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Evaluation of RUSLE 2 to estimate soil loss from pastures

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Evaluation of RUSLE 2 to Estimate Soil Loss from Pastures

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Abstract

The accurate estimation of soil erosion by the Revised Universal Soil Loss Equation version 2 (RUSLE2) is critical for several conservation assessments, least of which is its use in the Phosphorus Index (PI) to identify and rank the vulnerability of agricultural fields to phosphorus (P) runoff. Earlier versions of RUSLE reported a soil loss overestimation, which were revised to give RUSLE2, where biomass production in different climatic regions was more accurately represented. RUSLE version 2.0, which contains the new vegetative biomass production routine, was evaluated using two performance indices, the Nash Sutcliffe Efficiency Index (NSE) and Index of Agreement (D) across 27 cattle grazed fields in Southeastern U.S. An overall NSE of -0.164 and D of 0.242, indicated RUSLE2 poorly predicts soil loss for this region. Further investigation was needed to understand the reason for these poor soil loss estimates by RUSLE2. RUSLE2 estimates of soil loss are based on Hortion overflow sediment delivery from daily storm events accrued to an annual soil loss along a given field slope. Compared with measured sediment delivery from seven tall fescues (*Festuca arundinacea*) fields in northwest Arkansas over five years, with various manure and grazing management, sediment delivery estimated by RUSLE2 was acceptable, with log NSE (1.4). However, RUSLE2 over-predicted the number of storm events between 2009 - 2013 for all seven fields, from field collected rainfall- intensity data which created the localized 5- years erosivity values. Over-prediction on the number of storm events would lead to an increase in annual soil loss estimate. A need for a lower restrictive rainfall threshold value that does not initiate field runoff, and in turn, sediment delivery, particularly in grassland system, needs to be incorporated into RUSLE2 soil loss estimates.

Keywords: Soil loss, Sediment delivery, Erosion, Revised Universal Soil Loss Equation, Phosphorus Index, Pasture runoff, Water quality.

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List of Abbreviations

ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
API	Arkansas Phosphorus Index (US)
CREAMS	Chemical Runoff and Erosion, and Agricultural Management Systems
d	Index of Agreement
E_{NS}	Nash -Sutciffe Efficiency Index
EPA	Environmental Protection Agency (US)
EPIC	Erosion –Productivity Impact Calculator
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
MAE	Mean Absolute Error
NAS	National Academy of Sciences (US)
NRCS	National Resources Conservation Services (US)
NRI	National Resources Inventory (US)
NSE	Nash –Sutcliffe Efficiency Index
NSRL	National Soil Research Laboratory (US)
PI	Phosphorus Index
R^2	Coefficient of Determination
RIST	Rainfall Intensity Summarization Tool

RMSE	Root Mean Squared Error
RUSLE	Revised Universal Soil Loss Equation
RUSLE2	Revised Universal Soil Loss Equation Version 2
SWAT	Soil and Water Assessment Tool
USDA	United States Department of Agriculture (US)
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project

List of Equations

$$g_{out} = g_{in} + \Delta x\ D$$ Equation 1

$$T_c = K_T\ q\ s$$ Equation 2

$$q = q_{i-1} + \sigma(x - x_{i-1})$$ Equation 3

$$S = \frac{25400 - 254\ \mathrm{CN}}{CN}$$ Equation 4

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$ Equation 5

$$EI_{30ev} = P_{ev}E_{ev}edm_{ev}$$ Equation 6

$$E = 0.29[1 - 0.72\exp(-0.08\ I)$$ Equation 7

$$Z = 1 - \frac{\sum_{e=1}^{N}(lny_o - lny_c)^2}{\sum_{e=1}^{N}(lny_o - lny_m)^2}$$ Equation 8

Chapter 1

1.1 Introduction

Remedial efforts to address water impairment have focused on reducing nutrient and sediment loss from agricultural lands (USDA – Natural Resources Conservation Service, 2014; U.S. Environmental Protection Agency, 2010). However, the measurement of water quality improvements as a result of agricultural management changes has been less than expected in many cases (Jarvie et al., 2013; Schulte et al., 2010). The lack of improvement of water quality is partly due to long- term release of phosphorus (P) from deposited fluvial sediments (Meals et al., 2010; Sharpley et al., 2012). Thus, sediments remain a major cause of surface water impairment (Beeson et al., 2014).

Realistic representation of sediment delivery from agricultural fields is essential to mitigation efforts of P losses especially in vulnerable areas such as the Mississippi River Basin. With the increasing use of poultry litter as an affordable fertilizer on pastures in the southeastern U.S. (Slaton et al., 2004), the need for accurate and reliable sediment and runoff estimates are important to the on-farm nutrient management planning that protects off-farm water quality. The U.S. Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) has developed national conservation practice standards for on-farm nutrient management planning (i.e., CPS 590; U.S. Department of Agriculture – Natural Resources Conservation Service, 2015). A component of this is the assessment of the risk of P loss in runoff on a field-by-field basis, using a P Index, which defines appropriate land and nutrient management as a function of risk (Sharpley et al., 2003). A major component of the P Index is RUSLE2 (Revised Universal Soil Loss Equation version 2.0), used to estimate soil loss (Sharpley et al., 2012).

