 1997).

The S portion of the LS factor incorporates the gradient of the landscape into RUSLE. S is the ratio of soil loss from the slope found in the field to that from a 9% slope believed to be under the same conditions. Soil particle size and vegetation density along the slope influence the ratio of soil loss to slope steepness. L and S = 1 under the

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unit plot conditions of 22.1m (72.6ft) long and 9% slope. LS factors for field plots represent how erodible the plot is relative to the standard plot conditions (Michigan State University, 2001; Renard et al., 1997). The LS factor is unitless.

<u>C Factor</u>

Cover management is considered by RUSLE through the C factor. The C factor represents the effect of surface cover and roughness on soil erosion. The cover factor is the most common factor used to assess the impact of best management practices (BMPs) on reducing erosion because the C factor represents the effect of land use on soil erosion (Renard et al., 1997). By definition, C=1 under standard fallow conditions. As surface cover is added to the soil, the C-factor value approaches zero. For example, a C-factor of 0.20 signifies that 20% of the amount of erosion will occur compared to continuous fallow conditions. C factors vary from region to region because they are strongly influenced by different R factors. Erosive rainfall occurs during various periods of cover development in different locations, so the C factors are influenced accordingly (Wischmeier and Smith, 1978). The unitless cover management factor can be determined in two ways. The more common method involves adopting empirical values, which can be derived from the linear regression of soil loss data. The second method involves estimating a C value from five subfactors (Renard et al., 1997). They are:

1) Prior Land Use (PLU)

2) Canopy Cover (CC)

3) Surface Cover (SC)

4) Surface Roughness (SR)

5) Soil Moisture (SM)

P Factor

P is the support practice factor in RUSLE. The P factor reflects the impact of support practices on the average annual erosion rate. P is the ratio of soil loss with a support factor to that with straight row farming up and down slope. Stripcropping, contouring, and terracing are all activities that are considered support practices by RUSLE (Michigan State University, 2001). The agriculture support factor is unitless.

Why RUSLE is Commonly Used

RUSLE is widely used for several reasons. The equation is believed to be applicable wherever values of its factors are available (Renard et al., 1997). According to the National Sedimentation Laboratory (2001), RUSLE is the best available tool for erosion prediction from specific field sites and contains a rich data base supported by world recognized scientists and the USDA National Resources Conservation Service (NRCS), which has more than 50 years of erosion prediction experience. In addition, the equation combines the interrelated physical and management parameters of climate, soils, topography, and land use that influence the rate of erosion. These parameters are represented in RUSLE's five factors whose site-specific values can be easily expressed mathematically (Foster et al., 1999).

Mis-use of RUSLE

The equation continues to be used outside the context of its intended purpose even though there is a large pool of information regarding its proper use. The equation is not intended to predict soil loss from individual storms. Measurements need to be made over a minimum of three years, when a range of sediment yield and weather conditions have occurred (Foster et al., 1999). Lastly, RUSLE should be interpreted in the context of its

intended purpose and should not be considered absolute; rather the equation should be used as a guide (USDA-Agriculture Research Service, 1999; Foster et al., 1999).

<u>Accuracy of RUSLE</u>

Replications of field studies are often limited because the studies are costly, labor intensive, and time consuming. Variability in data caused by differences in plot preparation or soil characteristics could result in misleading conclusions. Hillslopes without variation in soil properties where numerous replications can be studied are hard to find (Foster et al., 1999).

Studies addressing the accuracy of USLE/RUSLE indicate that the equation estimates within 25% for soil loss values exceeding around 9 metric tons per hectare per year (4 tons per acre per year) and within 50% for soil loss values ranging from 1.1-9 metric tons per hectare per year (0.5-4 tons per acre per year) (Risse et al., 1993). It was found that the uncertainty increases with soil loss values less than 2.2 metric tons per hectare per year (1 ton per acre per year) and with soil loss values above 67.3 metric tons per hectare per year (30 tons per acre per year) (Foster et al., 1999).

Risse et al. (1993) compared predicted soil losses from USLE to measured soil loss values from 208 natural runoff plots to assess the error associated with the equation. The data used were annual plot soil loss values from 1931-1971. In general, the study showed that the equation over-predicted soil losses on plots with lower soil loss rates and under-predicted on plots with higher erosion rates. Further, R factors taken from isoerodent maps, rather than calculated EI values, also lowered the equation's accuracy. This study also showed the equation's ability to accurately predict soil loss improves as total soil loss amounts increase.

The R factor has been altered in hopes of making the equation a more accurate predictor of event soil loss. The equation is termed MUSLE (Modified Universal Soil Loss Equation) when the rainfall erosivity factor is replaced with the Williams' erosivity factor. The Williams' R factor attempts to better predict event soil loss by incorporating watershed area, volume of runoff, and peak flow rate. MUSLE does not incorporate a rainfall variable so the equation would not predict soil loss if runoff did not occur. MUSLE predictions are also related to a specific watershed area (Laflen et al., 1985).

The Onstad-Foster (OF) method of altering the R factor is similar to MUSLE. The OF replacement for the erosivity factor considers volume of runoff and peak flow rate, but also considers 50% of the normal USLE R factor value. Soil loss is possible with the OF method when runoff does not occur. The OF method is not related to a specific watershed area. Both the MUSLE and OF methods will predict less soil loss than USLE when runoff erosivity is low relative to rainfall erosivity (Laflen et al., 1985).

Kinnell and Risse (1998) proposed altering USLE by adding a runoff ratio component to the erosivity factor to increase the equation's ability to predict event soil loss. The results of the study supported the author's claim that the modified equation, termed USLE-M, predicted event soil loss more closely than USLE. However, this method incorporated more information than USLE in the form of known runoff data. Critics of USLE-M suggest that all soil loss could be predicted more accurately than USLE if the anticipated runoff levels were known before the rainfall events occurred (Nearing, 2000). USLE-M also violated one of the three original goals of USLE that stated each variable could be estimated from meteorological, soil, or erosion research data for the specific location.

Knowledge of the variability in soil loss is limited. It is hard to assess error to an erosion prediction model if little is known about the variability in erosion data (Nearing et al., 1999). A study by Wendt et al. (1986) provided a relatively large number of replicated erosion plots to compare. The 40 plots studied by Wendt and others were 3.2m (10.5ft) wide X 27.4m (90ft) long at a 3-3.5% gradient and were similarly cultivated up and down slope and treated identically. The Wendt study concluded that variability in soil loss and runoff existed between plots that were considered to be prepared identically during the 25 natural rainfall events that took place over the course of the study period. The study also determined that variability between plots tended to increase as the amount of soil loss and runoff increased.

Rüttimann et al. (1995) reported coefficients of variation ranging from 3.4% to 173% for soil loss and from 8.1% to 104.7% for runoff. The study used data from four sites with five to six treatments replicated three times. The authors stated that "enormous" variability was encountered from single rainfall events. Their conclusion was to use "as many replications as possible" for erosion experiments. A high number of replications in erosion experiments are needed to help control the variability associated with erosion tests (Nearing et al., 1999). Foster et al. (1999) state that variability is inherent to soil erosion studies and is hard to explain by differences in soil, plot preparation, or plot condition differences.

Numerous potential causes of variability in soil loss studies have been suggested. Bryan (1981) suggested that aggregate stability, varying raindrop sizes, and surface water films may combined to influence soil loss variability. Debris dams forming and dislodging during rainfall events may also contribute to soil loss variability (Simanton

and Renard, 1982). Variability is also suggested to be influenced by spatially varying infiltration rates within test plots (Wendt et al., 1986). Perhaps the most obvious and seemingly controllable potential cause of variability is differences in tillage during plot preparations (Gard and Van Doren, 1949; Wendt et al., 1986).

RUSLE's Use Today

RUSLE continues to be used by numerous government agencies, and by private businesses and individuals to help determine where erosion is serious, and to guide development of erosion control plans. Erosion control product testing facilities base the success of their products on predicted soil loss amounts by RUSLE (North American Green, 1998). RUSLE is the tool currently used by the US Environmental Protection Agency (EPA) and other government agencies to predict erosion losses from disturbed sites.

Future Use of RUSLE

RUSLE will continue to be used in agricultural settings as it was originally intended. The equation may be applied more extensively to construction activities in the near future because of society's commitment to reducing nonpoint source discharges, the rapid rate of urban sprawl, and upcoming litigations.

Construction sites are major sources of sediment, which is considered the number one pollutant of water bodies on a volume basis. Construction activities are considered to be one of the most severe modifications of the human landscape and cause soil erosion rates to increase 2-40,000 times (Meyer and Mannering, 1963; Goldman et al., 1986). Sediment delivered by polluted storm water causes physical and biological harm to water

bodies. Proper erosion control measures can greatly reduce the amount of soil that leaves construction sites and thus reduce the amount of pollutants entering water bodies.

In March 2003, the US EPA will begin to issue Phase II National Pollutant Discharge Elimination System (NPDES) permits. Phase II NPDES permits are a result of prior amendments made to the Clean Water Act and are the regulatory backbone protecting water resources (US EPA, 2001). Construction activities on areas as small as .4ha (1acre) will be required to apply for NPDES permit coverage. These permits will require the owners and operators of the sites to implement practices to control polluted storm water runoff (US EPA, 2001). The exact methodology of determining the runoff limits for the Phase II NPDES permits has yet to be released, but it is likely that some form of the RUSLE will be utilized. Because most construction activities have durations of less than one year, an accurate predictor of soil loss during periods of less than one year is needed.