RUSLE2 a second-generation model to estimate soil loss across spatial and temporal field scales, which is subsequently used in conservation policies and mitigation measures.

RUSLE2 was developed by NRCS to accurately represent soil loss from cropped fields (NRSL, 2015). However, the efficacy of RUSLE2 soil loss estimates is yet to be validated using measured soil loss data from pastures in southeastern U.S. Dabney et al. (2006) reported a general overestimation of soil loss in its earlier version, resulting in a conflicting view on the use of RUSLE2 particularly for pastures. The research described in this thesis evaluates the accuracy and reliability of RUSLE2 to estimate soil loss using previously published data for pastures across a wide range in southeastern U.S. pastures and in runoff from pastures measured in northwest Arkansas.

1.2 Research Objectives

1. Assess the accuracy using performance indices between the measured field soil loss to that of RUSLE2 average soil loss estimates for varied grassland environments across the humid Southeastern U.S.
2. Compare the temporal pattern of RUSLE2 sediment delivery to measured temporal sediment delivery distribution from pastures in northwest Arkansas.
3. Assess the performance of RUSLE2 sediment delivery to that of measured sediment delivery in northwest Arkansas under different poultry litter application and grazing practices.
4. Determine whether coefficient of variation of storm events for sediment delivery from RUSLE2 is consistent to that of the measured field sediment storm delivery.

1.3 Thesis Outline

The thesis structure is represented in the schematic Figure 1.3.1 following a literature review (Chapter 2), Chapter 3 compares RUSLE2 estimates of soil loss from grassed fields varying in size and management across the humid southeastern U.S., with published data. Chapter 4 focuses on one site in northwestern Arkansas; the Harmon Road field plots that are part of the University of Arkansas Animal Physiology Farm, comparing RUSLE2 estimated sediment delivery with values measured for storm runoff events between 2009 and 2013. Chapter 4 also investigates these RUSLE2 sediment delivery on a storm-by-storm basis as a function of pasture management (i.e., with and without manure, continuous and rotation grazing, and haying). Finally, Chapter 5 gives the overall conclusions of this research.

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Chapter 2

Literature Review

2.1 Agricultural Erosion and Water Quality

In the 1930s era, erosion was identified as the major contributor to the drastic reduction in crop productivity and soil in the Great Plains region, which resulted in Federal legislative measures to mitigate soil loss fertility (Evin and Ervin, 1982; Mc Connell, 1983). The Act of Soil Conservation and Domestic Allotment was created as a preventative initiative to improve and preserve the national soil resources, as well as the creation of soil erosion services to address the problematic phenomenon of soil erosion (Toy et al., 2002). At the time, the 1930's were also known as the "Dirty 30s" (Meyer and Moldenhauer, 1985), posing a major economic burden on the U.S., with annual estimates of loss ranging from 30 to 40 billion US $ (Pimental et al., 1995). This led to focused research to elucidate the mechanisms of soil loss, agents of erosion, and the most significant factors contributing to erosion in the mid-western region of the U.S. (Meyer and Moldenhauer, 1985; Renard et al., 1997; Skidmore, 1986; Wischemier and Smith, 1978). From various erosional studies across U.S., it was agreed that soil erosion agents of wind and water are the responsible for natural and anthropogenic accelerated soil loss (Morgan 2005; Lal et al., 1998). Of these agents, water is the more predominant and is problematic in Lower Mississippi River Basin (Morgan, 2005).

In 1970's, sediments were also identified as the major contributor to water quality, posing a national environmental problem in terms of siltation of navigational waterways and flood control dams (Ice, 2004; Meyer and Moldenhauer, 1985). Sediment also represented a source of nutrients that accelerated the eutrophication of lakes (Carpenter et al., 1998; Sharpley et al., 1994). More recently, erosion of agricultural nutrients in the Mississippi River Basin is seen as a major cause of the development and the expansion of the hypoxic zone in the Gulf of Mexico located on the Louisiana /Texas continental shelf, which ranges in area of 5000 to 20,700 km^2 (Howarth et al., 2002; Rabalais et al., 2002).

The Mississippi River Basin supports highly productive crop and pasture lands, which are responsible for majority of the agricultural produce in the U.S. In the 1970's, environmental problems were highlighted where soil loss was causing siltation of navigable waterways of the U.S. During this period, the federal Clean Water Act was passed in attempt to manage and mitigate these issues (Ice et al., 2004).   For instance, a 50 % reduction in soil fertility over 150 years in Iowa was attributed to water induced soil loss (Pimentel, 2006; Risser, 1981. In response, there was a requirement to estimate soil loss and to evaluate and identify measures and practices to control soil loss. One method developed to estimate soil loss is the universal soil loss estimation tool. The proposed solution that meet those requirements was to develop a universal soil loss model (Wischemier and Smith 1978; Renard et al., 1997; USDA, 2008; Foster et al., 2013). As a result, research was focused on understanding and determining the factors of controlling soil loss by water.

Soil erosion by water was found to be a ubiquitous site problem (Pimentel, 2006). Thus, a time scale to effectively monitor and estimate soil loss was chosen to be in yearly increments and spatially to investigate the major factors of soil loss was at a plot scale (Wischemier and Smith, 1978; Renard et al., 1997). By 2003, Pimentel (2006) and NAS (2003) suggested technological advance in soil management and conservation had resulted in more than 25% reduction in cropland erosion. However, NAS (2003) reported on average soil loss of 10 tonnes per hectare of which 6 tonnes per hectare occurred from pasture and rangeland across the Mississippi River

Basin; hence there was little reduction in erosion from pastures and rangeland. Thus, there is a particular need to focus on soil loss research on pastures.

2.2 Models to Estimate the Risk of Erosion and Phosphorus Runoff

Models are part of the erosion prediction technology, used in development of soil conservation and environmental degradation planning systems. Erosion are based on defining the relation among controlling factors and soil loss delivery soil loss from one point on the landscape to another within a given set of management conditions (Toy et al., 2002). The types of soil erosion models are summarized in Table 1.2.1. These factors were identified as climate, soil, topography, vegetation and conservation practices (Wischemier and Smith, 1978), which have either a positive or negative effect on soil loss. These primary factors are the basis of the universal soil loss model.

Table 2.2. The description of various Soil Erosion Models and their characteristics (adapt from Toy et al., 2002).

Model Type	Forms	Derivation Methods	Strengths
Regression -derived	Single or few equations having a form that best suits the data	Derived from fitting equations to an empirical database as field conditions	Simple input and easy to obtain
Indexed- Based	Uses indices generally in a multiplicative form shows how the factors affects erosion	Values from the indices are determined from a large empirical database representing field conditions	Simple and easy to use, input values are simple and easy to obtain
Simple processed based	Represents individual erosion processes using steady state equations	Equations are derived from theory and empirical databases for erosion processes and validated against database representing field conditions	Can be simple, represents fundamental erosion processes, improved performance
Combined index and processed based	An index based form in which simple process based equations are used to determine the values of indices	Components derived from empirical database for erosion processes and land use sub-factors and theory, validating against database representing field conditions	Uses both index and processed based models, robust, land use independent, very powerful
Dynamic between storms	Uses equations to represent how the factors are changing between storms, uses steady state conditions and compute for each storm	Derived from theory and empirical database for fundamental erosion processes and integrating conservation of mass equation	Powerful, captures a wide range of conditions, uses fundamental erosion processes without excess detail, can be constructed to be land use dependent
Dynamic within and between storms	Additional computing features through time within an event	Same as dynamic between storms but has temporal variation within storm event	Most powerful, represents erosion processes to maximum detail

2.2.1. USLE

The Universal Soil Loss Equation (USLE) model is a widely recognized empirical soil loss model with combined indices to estimate loss at field scale (Merrit et al., 2003). Original detailed validation of USLE was for cropland erosion (Renard et al., 2003). The model input parameters consist of R (erosivity), K (erodibility), LS (Length and Slope), C (crop), and P (management practice). These parameters are factors representing the drivers of water derived erosion (climate, soil, topography, vegetation and conservation practices). This model computes soil loss based on sheet and rill erosion and not deposition (Renard et al., 1991). When applying USLE, land use is limited to crop data provided in the USDA Agricultural Handbook 537. This presented a problem in national soil conservation inventories due to its limited land-use applicability (Renard et al., 1991; Toy et al., 2002; EPA, 2007). Also, the R factor that was developed for the USLE uses rainfall intensities to calculate R, even though these datasets are not readily available (Renard et al., 1991) and require at least 30 years of hourly rainfall intensity data to develop relationship to establish R (Wischemier and Smith, 1978). As a result, Wischemier and Smith (1978) suggested using an estimated average annual estimate of soil loss but cannot be applied to extreme soil loss events (Merrit et al., 2003).

2.2.2 RUSLE

To address the shortcomings of USLE, a revised erosion estimator tool was developed (Meritt et al., 2003 and Lane et al., 1992). Like USLE, the Revised Universal Soil Loss Equation (RUSLE) is empirical and be applied to various sites. This model updated the R factor such that the users just have to use iso-erodent maps provided by the NRCS rather than the more complex calculation method making RUSLE more user friendly (Renard et al., 1991; Renard et al., 1997). Land vegetative database was expanded to include crops and other plants C factor indices which increases its applicability throughout the US (Renard et al., 1991; Merrit, 2003).

This model is based for field assessment on soil erosion and sediment transport for average annual soil loss (Renard et al., 1997). Also, the modification of the K factor to represent the seasonal distribution of K (soil erodibility) is adapted in RUSLE. This provide an improvement of erosion estimates (Renard et al., 1997). However, it still does not address the problem of identifying the large soil loss event (Merrit et al., 2003). Even so, Tiwari et al. (2000) noted improvements in soil detachment, transport and deposition processes in the modified RUSLE equations. However, Merrit et al. (2003) pointed out that the problem of not identifying extreme soil loss event but still exists in RUSLE where soil depositional processes were not fully addressed or accounted for.