Owners and operators of construction sites must have an estimate of soil loss before erosion control plans can be developed. Land planners can develop proper erosion control designs based on accurate soil loss predictions by RUSLE. The cover management factor (C factor) of the equation signifies the ability of a specific surface cover to reduce erosion. The C factor can be matched to an erosion control product that successfully protects the soil from erosion throughout the construction period. Most manufactured erosion control products have published C factor values associated with them that were determined through prior testing of the product based on single rainfall test series. The accuracy of RULSE to predict event soil loss must be known to confirm the procedure of determining erosion control product's C factor values based on single

events. Operators will be able to select successful BMPs based on the RUSLE C factor calculation from single rainfall events if RUSLE can be shown to be a valid event soil loss prediction tool.

In addition, one of the two waivers to the Phase II NPDES permits will be based on the RUSLE R factor (rainfall erosivity factor) occurring over the anticipated construction activity (US EPA Office…, 2001). The R factor values will be determined by extrapolating maps of R factor values that are based on long-term averages. If RUSLE is shown to be a reliable predictor of event soil loss, operators of construction sites would be able to design erosion controls for rainfall events specific to their geographic region based on single events. R factors can be easily calculated for single events. Operators could base their designs on the greatest anticipated event that would occur over the construction period versus the long-term average value. By designing their erosion control plans based on the greatest single event anticipated, the operators would assure compliance with their NPDES permit. Assuming RUSLE can be accurately utilized for periods of less than one year, the equation would continue to be the most effective tool for land planners and government agencies

Introduction Summary

Since 1936, the practice of estimating soil erosion by water has proven to be an ever-changing discipline. Many erosion specialists and users of the various equations have paved a road for future generations. RUSLE is the leader in predicting soil erosion by water on an annual basis, but there are still questions about utilizing the equation to predict event soil loss.

Important properties of RUSLE and past research have identified some important sources of inaccuracy associated with the equation. Past studies may be questioned due to lack of replication as a result of plot variability, monetary constraints, and the amount of labor and time involved in such a study. It should be noted that previous studies compared USLE/RUSLE's soil loss predictions to field measured soil loss values that were taken over an entire year.

Few previous studies have assessed the accuracy of USLE/RUSLE compared to field measured event soil losses. Wischmeier and Smith suggest that USLE/RUSLE may be used for periods of less than one year, such as construction activities. Construction activities continue to increase each year. The next revelation with soil loss prediction equations may be greatly influenced by soil loss data produced by single storm events. This study grew from the need to understand RUSLE's ability to predict event soil loss.

OBJECTIVE

The objective of this project is to assess the use of RUSLE as a tool to predict event soil loss.

METHODS

This study involves two sub studies:

1) Compare measured event soil loss from erosion plots under simulated rainfall to predicted event soil loss amounts from RUSLE using the same climatic, pedological, land use, and topographic properties as those encountered during simulated rainfall testing.

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2) Compare back-calculated K factors from bare soil test series to nomograph and published values that are based on average annual conditions.

Study Site

Field work for this study was completed at American Excelsior Company's ErosionLab™ during the months of May through October in 1999, 2000, and 2001. The lab is an outdoor erosion control research and development facility located near Rice Lake, Wisconsin. This study used the Rainfall Erosion Facility (REF), which is the simulated rainfall portion of the lab. REF testing follows the procedures provided in American Society for Testing and Materials (ASTM) ASTM D-6459 (2000), "Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfall-Induced Erosion." The facility contains 12 erosion plots that were created at an approximate 33% slope. Three soil types are replicated four times each across the plots. All 12 plots are 12.2m (40ft) long by 2.4m (8ft) wide and are separated from one another by a 4.9m (16ft) wide buffer of vegetated soil. Each plot contains either a 265L (70gal.) or 843L (223gal.) tank buried at the bottom of the plot. V-shaped metal flashing at the bottom of each plot directs the materials leaving the plot into the collection tanks.

Simulated Rainfall

The ability of rainfall simulators to accurately produce rainfall events similar to natural events is often criticized (Rüttimann et al., 1995). American Excelsior Company performs numerous quality assurance procedures to ensure the replication of natural rainfall. The rainfall simulator is regularly calibrated and the raindrop size and

distribution produced by the system are monitored. In addition, the rainfall risers utilized at the ErosionLab™ are 3m (10ft) high to allow the raindrops to achieve terminal velocity. The ErosionLab™ rainfall simulator has been shown to closely resemble natural rainfall.

Water is pumped to rainfall risers from an on-site 2ha (5acre) pond to start the simulated rainfall process. Eleven 3m (10ft) high risers are located around the plots in fixed positions, which were predetermined to insure optimal plot coverage. Gate valves located on each of the risers control the amount of water flowing through the rainfall simulator system. Pressure gauges on the risers in combination with the gate valves allow the system to be operated at specified pressures. Operating pressures were determined to achieve target intensities of 5.1, 10.2, 15.2, and 20.3cm/hr (2,4,6,&8in/hr respectively) through a calibration process. Four sprinkler heads located at the top of each riser control the amount of water that leaves the riser. An approximate 5.1cm/hr (2in/hr) event is produced with one sprinkler head open on each of the risers:

> 2 heads open on each riser = 10.2cm/hr (4in/hr)
>
> 3 heads open on each riser = 15.2cm/hr (6in/hr)

The maximum potential of the rainfall simulator of 20.3cm/hr (8in/hr) is achieved when all four sprinkler heads are open on the 11 risers surrounding the plots. During field tests, the plots were exposed to a series of rainfall intensities, which lasted 20 minutes each. Simulated rainfall was performed when winds were less than or equal to 8 km/hr (5mph) to insure uniform plot coverage.

Soil Types Tested

Three soil types were tested for this study. Chetek sandy loam is the native soil on site, and has a particle size distribution of 82.3% sand, 2.8% silt, and 14% clay. An imported topsoil categorized as a gravelly loam soil according to the USDA textural triangle was also tested. The material has a particle size distribution of 43.6% sand, 30.4% silt, and 10.5% clay. The third soil tested is classified as a silty clay loam with a particle size distribution of 1% sand, 61.6% silt, and 37.4% clay. The erosion plots are restored with soil from on-site stockpiles as needed. Soil test reports for each of the study soils are in Appendix A.

Dependent Variable Measured

Total soil loss per simulated rainfall event was the dependent variable in this study. Soil losses were measured to the nearest half pound due to the available instrumentation precision.

Independent Variable Measured

The only independent variable measured in this study was rainfall intensity. Six rain gauges were randomly placed throughout the plots during each test increment. The accumulation of rainfall measured and the duration of the test were used to determine storm intensity. As with most studies, there are other variables that could have influenced the results.

Erosion Plot Preparation

Each plot tested over the course of the study was prepared the same way. Plots were tilled up and down slope with a walk-behind roto-tiller. The plots were hand-raked to a uniform surface after tillage. Following raking, a 31.75kg (70lb) rolling pin was used

to lightly compact the material. If surface cover BMPs were to be tested, they were then installed on the plots. The plots were not manipulated between storm increments. All plots were reconditioned following the last 20-minute storm increment.

Surface Conditions Tested

Four surface cover BMPs and bare soil conditions were tested over the course of the study. A series of bare soil tests (see Figure 1) where no surface cover was added to the plots were used as the control in the study. The BMPs included wood fiber blankets, blown straw, straw blankets with netting on the top only, and straw blankets with netting on the top and bottom of the blanket. The wood fiber blankets (see Figure 2) weighed 0.40kg/m^2 (.73lbs/yd^2) and were covered on top with photo degradable, extruded plastic mesh netting. Blown oat straw (see Figure 3) was tested at an application rate of 459kg/ha (2500lb/acre). Both of the straw blankets weighed 0.27kg/m2 (.50lbs/yd^2), but the single net straw blanket (see Figure 4) contained photo degradable netting on the top only and the double net straw blanket contained the netting on the top and bottom of the straw blanket. Each cover scenario was replicated three times on each of the three soil types tested.

Rainfall Testing Series

Each bare and blanketed plot was subjected to sequential events of approximately 5.1cm/hr (2in/hr), 10.2cm/hr (4in/hr), and 15.2cm/hr (6in/hr) for a duration of 20 minutes each. The blown straw series did not include the 15.2cm/hr

Figure 1. Loam test plot following storm series under bare soil conditions.

Figure 2. Sandy loam plot covered with excelsior blanket prior to testing.

Figure 3. Sandy loam plot covered with blown straw following storm series.
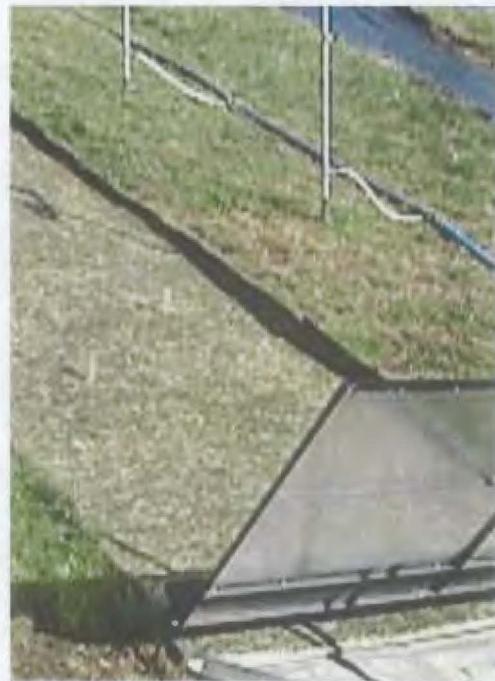
Figure 4. Loam plot covered with single net straw blanket preceding storm series.

(6in/hr) 20-minute event. The blown straw on the sandy loam soil was subjected to

sequential 5.1cm/hr (2in/hr) events lasting 20 minutes each followed by a 10.2cm/hr

(4in/hr) segment for a duration of 20 minutes. The blown straw on the loam and silty clay

loam soils was subjected to only one 5.1cm/hr (2in/hr) event followed by a 10.2cm/hr

(4in/hr) segment last 20 minutes. The unique rainfall series assigned to the blown straw

cover type was followed in accordance to an EPA grant. All intensities were only target

intensities. Exact intensities were not necessary since the EI units of each event were

determined from measured data. Depending on cover type, the two or three 20-minute

increments per plot were combined into single events lasting 40 or 60 minutes.

Data Collection

Water was decanted from the collection tanks following each 20-minute

simulated rainfall event. The soil slurry was transferred from the collection tanks into

pre-weighed pails. The pails were then weighed to determine soil loss on a wet basis. A

homogeneous sample of the soil slurry was taken to later determine soil moisture content

so the equivalent dry basis soil loss could be determined. The samples were immediately

analyzed, or refrigerated when they were not analyzed on the same day the test was

conducted. The six rain gauges were also recorded after each 20-minute increment.

Determining RUSLE Factors For the Test Conditions

Rainfall Erosivity Factor (R)

The rain gauge readings from each 20-minute test segment were used to calculate

the total storm kinetic energy (E) component of the RUSLE R-factor. The following

equations taken from Agriculture Handbook 703 (1997) were used to calculate the R

factors of each segment:

$R = \Sigma EI_{30}(10^{-2})$

where:

R = Rainfall-runoff erosivity
E = Total storm kinetic energy
I_{30} = Maximum 30-min. rainfall intensity

and

$$EI_{30} = \left[\sum_{K=1}^{m} e_r \Delta V_r \right] I_{30}$$

where:

e_r = Rainfall energy per unit of rainfall {MJ/ha*mm} (foot*tonf/acre*inch) for the rth increment of the storm,

and

Δv_r = Depth of rainfall for the rth increment of the storm hyetograph which is divided into m parts, each with essentially constant rainfall intensity {mm} (in)

Unit energy, e, is a function of rainfall intensity and is computed as

$e_k = 1099[1 - 0.72 \exp(-1.27 i_r)]$

where:

$i_r = \Delta V_r / \Delta t_r$

where:

Δt_r = Duration of the increment over which rain intensity is considered to be constant (h),

and

i_r = Rainfall intensity (in/hr)

and

I_{30} = The maximum intensity over 30 consecutive minutes {mm/h}(in/h). If the duration of the test is greater than or equal to 30 minutes, the measured intensity is used.

When the incremental duration is less than 30 minutes, data must be combined from two incremental periods. Most tests lasted 20 minutes in this study. To figure the maximum intensity over 30 minutes (I_{30}) from two increments, the first 10 minutes are taken from the lower intensity test and the last 20 minutes are taken from the higher intensity test. The following equation from Clopper et al. (2001) was applied to calculate the maximum 30 minute intensity between two 20-minute test increments:

$$I_{30}=[A*(.33h/.5h)]+[B*(.5h-.33h)/.5h]$$

where:

A=Larger rainfall intensity of the two 20-minute increments of interest {mm/hr} (in/hr)

and

B=Smaller rainfall intensity of the two 20-minute increments of interest {mm/hr} (in/hr)

Soil Erodibility Factor (K)

The K factors for the three soil types used in RUSLE to predict event soil loss in this study were derived from the soil erodibility nomograph (Wischmeier and Smith, 1978). A soil erodibility nomograph can be found in Appendix B. This procedure is possible since all three soils contain less than 4% organic matter content (Renard et al., 1997).

K factors were also back calculated based on the bare soil data set. Event soil loss predictions by RUSLE are affected by the erodibility rate of the soil. The closer the back-calculated and average annual K factors are to one another the closer the soil loss

estimates should be. The back-calculated values were compared to the nomograph estimations for the loam and silty clay loam materials. The back-calculated values on the sandy loam were compared to Barron County, WI, Soil and Water Conservation Department (1992) values for the Chetek sandy loam series in addition to the nomograph value.

Back Calculating K Factors

The RUSLE K factor can be back calculated when the amount of soil loss (A) and RUSLE R factor are known. By definition, C&P =1 under bare soil conditions. The K factor can be determined by rearranging the equation as follows:

A=RKLSCP
where:
 A=Total Soil Loss
 R=Rainfall Erosivity
 K=Soil Erodibility
LS=Slope Length and Steepness
 C=Cover Management
 P=Support Practice

Because A and R were known following each test, it was possible to plot A as the dependent variable and R as the independent variable. The resulting slope m of the least-squares regression line fitted through the origin was equal to:

m=K*LS*C*P

And because C and P equal one for bare soil conditions,

m=K*LS

Solve for K,

K=m/LS

Substitute in the known LS factor (2.81) of the plots,

K=m/2.81

An example of back calculating for the K factor is illustrated in Figure 5. Soil

Loss vs. RUSLE R factor values are plotted in US customary units. The K factor was

calculated by dividing the slope of regression line by the LS factor value.

Soil Loss vs R Factor (bare soil tests on loam)
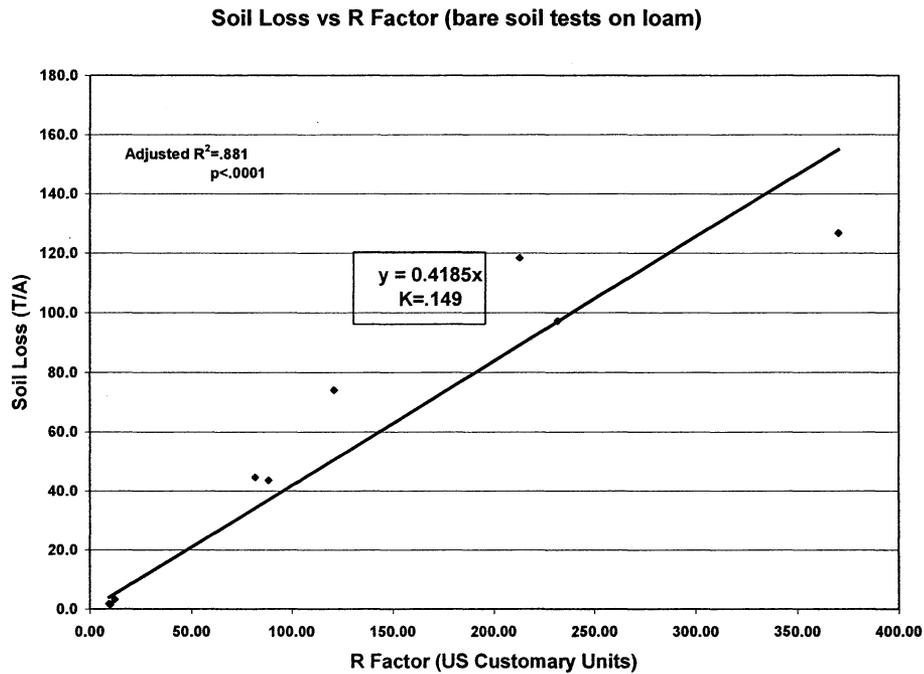
Figure 5. Regression of soil loss vs. RUSLE R factor using bare soil data from loam plots. The slope of the regression line was used to back calculate the soil erodibility factor (K) of the loam material. Multiply K by 0.1317 to convert to S.I. Units.

Slope Length and Steepness Factor (LS)

Table 4-3 from Agriculture Handbook Number 703 (see Appendix C) was

interpolated to determine the LS factor. Because the horizontal slope length of 12.2m

(37.8ft) and slope gradient of 33% are uniform for all 12 plots, the plots share the same

LS value.

Cover Management Factor (C)

Published C factor values were used in RUSLE to obtain predicted soil loss values when available. American Excelsior Company provided the C factor value for the wood fiber blanket that was tested. Table values from Wischmeier and Smith (1978) were used for blown straw cover, because the straw was not anchored by any means. By definition, the C factor =1 for bare soil conditions. Published C factor values were not available for the two straw blankets that were tested. The C factors for these blankets were back calculated in a manner similar to that used for the K factors.

Back Calculating C Factors

The main difference between back calculating for C and K factors is the K factor values were based on the bare soil data set and the C factors were based on the total soil loss (A) and rainfall erosivity (R) values for the testing completed with the single and double net straw blankets installed on the plots.

Once again, because A and R were known following each single and double net straw test series, it was possible to plot A as the dependent variable and R as the independent variable with slope m of the least-squares regression line equivalent to:

$$m = K * LS * C * P$$

but now the equation is solved for C,

$$C = m / K * LS * P$$

and P=1 because no support practices were used during this study and the LS factor equals 2.81,

$$\mathbf{C = m / 2.81K}$$

Figure 6 illustrates the process of back calculating for the C factor of the single net straw blanket on loam soils. US customary units of soil loss and the rainfall erosivity factor are shown.