2.2.3. RUSLE 2

With the development and application of GIS technologies, and expansion of computational power and refinement of mathematical expression, estimating erosion transitioned from an empirical to a process-based model (Tiwari et al., 2000; Foster et.al, 2013). Although, RUSLE2, is empirical by nature, the model consists of the newest development of mathematical representations of tillage conservation and sub-factors of crop systems. This model is user friendly computer-integrated system to analyze field plot to watershed assessment in daily cited as time scale (Foster et al., 2013). RUSLE2 improves predictive ability by identifying extreme loss event using daily inputs. Also, addition of steady state mass system and Hortonian overland flow descriptions provide computation for large drainage areas, q, while incorporating deposition processes, making this a model quasi- state soil erosion model. RUSLE2 model enhances its ability to estimate soil loss in cropped, urban and general vegetative area (Foster et al., 2013). However, there is a need to evaluate this model over a range of different environment as Dabney (2012) noted that the earlier model of the RUSLE2 overestimates soil loss in pasture vegetation.

2.2.4. RUSLE 2 Limitations on Pastures

Foster et al. (2003) noted that RUSLE2 estimates average annual soil loss were 20 % greater than using RUSLE. This is attributed to the fact that RUSLE2 sums the calculated daily soil loss over a year to produce an annual soil loss. This algorithm is responsible for the net increase in soil loss estimation compared to either RUSLE or measured losses. The inaccuracy is of critical importance to the use of the Arkansas Phosphorus Index (API) which uses RUSLE2 to estimate soil loss as an input in estimating the risk of P loss from a given field and management scenarios. (Sharpley et al., 2012). Therefore, a quantitative assessment on the impact of RUSLE 2 on API recommendations is needed.

Dabney et al. (2006) noted a 10-fold variation in soil loss estimates using RUSLE on pastures although erosion from pastures was consistently measured to be appreciably lower. This indicates a high variability of soil loss from pasture and highlights the importance to validate the RUSLE 2 soil loss estimate particularly for pastures. Also, Dabney et al. (2006) identified the most influential sub-factors responsible for the reduction of soil loss when compared to a row crop such as maize, are the surface ground cover and prior land use factor. These factors are integrated into the RUSLE 2 numerical framework and their interactions are crucial to the soil loss RUSLE 2 output (USDA, 2013).

Dabney and Yoder (2012) further noted an overestimation with pasture lands in an earlier version of RUSLE 2 which calculated the vegetative residue production during the period of canopy decline, resulting in an underestimation of the biomass for grazed and hayed pastures. In order to resolve this problem, a new vegetative routine was introduced in the RUSLE 2 framework. This was a revision of the model estimating aboveground biomass conversion to standing residue and the addition of active and woody residue when the crop lifespan is exceeded. This vegetative growth model also tracks dead biomass through standing residue, surface residue and buried and dead roots (Dabney et al., 2012). However, there remains a need to compare the RUSLE 2 estimates of this vegetative model to observed soil loss for pastures.

2.2.5. Phosphorus Index Risk Assessment

In the U.S., a site assessment tool, or P Index, was proposed in 1993 and eventually adopted into the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS) Conservation Practice Standard for nutrient management (i.e., the NRCS 590 Standard). The P Index was designed to identify and rank critical source areas of P loss based on site-specific source factors (soil P, rate, method, timing, and type of P applied) and transport factors (runoff, erosion, and proximity to streams) (Lemunyon and Gilbert, 1993). The fundamental advantage of the P Index is to enable targeting of remedial management to critical source areas where high P source and transport potential coincide. This approach differed profoundly from prior environmental risk tools that were based solely on soil P concentrations. Although indices require more information on site source and transport conditions, they more reliably identify nonpoint sources of agricultural P and provide greater flexibility in remedial options and management.

Currently, 47 U.S. states have adopted the P Index as a site assessment tool to identify critical source areas and target remedial practices (Sharpley et al., 2003). In addition, versions of the P Index have been proposed for several Canadian provinces and Scandinavian countries (e.g., Finland, Norway, and Sweden). As different versions of the P Index have emerged, ostensibly to account for local topographic, hydrologic, soil, land use, and policy conditions; so too have differences in the P management recommendations that are made using the P Index. A survey of 12 P Indices from states in the southern U.S. revealed major differences in the way that Indices, even those from neighboring states, rated site vulnerability to P loss (Osmond et al., 2006). Differences in management inferences derived from those P Index ratings for the same fields, ranged from recommending no restrictions on field management (continue status quo or N-based management) to recommending the most restrictive remedial actions (no further P additions allowed).

In addition to an obvious absence of cross-border coordination in Index development, some of this disparity may be attributed to the paucity of validation efforts by individual states to fully justify their version of the P Index. Some states have pursued rigorous validation of the P Index, or at least quantitative calibration of P Index components using tools such as rainfall simulators and unit source watersheds (e.g., Delaune et al, 2004; Harmel et al., 2005; Butler et al., 2010). However, many states have not had the resources, ability, or motivation to test the alternative versions of P Indices they have promulgated. Differences in State P Index performance also point to the complex nature of critical source areas and the inherent difficulty in their identification.