Soil Loss vs R Factor (single net straw tests on loam)
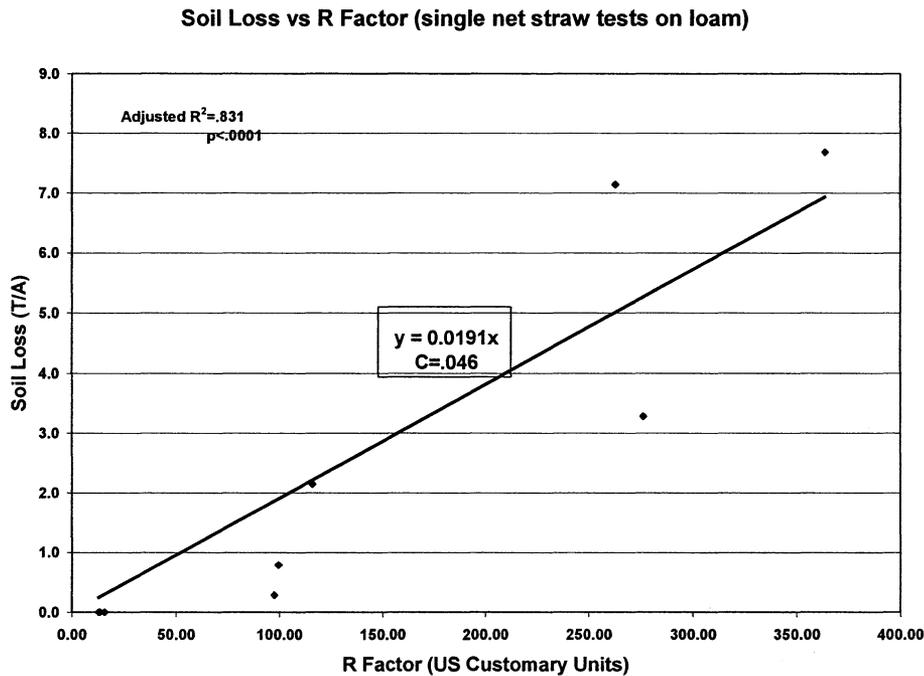
Figure 6. Regression of soil loss vs. RUSLE R factor using single net straw data from loam plots. The slope of the regression line was used to back calculate the cover management factor (C) of the single net straw blanket.

Support Practice Factor (P)

P equaled one for all testing performed during the course of this study because no support practices were applied to the plots.

Laboratory Procedures

Homogeneous samples of the soil slurry were taken following each 20-minute storm increment to determine the moisture content of the soil lost from the plots. The Microwave Method, ASTM #4643, was followed (ASTM D420, 2000). The Microwave Method is equivalent to oven drying the soils at 105°C for 24 hours. After the moisture

content of the sample was known, the ratio of dry to wet soil was used to calculate the

equivalent amount of dry soil that was collected during the test. This was necessary

because RUSLE computes soil loss on a dry basis.

Statistical Analysis (Sub Study 1)

SPSS (Statistical Package for the Social Sciences), a statistical computer

application, was utilized to execute all statistical calculations. The Wilcoxon Signed

Ranks Test was used to analyze the data because some of the data sets were non-normally

distributed. Both the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality were

applied to all surface cover/soil type combination data sets. All tests were run with

$\alpha = .05$. There are five comparisons (cover types) for each soil type so the significance

level was adjusted according to the Bonferroni technique. The adjusted significance level

using the Bonferroni technique is .01 ($\alpha/5$ or .05/5). Differences were considered

statistically significant when $p < .01$. The null (Ho) and alternative (Ha) hypotheses were

as follows:

Ho: Measured soil loss from the erosion plots =
   Predicted soil loss by RUSLE from the erosion plots.

Ha: Measured soil loss from the erosion plots ≠
   Predicted soil loss by RUSLE from the erosion plots.

RESULTS
(Sub Study 1) *Compare measured event soil loss from erosion plots under simulated rainfall to predicted event soil loss amounts from RUSLE using the same climatic, pedological, land use, and topographic properties as those encountered during simulated rainfall testing.*

The statistical analyses recognized five significant differences between what RUSLE predicted and what was measured from the plots (see Table 2). The data on which the statistical analyses are based is in Appendix E.

Table 2. Summary of statistical analyses between measured and predicted soil loss by RUSLE using the Wilcoxon Signed Ranks Test. The significance levels (p) are listed for each cover type tested on each of the three soil types. The critical value of .01 was used to test the null hypothesis. Significant differences are in bold type.

Cover Type	Soil Type		
	sandy loam	loam	silty clay loam
bare soil	0.110	0.678	**0.008**
wood fiber blanket	0.260	0.440	**0.008**
*blown straw	**0.007**	0.345	0.463
single net straw blanket	0.317	0.259	**0.008**
double net straw blanket	0.317	0.109	**0.008**

*Blown straw covered plots on the loam and silty clay soils were only subjected to the 5.1cm/hr (2in/hr) and 10.2cm/hr (4in/hr) intensities for durations of 20 minutes each. Blown straw testing on the sandy loam soil was subjected to sequential 5.1cm/hr (2in/hr) intensities lasting 20 minutes each followed by a 10.2cm/hr (4in/hr) event for 20 minutes. The blown straw was the only surface condition tested that did not experience the 15.2cm/hr (6in/hr) intensity following the first two 20-minute rainfall segments.

RESULTS
(Sub Study 2) *Compare back-calculated K factors from bare soil test series to nomograph and other published values that are based on average annual conditions.*

The soil erodibility factors (K) for each of the three soil types were back calculated utilizing the bare soil data set. The back-calculated values are displayed in Table 3 along with the nomograph values and the published value for the Chetek sandy loam series.

Table 3. Published vs. back-calculated K factor values for the three soil types tested.

Soil Type	*K factor Values		
	[†] Nomograph	Back Calculated	[‡]Series Description
Chetek sandy loam	0.03	0.27	0.24
loam	0.15	0.15	n/a
silty clay loam	0.49	0.06	n/a

*All values listed are in US customary units of ton*acre*h/hundreds of acre*ft*tonf*in.

[†] From the soil erodibility nomograph (Wischmeier and Smith, 1978)

[‡] From Barron County, WI, publication (1992)

DISCUSSION

Four of the five scenarios where significant differences were recognized between measured soil loss and what RUSLE predicted took place on the silty clay loam plots. Overall, RUSLE over-predicted soil loss for each of the four tests that were statistically significant on the silty clay loam soil. Soil loss differences could have resulted because of various reasons.

RUSLE is believed to over-predict soil loss amounts from hillslopes of more than 22% slope (Foster et al., 1999). All hillslope plots tested through out this study were constructed at a slope of 33%. All soil type/cover type combinations would have been recognized as statistically significant if the 33% slope was the only factor contributing to the difference between measured and RUSLE predicted soil loss amounts. The equation did successfully predict soil loss from 67% of the tests, thus factors other than the "excessive" slope need to be considered.

One cause for the differences between what the equation predicted and what was measured from the silty clay loam plots could have been inaccurate C factor values assigned to the covers. However, differences caused by surface cover values may be

excluded because the equation did not accurately predict what was measured from the bare soil tests where no surface cover was applied and C=1 by definition (Renard et al., 1997).

Differences in the soil erodibility factor (K) could be another cause for the predicted vs. measured soil loss from the silty clay loam plots. Table 3 shows the back-calculated average event K factor value for the silty clay loam soil equals 0.06 in US customary units (.008 SI units). The nomograph value for the soil, which was used in the equation when calculating soil loss from the plots, equals 0.49 in US customary units (.06 SI units). The drastic difference between the two K factor values emphasizes that the silty clay loam soil was less erodible under the project testing conditions than was predicted by the average annual nomograph value. The higher soil erodibility factor caused RUSLE to over-predict soil loss in 80% of the tests conducted on the silty clay loam soils. Exact reasons for the difference between event and average annual K factors for the silty clay loam soil are uncertain at this time.

RUSLE over-predicted soil loss from tests involving blown straw on the Chetek sandy loam plots. Chetek sandy loam soils are somewhat excessively drained and have a permeability rate of 15-51mm/hr (0.6-2in/hr) in the upper 41cm (16in) of the soil. Blown straw debris dams were witnessed on the plots during testing. The debris dams are believed to have slowed the down slope movement of the runoff, thus aiding the infiltration ability of the sandy loam material especially during the 5.1cm/hr (2in/hr) segments of the test. The effect of the debris dams is very important because RUSLE does not account for the infiltration capacity of soil. The blown straw on the sandy loam soil was the only cover/soil combination that was subjected to two sequential 5.1cm/hr

(2in/hr) events. RUSLE predicts more soil loss as the R factor increases. The additional 5.1cm/hr (2in/hr) segment of the blown straw tests on the sandy loam increased the RUSLE R factor, but the inherent properties of the soil combined with the debris dams allowed the rainfall to infiltrate into the plot, and ultimately resulted in the over-prediction of soil loss by RUSLE.

RUSLE generally predicted event soil loss accurately from sandy loam and loam plots. In only one of the ten test combinations involving the sandy loam and loam soil types did RUSLE not accurately predict event soil loss. The statistical analyses reveal the one and only difference between measured and RUSLE predicted soil loss values on the sandy loam and loam plots and thus supports the use of RUSLE to predict event soil loss from hillslopes comprised of these materials.

The back-calculated event K factor value for the loam material is extremely close to the estimated average annual nomograph value (Table 3). The back-calculated event K factor value for the Chetek sandy loam soil also closely resembles the published annual average value provided by the Barron County SWCD (Table 3). The nomograph K factor for the sandy loam material (.03) is lower than both the back-calculated (.27) and published series value (.24). The nomograph value was based on the particle size distribution, which was determined from the soil tests performed on the test material. The particle size distribution of the sandy loam material tested contains fewer finer particles than the amounts listed by the Barron County SWCD (1992) and resembles the lower portion of the Chetek sandy loam series. The nomograph K factor value for the Chetek sandy loam material tested is lower than both the back-calculated and published values because K factors generally decrease as the amount of silt-sized particles decrease.

The published soil erodibility value for the Chetek sandy loam material is greater than the nomograph value. The higher soil erodibilty values provided by Barron County are safer because they predict more erosion. The higher limits are important when erosion control plans are designed to protect disturbed lands. The back-calculated event soil erodibility value for the test sandy loam material supports the higher Barron County K factor. The back-calculated event K-factor values for the sandy loam and loam soils also support the use of RUSLE to predict event soil loss from hillslopes comprised of these soil types.

RUSLE's ability to predict event soil loss on the sandy loam and loam soil types combined with the similarity of event and average annual soil erodibility factors supports the use of RUSLE for determining the cover management factor (C) value for surface covers on the two soil types.

SUMMARY

This study supports that cover management factors can be back calculated and assigned to various surface cover BMPs based on accurate event soil loss estimates by RUSLE. Soil type and the associated K factor was found to be the most influential factor affecting the equation's ability to predict event soil loss.

RUSLE was found to be an accurate predictor of event soil loss on loam soils through out this study. The ability of RUSLE to predict event soil loss on sandy soils may be restricted in some situations such as longer lower intensity rainfalls because infiltration ability is not directly considered by the equation. RUSLE yields varying results when used to predict event soil loss from soils with increased amounts of silt-sized particles such as silty clay loam soils. Additional testing is needed on the more "clayey"

soils to better understand why the equation struggles to accurately predict event soil loss

from soils of this nature.

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APPENDIX A-1. Test reports for Chetek sandy loam soil.

GRAIN SIZE DISTRIBUTION TEST REPORT
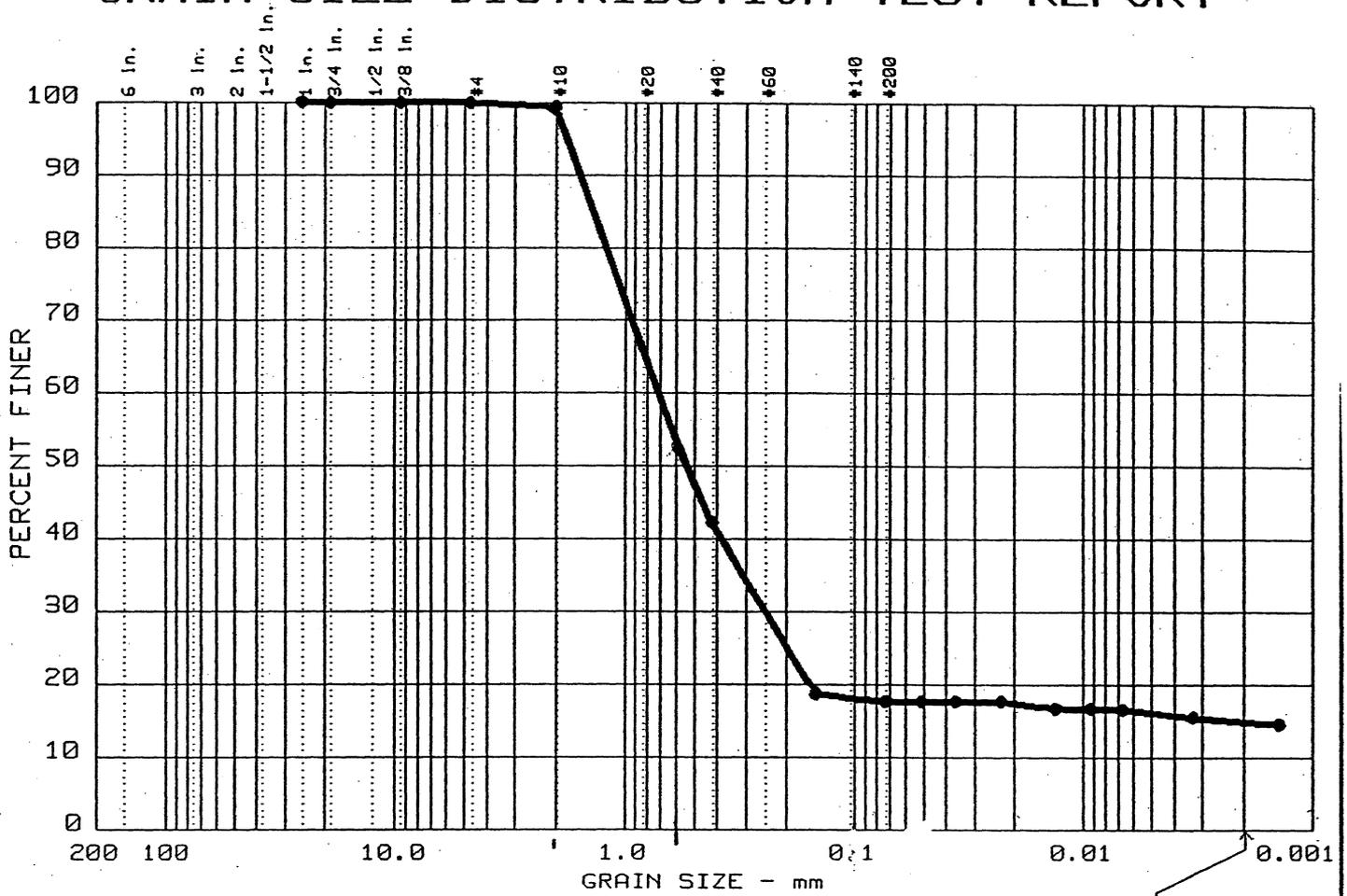
Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
● 1	0.0	0.1	82.3	2.8	14.8

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	NP	NP	1.36	0.71	0.53	0.244	0.0021			

MATERIAL DESCRIPTION	USCS	AASHTO
● Brown, poorly graded sand with clay	SP-SC	A-1-b

Project No.: 34-0335.98

Project: American Excelsior

● Location: North Slope Sand

Date: 12/15/95

Remarks:

Checked By: CAD

GRAIN SIZE DISTRIBUTION TEST REPORT

AYRES ASSOCIATES

Figure No. 2

MOISTURE-DENSITY RELATIONSHIP TEST
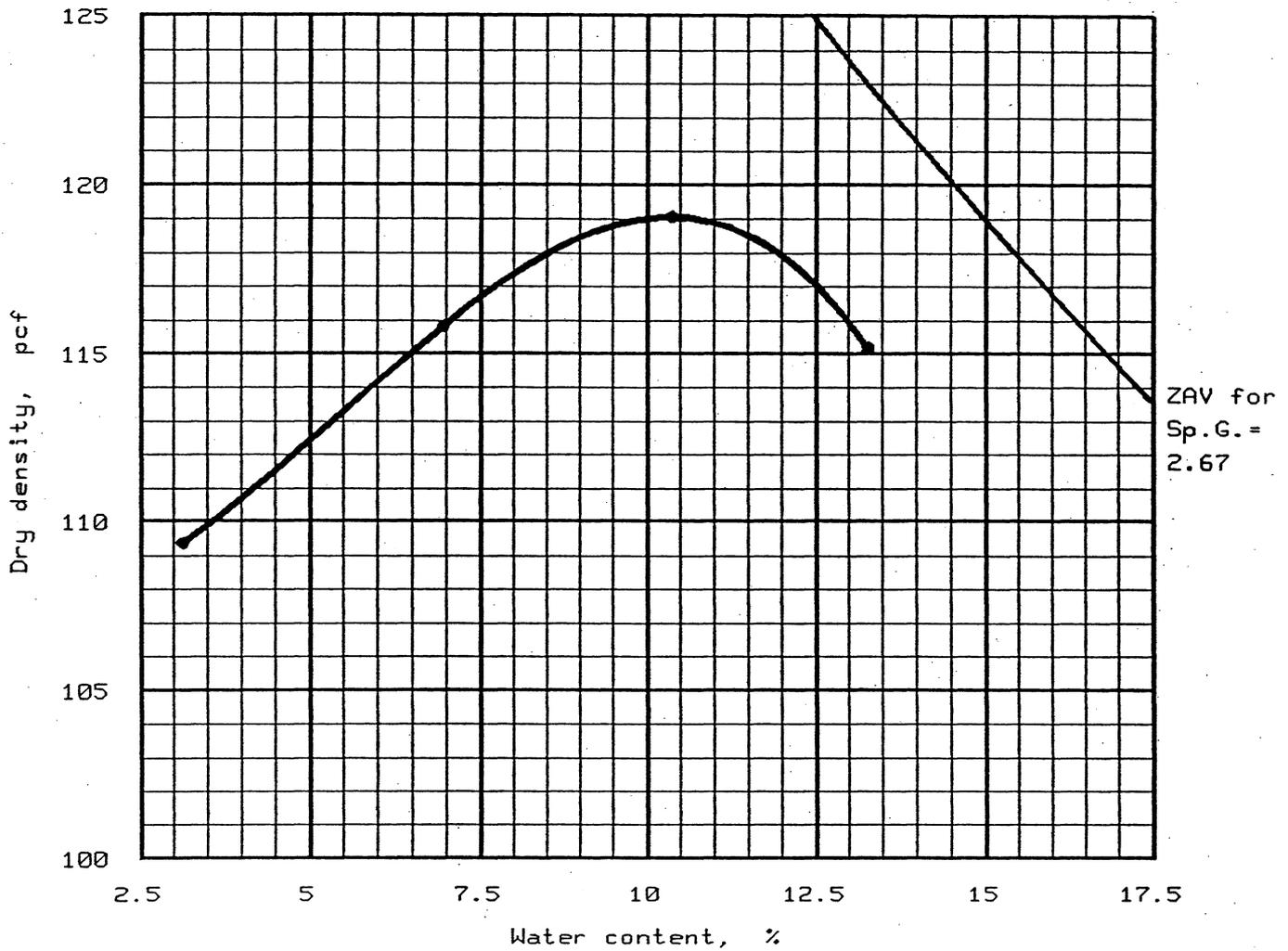
Test specification: ASTM D 698-78 Method A, Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
	SP-SC			2.67	NP	NP	0.1 %	17.6 %

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 119.0 pcf Optimum moisture = 10.3 %	Brown, poorly graded sand, little clay