The lesson of Osmond et al. (2006), coupled with a poor public understanding of P Indices and public impatience over the slow rate of water quality improvements following management changes based on P Index implementation, have culminated in a review and revision of the U.S. standard for nutrient management; the NRCS 590 Standard. In regions where P management has been highly politicized (e.g., Chesapeake Bay Watershed), there have been proposals to supplant the P Index with single, soil-based management guidelines that are easier for regulators to implement and the public to understand. These proposals force more restrictive outcomes of site assessment, essentially using site assessment to drive local export of manure to other regions, but have had little to do with risk of P loss in runoff.

Many U.S. state P Indices are currently being revised to address some of the limitations described above. In addition, there has been a movement toward developing versions of the P Index that estimate runoff P loads. A growing number of states (e.g., Iowa, Oklahoma, Wisconsin, and Texas) have unveiled tools that estimate edge-of-field or watershed level P load changes with alternative management scenarios. Such load prediction tools directly report the potential water quality outcome of management changes (e.g., kg P $ha^{-1}yr^{-1}$) and are in particular demand by agencies and end users focused on enumerating watershed management outcomes. However, critics argue that the precision of the load predictions belie the uncertainty in the estimations, and that, at a minimum, are not scalable between field and watershed.

Major advances have been made toward representing P source availability in the P Index, even identifying failings in established P routines used by most fate-and-transport models (e.g., Vadas et al., 2007). However, representation of transport processes has been more elusive. Quantifying flow, a requirement of P load estimation, requires robust models that can reconcile field, landscape and, depending upon the inference scale, watershed hydrologic processes. Thus, debate remains over the appropriateness of using P Indices to predict edge-of-field P loss.

2.3 Mitigating Erosion

Best management practices (BMPs) are primarily effective mitigation measures to control non-point sources pollutants. Decision-making processes to implement a particular set of BMPs for an agricultural, forest, and urban settings rely on their effectiveness (Gitau et al., 2005). How effective is a BMP? What are the criteria used to establish an effective BMP? Are these BMPs applicable across different landscape scales? These ongoing questions evolve the BMPs approach from simple field scale studies in the experimental stages to the natural large-scale environment to reduce the effects of non-point source pollutants (Park et al., 1994; Meals et al., 2010).

Early field studies of farm fields introduced the technology of conservation tillage. For example, Mc Dowell and McGregor (1984) demonstrated a reduction of sediment in runoff from a Mississippi farm of 92% as compared to conventional tillage. While McConnell et al. (2006) reported a reduction of 84%in field sediment loss for cotton crops when compared to that of conventional tillage for gently sloping fields (1-2 %) and a coarse textured Alfisol in the Mississippi Delta region. They estimated sediment yield to be 0.45 tonnes ha^{-1} as compared to 4 tonnes ha^{-1} on that site with just a change in tillage application.

Another option is conservation tillage; which practices further reduces sediment loss from a system compared to that from conventionally tilled systems. Meyer et al. (1999) used 16 erosion plots with a 4% slope, three crops soybeans, corns and sorghum which reduced soil loss 80% and 70% for cotton when compared to conventional till. Tillage also plays an active role in sediment reduction as seen at a watershed scale, where sediment loss from conventionally tilled soybeans with grassed waterways and buffer strips was 30 tonnes ha^{-1} compared with less than 1 tonne ha^{-1}

from no-till soybeans (Meyer et al., 1999). This change to no till increases the amount of surface residue protecting the soil surface and thereby decreasing sediment loss.

The adoption of riparian buffers is applied at a larger land scale and normally linked to stream bank erosion conservation (Willet et al., 2012; Zamine and Schultz, 2011). Willet et al. (2012) found a significant three-way interaction between factors of the season, land use, and stream order for bank erosion rates, indicating the complexities associated with stream sediments for Crooked and Otter Creek in Missouri Central Claypan areas. Therefore, the questions regarding the effectiveness of the riparian buffers and how they are implemented to maximize buffer efficiency at reducing sediment load need to be addressed. Zaimes et al. (2011) indicates that although prior knowledge of riparian buffer provides a 97% reduction in sediments (Polyakov et al., 2005), care must be taken especially in stream ecology since there are multiple processes with different interactions (Renwick et al., 2008). The holistic view of stream ecology and their pertinent interactions still remains unclear. A better understanding of system mechanisms and integrated framework needs to be developed.

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Chapter 3

Evaluation of the RUSLE 2 for Soil Loss for Temperate Humid Southeastern Pasturelands in the U.S.

3.1 Abstract

Evaluation of models used to assess soil loss in nutrient management planning is necessary to ensure accurate planning. In this study, soil loss estimates from the RUSLE2 were compared to 27 grazed field across the Southeastern U.S. Site physical characteristics and grazing management were input to RUSLE2 and assessment of soil loss estimates in relation measured field soil loss data were carried out using the Nash Sutcliffe Efficiency Index (NSE) and Index of Agreement (D). These indices evaluated the performance of the simulated soil loss to that of the measured actual soil loss from a grazed field by quantitatively measuring the difference between the actual and simulated soil loss. Overall, RUSLE2 poorly predicted soil loss for all site with a performance index of -0.164 (NSE) and 0.242 (D). Estimates of NSE and D for estimates where fields have poultry litter were -43.893 and 0.163 respectively and with no litter were -0.275 and 0.398 respectively. Clearly, RUSLE2 overestimated soil loss from pastures in this region and further evaluation of RUSLE2 component is needed. RUSLE 2 overestimation presents a crucial problem since RUSLE2 is the standardized soil loss estimator required for the development nutrient management plans in U.S. from both water quality risk assessment as well as Government cost sharing funding.