Project No.: 34-0335.98 Project: American Excelsior Location: North Slope Sand Date: 12-15-95	Remarks: Checked By: CAD
MOISTURE-DENSITY RELATIONSHIP TEST ## AYRES ASSOCIATES	Fig. No. 2

MOISTURE-DENSITY TEST DATA   DATA FILE: 41

PROJECT DATA

Date: 12-15-95
Project No.:   34-0335.98
Project: American Excelsior
Location 1:   North Slope Sand
2:
Remarks 1:
2:
3:                       Checked By:
Material   1:   Brown, poorly graded
description 2:   sand, little clay
Elevation or depth:
Fig. No.:   2

SPECIMEN DATA

USCS classification: SP-SC   AASHTO classification:
Natural moisture: Specific gravity: 2.67
Percent retained on No.4   sieve: 0.1
Percent passing No. 200 sieve: 17.6
Liquid limit: NP   Plastic limit: Plasticity index: NP

TEST DATA AND RESULTS FOR CURVE 2

Type of test: Standard, ASTM D 698-78 Method A
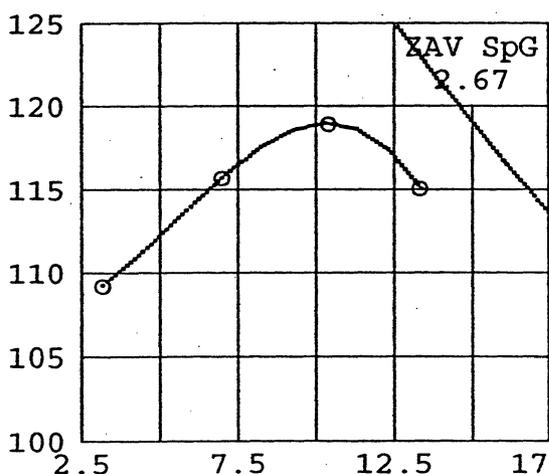
POINT NO.	1	2	3	4
WM + WS	12.97	13.34	13.59	13.56
WM	9.21	9.21	9.21	9.21
WW+T #1	140.75	157.63	194.76	196.84
WD+T #1	137.26	149.09	178.93	176.81
TARE #1	26.24	26.50	26.37	26.11
MOIST #1	3.1	7.0	10.4	13.3
MOISTURE	3.1	7.0	10.4	13.3
DRY DEN	109.4	115.8	119.0	115.2

Chart: Y-axis 100 to 125, X-axis 2.5, 7.5, 12.5, 17.5. ZAV SpG 2.67

Max dry den= 119.0 pcf, Opt moisture= 10.3 %

43

APPENDIX A-2 Test reports for the gravelly loam soil.

GRAIN SIZE DISTRIBUTION TEST REPORT

Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
● 20	0.0	15.5	43.6	30.4	10.5

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	24.24	4.63	4.95	0.46	0.28	0.038	0.0082	0.0016	1.93	278.6

MATERIAL DESCRIPTION	USCS	AASHTO
● Silty, clayey sand with gravel, trace organics	SC-SM	

Project No.: 35-0335.98

Project: AMERICAN EXCELSIOR

● Location: Topsoil (Rec'd 10/11/96)

Date: 10/23/96

GRAIN SIZE DISTRIBUTION TEST REPORT

AYRES ASSOCIATES

Remarks:

ASTM C136

ASTM D422

Organic Content = 3.1%

Checked by: CAD

Figure No. 20

MOISTURE-DENSITY RELATIONSHIP TEST

Test specification: ASTM D 698-78 Method C, Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/4 in	% < No.200
	USCS	AASHTO						
	SC-SM			2.72	24.2	4.63	1 %	41 %

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 121.9 pcf Optimum moisture = 11.1 %	Silty, clayey sand with gravel, trace organics

Project No.: 35-0335.98 Project: AMERICAN EXCELSIOR Location: Topsoil Date: 10/24/96	Remarks: Organic Content = 3.1% Checked by: CAD
MOISTURE-DENSITY RELATIONSHIP TEST AYRES ASSOCIATES	Fig. No. 95

PROJECT DATA

Date: 10/24/96
Project No.:   35-0335.98
Project: AMERICAN EXCELSIOR
Location 1:   Topsoil
2:
Remarks 1:   Organic Content = 3.1%
2:
3:                     Checked by:
Material   1:   Silty, clayey sand with
description 2:   gravel, trace organics
Elevation or depth:
Fig. No.:   95

- -

SPECIMEN DATA

USCS classification: SC-SM   AASHTO classification:
Natural moisture: Specific gravity: 2.72
Percent retained on 3/4 in sieve: 1
Percent passing No. 200 sieve: 41
Liquid limit: 24.2   Plastic limit: 19.57   Plasticity index: 4.63

- -

TEST DATA AND RESULTS FOR CURVE 95

Type of test: Standard, ASTM D 698-78 Method C
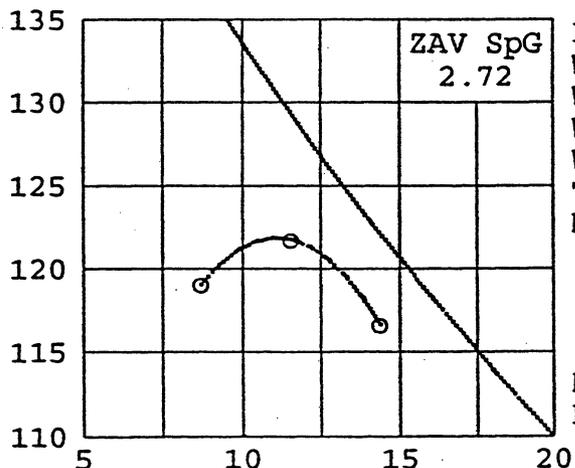
	POINT NO.	1	2	3
	WM + WS	22.23	22.71	22.53
	WM	12.52	12.52	12.52
	WW+T #1	229.30	271.76	260.23
	WD+T #1	213.19	246.41	230.90
	TARE #1	27.10	26.06	26.18
	MOIST #1	8.7	11.5	14.3
	MOISTURE	8.7	11.5	14.3
	DRY DEN	119.2	121.8	116.7

ZAV SpG 2.72

Max dry den= 121.9 pcf, Opt moisture= 11.1 %

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APPENDIX A-3 Test reports for the silty clay loam soil.

| | 6 | 4 | 3 | 2 | 1.5 | 1 | 3/4 | 1/2 | 3/8 | 3 | 4 | 6 | 8 | 10 | 14 | 16 | 20 | 30 | 40 | 50 | 70 | 100 | 140 | 200 | |

GRAIN SIZE IN MILLIMETERS
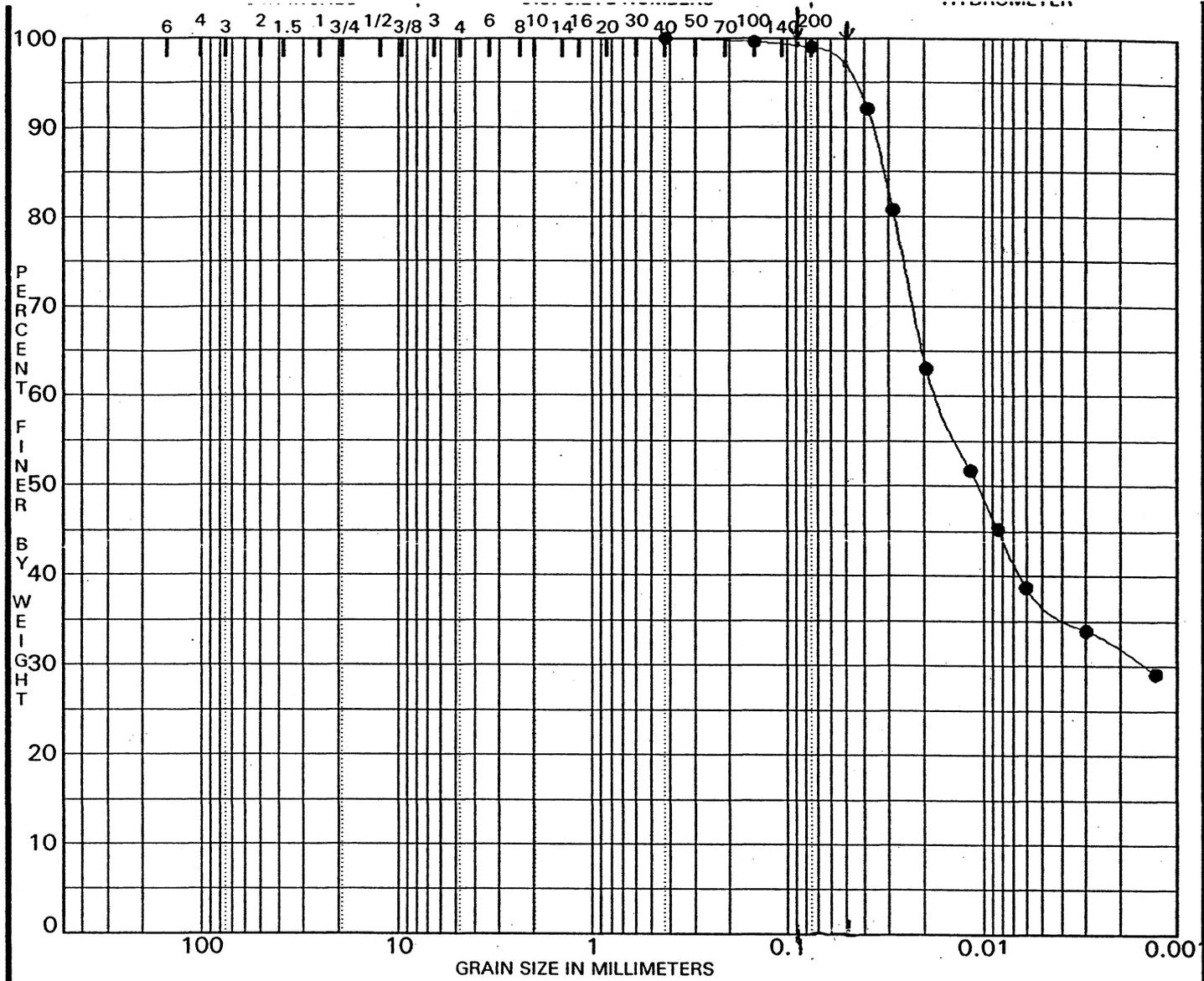
COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification		Classification	MC%	LL	PL	PI	Cc	Cu
● S-1	0.0	LEAN CLAY CL	28	31	21	10		