3.2 Introduction

Water quality remains a predominant issue in many parts of the southeastern U.S. where pastures and rangeland dominate land use, even with adoption of many best management practices. Research continues to focus on mitigation strategies to mitigate or reduce eutrophication of waterways via surface runoff and sediments (Edwards et al., 1996; Russell and Holly, 2014). Schindle and Nighswander (1970) identified phosphorus (P) as the limiting nutrient for eutrophication in freshwater lakes. Phosphorus enter a stream mainly in surface runoff as dissolved or sediments adsorbed forms from adjacent agricultural fields.

The P Index approach has been adopted by 47 States in the U.S. and integrated into the NRCS Nutrient Management Standard 590 (NRCS, 2012). The P Index is a more reliable tool than simply using soil test P (STP) as P Index considers transport potential, site hydrology and proximity to a stream (Lemunyon and Gilbert, 1993)

Various versions of the P Index among states are a consequence of regional differences in landform, hydrology, climate, land management and local policy needs (Sharpley et al., 2012). However, Osmond et al. (2006) and (2012) reported that there was a wide variation in P rating using different P indices in the southeastern U.S. under similar site conditions. As a result of this variability in risk assignment, NRCS identified a need for a standardized framework that address regional differences in P runoff potential. Use of the P Index in the NRCS 590 Standard demands standardized approaches for parameters used in an index. For erosion, RUSLE2 soil loss estimator, which uses regional data, but is widely accepted worldwide, was the default required (Sharpley et al., 2012). Management practices such as the P Index integrates soil loss models as transport function for phosphorus contaminated water (Sharpley et al., 2003; Sharpley et al., 2012). The reliability of soil loss estimates using RUSLE2 plays a vital role in uncertainties associated with P Index outcomes (Osmond et al., 2012).

Users of soil loss models must be aware of the model reliability and predictive accuracy associated with model estimates. Environmental managers and policy decisions rely on the accurate estimation of soil loss in order to implement conservation measures that are appropriate to any given site. Understanding and determining model uncertainty is important to the successful adoption of outcomes based on the model estimates, particularly environmental applications, which vary spatially and temporally.

Uncertainty from complex statistical analysis of Generalized Likelihood, Monte Carlo simulation and Dynamic Dimensional Search Approximation are two methods used in parameterization, but these evaluate parameter error probability distributions within the model and require a large amounts of data. Overall model performance is usually assessed by comparing estimates and measured data using goodness to fit to test model accuracy.

Performance of soil loss models involves a validation processes where soil loss predictions are compared with measured soil loss. A reductionistic principle can be used to evaluate uses to complex biophysiochemical systems that leads to an imperfect representation of the real world. Basically, the validation process conducted by comparing model estimates with observed data, assessing soil loss estimates for a particular situation, and then reporting model efficiency for a specific objective or goal (Bevan and Frazier, 2011). Zhang et al. (1996) and Risse et al. (1993) evaluated the performance of Water Erosion Prediction Project (WEPP) and RUSLE models to estimate soil loss from cropland and crops and pasture, respectively, under natural rainfall conditions. The WEPP model over-predicted soil loss from cropland compared to measured loss, where actual soil loss was low (Zhang et al., 1996). These events are usually in the range less than 2.5 Mg/ha. Similarly, RUSLE over-predicted soil loss from small plots with an area of less than 0.009 ha (Risse et al., 1993).

The Walnut Gulch Experimental Watershed (WGEW) assessment highlighted discrepancies with RUSLE soil loss estimates (Renard et al., 2008). Research is needed to improve the accuracy of RUSLE estimates of soil loss from pastures and rangeland. Later, WGEW served as an extensive database for semi-arid rangeland to address the challenges in rangelands and pasture soil loss modeling (Renard et al., 2008).

As a result of inaccurate soil loss estimates, RUSLE was modified to RUSLE2 which has an expanded database including rangeland and pasture. However, testing and validation of the use of RUSLE2 to estimate soil loss from pastures is needed. Basically, RUSLE2 was developed and optimized for moderate soil loss (8.96-67.20 Mg/ha/yr) from cropland systems of clean tilled corn (*Zea mays*), soybeans (*Glycine max*), and wheat (*Triticum aestivum*) (NRSL, 2015). Generally, pasture systems maximum soil loss is 4.48 (Mg/ha/yr) (Pimentel, 2006).

RUSLE 2 is the mandated soil loss model to use in compliance with the NRCS Nutrient Management Standard (590) Standards for U.S. water quality conservation (NRCS, 2011), and should accurately estimate soil loss variability as a function of rainfall, soil series, vegetation, and topography. This is essential for effective decision with RUSLE 2.

This paper describes research examining errors associated with RUSLE2 from various measured published soil loss from pastures fields in southeastern U.S., by quantitatively using Performance Indices, to determine whether deviation of RUSLE2 soil loss estimates to that of measured soil loss, are acceptable for these pasture fields.

3.3 Eastern U.S. Pasture

Pastures in the southeastern U.S. encompass approximately 50,000,000 ha (Franzulebbers et al., 2012). This region is divided into four distinct eco-regional areas with varied rainfall and soil regimes that reflect various grass species (Sala et al., 1988; Parton et al., 1994). In the humid-temperate zones, warm-season and cool-season forages are usually grazed or cut for hay for winter feeding in Georgia and Arkansas (Franzluebbers et al., 2012; FSA2139).

Above ground net primary production (ANPP) is a quantitative photosynthetic indicator related to precipitation and soil water holding capacity (Sala et al., 1988). RUSLE 2 uses Net Primary Production (NPP) and dead biomass to estimate the biomass generation and removal. Net Primary Production provides a more reliable estimate of vegetative growth pattern since NPP takes into consideration the rooting biomass which plays a significant role in biomass production specially for pastures. Hence, Dabney and Yoder (2012) and Dabney et al. (2014) incorporated the NPP model into the vegetative description to a particular crop within the RUSLE computing framework.

Keys factors in a pasture system are represented in Figure 3.2.1. These factors of soil, biomass and nutrients support various processes which impact each other contributing to the overall health and production of the pasture ecosystem. For example, biomass provides a protective cover for the soil thereby reducing soil loss, while the soil is the medium for mineral and water uptake to produce biomass. In turn, biomass recycles nutrients via residue as well as the surface application of manure by grazing cattle. Nutrients such as potassium (K), nitrogen (N) and phosphorus (P) are incorporated into the soil and are either lost by plant uptake or soil erosion.

This balanced dynamic and complex cycling illustrates the grassland system typical of the southeastern U.S.

RUSLE2 must describe these complex processes (Figure 3.1.1) to accurately calculate annual soil loss resulting from sheet and inter-rill runoff. The operational system of RUSLE 2 involves three major inputs: grazing pressure, fertilization application and average annual biomass, as shown in Figure 3.2.2.

The process of biomass accumulation is represented by Dabney and Yoder (2012) vegetative time dependent growth curve model in which the rate of NPP relate to time related variable of the leaf area and carbohydrate substrate. RUSLE2 operates at a time step for the vegetative growth, which is supported by an annual vegetative growth pattern database (Dabney and Yoder, 2012). The grazing season is a function of perennial biomass and current standing residue removal by cattle (Dabney et al., 2014). There are 12 methods of forage removal, for which 19 process-related parameters are used to set up these methods (Dabney et al., 2014.). The factor such as the ratio of forage to surface residue describes the fraction of forage harvest that is returned as surface residue, which corrects the under estimation of residue amount. Inaccurate representation of this ratio results in an overestimation of soil loss, particularly in grassland systems (Dabney et al., 2014).

In RUSLE2, field management folder includes operation and grazing. In the Grazing module, biomass forage rate inputs, stocking rate, and the date grazing or hay cutting operation occurred are entered. This module integrates the biomass removal to vegetation forage growth and simulates ground cover of a field for the specified conditions. RUSLE 2 assumes that an animal unit for cattle grazing remove the equivalent of 11.8 kg of forage per day (Dabney et al., 2014).

Normally, in humid-temperate regions, there are three type of grazing operations: rotational, continuous, and haying but they vary from field to field due to biomass production.

Overall, average annual biomass production is based on the physiographic region in which the field is located. Soil moisture influences the growth of tall fescue (*Festuca arundinacea*) creating a distinctive bimodal peak at October-November and April- May under an annual growth curve (FSA 2139 and Franzeubber et al., 2013) and in turn impacts the annual grazing schedule. Biomass production is also altered by nutrient amendments, which increase potential forage yield, providing additional soil cover. Predominantly in pastures, the accumulation of soil organic matter improves soil–water retention and nutrient availability, thereby increasing biomass production and ground cover (Franzluebbers and Stuedemann, 2006). Ground cover retards sheet and rill erosion; as ground cover increases, rill and interrill erosion losses decrease and approach a zero value (USDA, 2003). It is, thus, essential that ground cover is correctly represented in a grassland system, where rill and interrill erosion are major contributors to soil loss.

3.4 Materials and Methods

The MANAGE database (http://www.ars.usda.gov/Research/docs.htm?docid=11079) provided the measured soil loss from nutrient-fed field plots across the southeastern U.S. from published literature on water quality (Harmel et al., 2005; Harmel et al., 2008). However, there were specific criteria for selection of fields used this the current thesis research, where each field must have an average soil loss value, slope length, slope percent and soil type, grazing management and nutrient application on information under natural rainfall storm conditions. These fields were then simulated in RUSLE2 (2.0.4.0 version) SCIENCE template with Agricultural Research

Service (ARS) access using the FORAGE management folder. The general characteristics of these grass fields or watershed used in RUSLE2 hillslope profiles were summarized in Table 3.2.1. In Georgia, the four named hillslope profile UAN1to UAN4 were continuous grazed and then replicated as rotationally grazed since Pierson et al. (2001) reported that in their study the continuous and rotationally grazed UANs fields produced similar measured soil loss.