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● S-1	0.0	0.43	0.02	0.002		0.0	1.0	61.6	37.4

PROJECT **SOIL ANALYSIS; - RICE LAKE, WISCONSIN**

JOB NO. ___2001101___
DATE ___5/15/00___

GRADATION CURVES
Maxim Technologies Inc.
Eau Claire, Wisconsin

MOISTURE-DENSITY RELATIONSHIP TEST
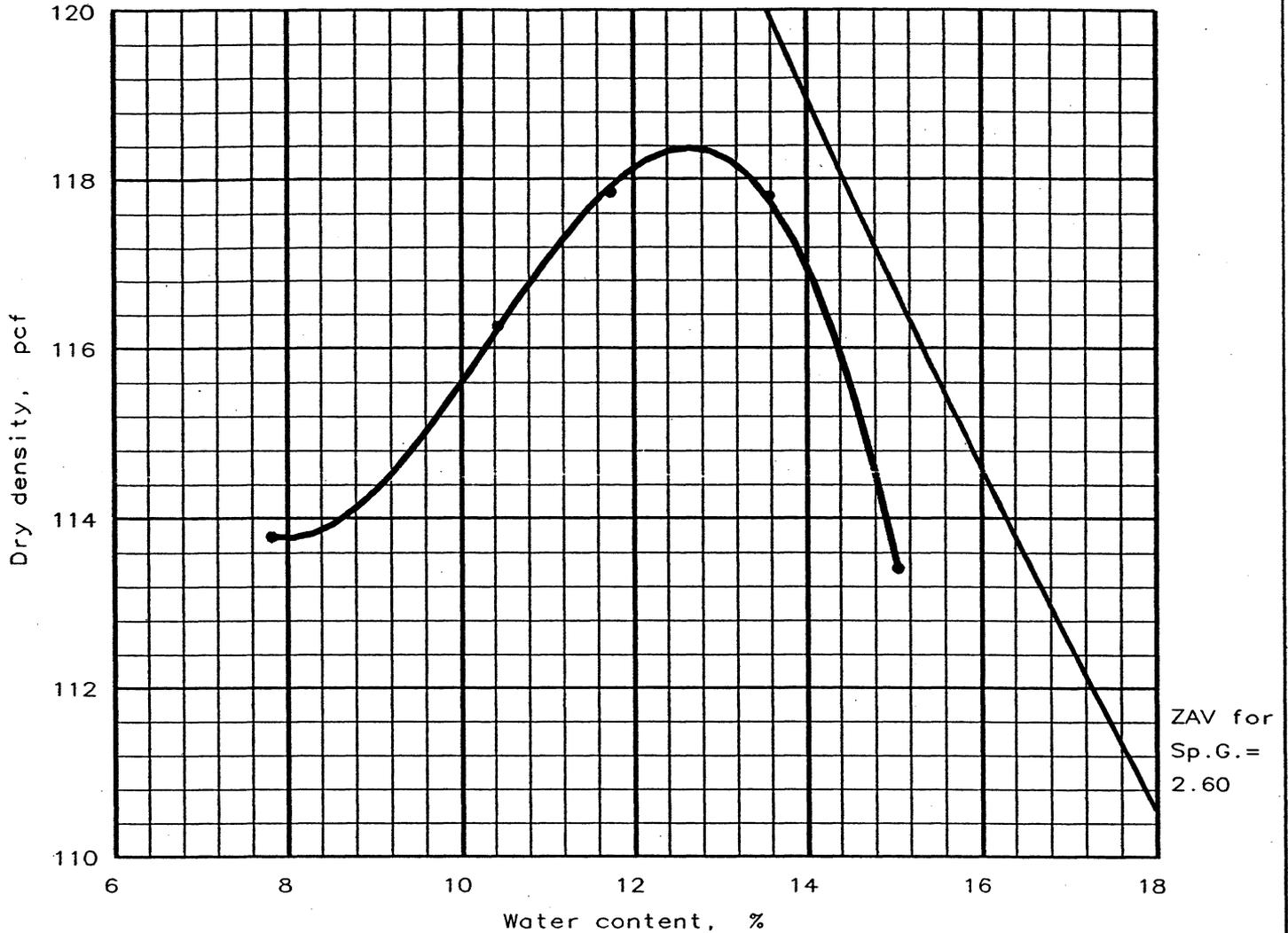
Test specification: ASTM D 1557-91 Procedure A, Modified

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
	CL		27.9 %		31	10	0.0 %	99.0 %

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 118.4 pcf Optimum moisture = 12.7 %	Lean Clay, brown (CL)-1

	Remarks:
Project No.: 2001101 Project: Soil Analysis Location: Rice Lake, Wisconsin American Exelsior Company Date: 4-24-00	

MOISTURE-DENSITY RELATIONSHIP TEST

MAXIM TECHNOLOGIES INC.

Fig. No. 1

PROJECT DATA

Date: 4-24-00
Project no.:   2001101
Project: Soil Analysis
Location 1:   Rice Lake, Wisconsin
2:                       American Exelsior Company
Remarks 1:
2:
3:
Material   1:   Lean Clay, brown (CL)-1
Description 2:
Elevation or depth:
Fig no: 1

---

SPECIMEN DATA

USCS classification: CL   AASHTO classification:
Natural moisture: 27.9   Specific gravity:
Percent retained on No.4   sieve: 0.0
Percent passing No. 200 sieve: 99.0
Liquid limit: 31   Plastic limit: 21   Plasticity index: 10

TEST DATA AND RESULTS FOR CURVE 1

Type of test: Modified, ASTM D 1557-91 Procedure A
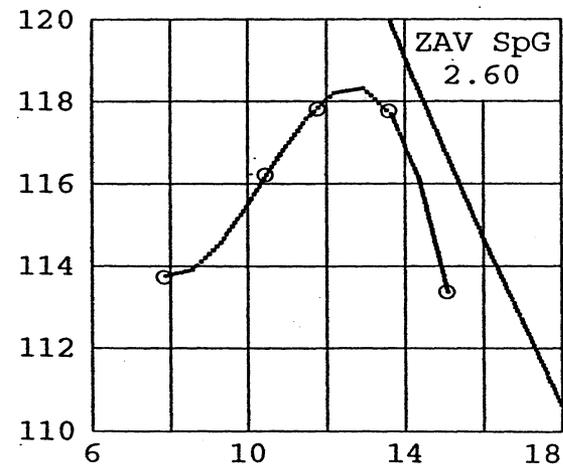
POINT NO.	1	2	3	4	5
WM + WS	13.61	13.72	13.79	13.68	13.42
WM	9.33	9.33	9.33	9.33	9.33
WW+T #1	226.50	333.80	356.40	366.00	253.40
WD+T #1	205.10	298.70	313.80	318.10	235.00
TARE #1	0.00	0.00	0.00	0.00	0.00
MOIST #1	10.4	11.8	13.6	15.1	7.8
MOISTURE	10.4	11.8	13.6	15.1	7.8
DRY DEN	116.3	117.9	117.8	113.4	113.8

Graph axes: y-axis 110 to 120, x-axis 6 to 18. ZAV SpG 2.60

Max dry den= 118.4 pcf, Opt moisture= 12.7 %

Oversize Correction Not Applied

APPENDIX B. Soil erodibility nomograph (Wischmeier and Smith, 1978). The nomograph is used to determine soil erodibility factors (RUSLE K).

1. very fine granular
2. fine granular
3. med. or coarse granular
4. blocky, platy, or massive

6. very slow
5. slow
4. slow to mod.
3. moderate
2. mod. to rapid
1. rapid
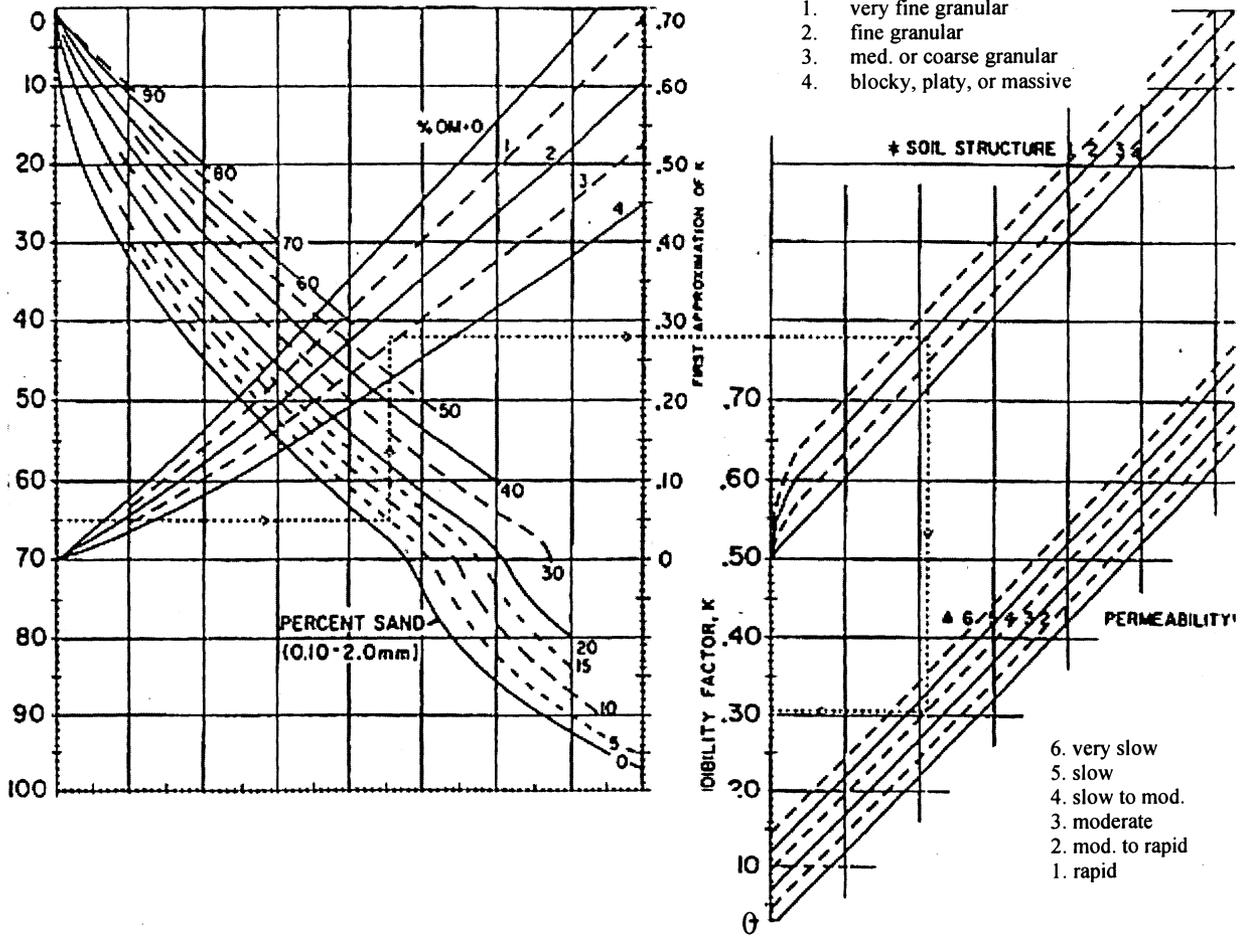
APPENDIX C. Table 4-3 from Agriculture Handbook 703 (1997). The table is used to determine slope length and steepness factors (RUSLE-LS).

Table 4-3.
Values for topographic factor, LS, for high ratio of rill to interrill erosion.[1]

Slope (%)									Horizontal slope length (ft)								
	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.26	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63	0.69
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10	1.23
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65	1.86
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25	2.55
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89	3.30
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24	4.91
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03	7.02
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17	9.57
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40	12.23
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69	14.96
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35	20.57
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24	27.66
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07	34.71
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29	48.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63	60.84
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93	72.15

[1] Such as for freshly prepared construction and other highly disturbed soil conditions with little or no cover (not applicable to thawing soil)

APPENDIX D. Dimensions and units.

Dimensions

L	=	Length
L^2	=	Area
F	=	Force
T	=	Time
M	=	Mass

SI units

MJ	=	Megajoule
t	=	Metric Ton
h	=	Hour
y	=	Year
mm	=	Millimeter
cm	=	Centimeter
m	=	Meter
kg	=	Kilogram
ha	=	Hectare
m^2	=	Square Meter
$^{\circ}C$	=	Degrees Celsius

US customary units

hundreds of	=	Value * $10^{\wedge 2}$
tonf	=	Ton Force
ton	=	Ton
hr	=	Hour
yr	=	Year
in	=	Inch
ft	=	Foot
lb	=	Pound
yd^2	=	Square Yard

APPENDIX E. Measured and RUSLE-predicted soil loss amounts by
RUSLE R factor according to cover/soil combinations tested.

Measured and RUSLE-predicted soil loss amounts for bare soil tests on sandy loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
135.48	1.5	0.0
255.98	2.8	2.6
281.68	3.1	0.0
401.01	4.5	0.0
659.12	7.3	0.0
1161.82	12.9	115.0
1844.86	20.5	229.3
1995.00	22.1	157.5
2413.14	26.8	280.1
4233.71	47.0	505.9
4363.51	48.4	360.2

Measured and RUSLE-predicted soil loss amounts for bare soil tests on loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
161.52	9.0	3.9
171.73	9.5	3.4
207.98	11.5	7.4
1391.45	77.2	100.0
1504.85	83.5	97.8
2060.19	114.4	165.9
3624.36	201.2	265.2
3944.43	219.0	217.9
6300.08	349.7	284.0

Measured and RUSLE-predicted soil loss amounts for bare soil tests on silty clay loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
141.95	25.7	1.5
161.52	29.3	4.8
189.43	34.4	1.7
1033.69	187.4	49.3
1567.78	284.3	25.9
1617.15	293.2	24.0
2812.72	510.1	117.6
4285.12	777.1	113.0
4899.75	888.5	64.6

Measured and RUSLE-predicted soil loss amounts for blown straw tests on sandy loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
247.75	0.5	0.0
251.90	0.5	0.0
268.81	0.5	0.0
673.28	1.3	0.0
685.29	1.3	0.0
828.85	1.6	0.0
1986.27	3.7	0.0
2424.40	4.6	1.8
2464.71	4.7	0.0

Measured and RUSLE-predicted soil loss amounts for blown straw tests on loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
178.71	1.7	0.8
182.33	1.7	0.6
273.12	2.6	0.6
1511.17	14.3	52.7
1845.98	17.4	65.9
2217.51	20.9	86.9

Measured and RUSLE-predicted soil loss amounts for blown straw tests on silty clay loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
175.19	7.6	0.0
215.82	9.4	0.0
247.75	10.8	12.2
1268.43	55.2	31.6
1463.89	63.7	174.7
1854.23	80.7	27.8

Measured and RUSLE-predicted soil loss amounts for wood fiber blanket tests on sandy loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
477.83	0.1	0.0
1092.11	0.1	0.0
1379.21	0.2	0.0
1759.27	0.2	0.0
3393.15	0.4	2.0
4690.63	0.5	5.3
4774.42	0.5	0.0
6675.73	0.7	3.8
9722.34	1.1	2.4

Measured and RUSLE-predicted soil loss amounts for wood fiber blanket
tests on loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
437.17	0.4	0.0
673.73	0.7	0.0
859.74	0.9	0.0
1540.34	1.5	0.9
2156.90	2.2	2.7
2762.41	2.8	1.0
3892.97	3.9	5.3
5041.73	5.0	2.8
5162.33	5.2	7.1

Measured and RUSLE-predicted soil loss amounts for wood fiber blanket tests on silty clay loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
175.12	7.1	0.0
193.19	7.8	0.0
215.71	8.7	0.0
1186.27	47.8	10.4
1370.06	55.2	10.2
1374.77	55.3	12.0
3582.68	144.2	6.8
4228.42	170.2	20.2
4921.74	198.1	22.4

Measured and RUSLE-predicted soil loss amounts for single net straw blanket tests on sandy loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
164.9	0.0	0.0
185.9	0.0	0.0
299.7	0.0	0.0
1185.0	0.0	0.0
1243.9	0.0	0.0
2321.3	0.1	0.0
3674.2	0.1	0.0
3752.4	0.1	0.0
6579.7	0.1	2.6

Measured and RUSLE-predicted soil loss amounts for single net straw blanket tests on loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
219.7	0.6	0.0
231.5	0.6	0.0
268.9	0.7	0.0
1659.9	4.2	0.6
1694.3	4.3	1.8
1976.1	5.1	4.8
4472.4	11.4	16.0
4700.4	12.0	7.4
6188.0	15.8	17.2

Measured and RUSLE-predicted soil loss amounts for single net straw blanket tests on silty clay loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
168.3	18.3	0.0
178.7	19.4	0.0
215.8	23.5	0.0
1290.5	140.3	2.8
1514.9	164.7	24.3
1603.5	174.4	53.9
2944.6	320.2	39.5
3562.4	387.4	65.9
3732.4	405.9	22.5

Measured and RUSLE-predicted soil loss amounts for double net straw blanket tests on sandy loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
204.2	0.0	0.0
231.5	0.0	0.0
247.8	0.0	0.0
1197.5	0.0	0.0
1574.5	0.0	0.0
1674.0	0.0	0.0
1943.6	0.0	0.0
3743.3	0.1	0.0
6228.3	0.1	1.7

Measured and RUSLE-predicted soil loss amounts for double net straw blanket tests on loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
171.7	0.4	0.0
189.4	0.4	0.0
264.5	0.6	0.0
1287.3	2.9	0.9
1449.0	3.3	0.7
1705.9	3.9	1.9
3341.3	7.6	3.5
4431.2	10.1	8.9
5661.7	12.9	17.6

Measured and RUSLE-predicted soil loss amounts for double net straw blanket tests on silty clay loam.

R-factor (MJ*mm/ ha*h*event)	Predicted Soil Loss (t/ha)	Measured Soil Loss (t/ha)
196.9	8.7	0.0
235.6	10.5	0.0
346.5	15.4	0.0
1588.7	70.5	0.7
1722.8	76.5	8.9
1801.4	80.0	0.3
3404.5	151.2	27.6
4237.3	188.2	1.7
4640.1	206.0	45.0