Grazing management for each watershed is described in Table 3.2.2 with their respective vegetation. In RUSLE2, the management tab, information about the biomass yield, stocking rate, and amount of poultry litter added for the field were entered with their respective dates. In creating the grazing files either "*grazing, continuous, set season rate*", "*grazing, set end ht, and time on*" or "*grazing/haying\Grazing, set rate time on*" were applied to the operation tab according to the site information available in cited literature referenced in Table 3.2.2. If biomass and stocking rate were not available, the RUSLE 2 FORAGE management default for that particular eco-region was used. Poultry litter amendments used in RUSLE required calculation from a wet basis to dry using the equations and guidelines given by RUSLE 2 operation ((http://fargo.nserl.purdue.edu/RUSLE2_ftp/NRCS_Base_Database/Manure%20drymatter%20calclations/RUSLE2Manure.pdf.).

3.4.1. Statistical Performance Index

Statistical Performance Index is widely used to decipher whether soil loss estimates are adequately predicted by the model. These are quantitative, pairwise comparisons of measured and predicted data. These indices only take into account the deviation from measured data and not errors associated with measured data (Harmel et al., 2010; Legates and Gabes, 1999). Harmel et al. (2010) and Zhang (1996) also used these indices in comparison analysis of models to determine which model was the best predictor of a particular system. Harmel et al. (2010) outlined commonly used performance indices which include the Nash-Sutciffe Efficiency Index (E_{NS}), Index of Agreement (d), Root Mean Square Error (RSME) and Mean Absolute Error (MAE), which are better evaluators than coefficient of determination (R^2). Table 3.3.1 shows the calculation used for these indices and their limitations.

Krause et al. (2005) iterated the objective assessments performance indices provides in determining whether the model prediction is closed to that the measured data particularly in hydrologic applications. These indices evaluate models ability to predict future and past events, help in model parameters adjustment by including observational temporal and spatial information, and compare various modelling outputs to certain criteria (Krause et al., 2005).

Normally, these indices such as the E_{NS} and d indicates the closeness of the model estimates to the measured data like sediment delivery, when the indices values approach unity as indicated in Figure 3.3.1. If the efficiency value or performance index value is 1, then model estimate perfectly matched the measured or field data (Nash and Sutcliffe, 1970; Willmott 1981; Krause et al., 2005). Any deviation from unity the perfect fit, the performance indices quantitatively indicates there is deviation of the simulated sediment delivery from the measured or field sediment delivery in these pasture treatments.

3.5 Results and Discussion

Average soil loss measured and predicted data from Southern U.S. grasslands given in Figure 3.4.1, indicate that the majority of the data are clustered between 0 to 0.1 Mg/ha. This is consistent for grassland systems, where soil loss is generally lower than from cropped soils

(Pimentel, 2006 and Renard et al., 2008). The closer the scattered data points in Figure 3.4.1 are to the projected 1:1 line, the more realistic RUSLE2 soil loss estimates are of the grassland. Major deviations from the 1:1 indicate model estimates are not simulating the grassland system correctly and misrepresenting soil loss estimates for those particular conditions. These situations are either out of the model predictability range, due to RUSLE2 boundary conditions and constraints of the numerical methods, or erroneous input data. Figure 3.4.1 identifies two such sites where there was an underestimation of RUSLE2 estimates around 0.4 and 0.8 Mg/ha for a grazing profile in Georgia.

In Figure 3.4.2 to Figure 3.4.4 in the eco-regions Georgia and Texas where there were a 1to 3 % slope, clay and silt loam soil composition with a time span of 2000 to 2010 and 1950 to 1960, showed two distinctive deviations from the 1:1 line. In these watersheds, there was no apparent major indicative factor of slope effect, textural class and time period but, a combined factorial effect contributing to the RUSLE2 soil loss deviation from measured grass field. In the earlier literature such as 1950s study, limited physical and management field information was available hence, RUSLE2 default was assumed. Also, for the 2000s period, the watershed identified as the largest deviation is from Georgia with a rotational grazing of fescue (*Festuca arundinacea*) thus rotational grazing structure ought to influence RUSLE2 but not to such excessive degree that the RUSLE2 under-predicted soil loss. Therefore, within the rotational module sub factors need to adjust to fit the grassland conditions to correct the RUSLE2 soil loss output.

In this study, RUSLE2 poorly predicted grassland conditions. Table 3.4.1 indicates that 27 rain-fed grazed field sites had NSE and D Indices below 0.5, resulting in overall poor fit between the measured and predicted values. For individual states, the NSE and D also reflect the overall fit, which was poor, although the MAE range from 0.057 to 0.199 Mg/ha and the RSME, 0.063-

0.382 Mg/ha, for individual and all states, respectively, have relatively low errors. Considering soil loss from pastures is normally less than 2Mg/ha (Harmel et al., 2008), the relatively low RSME and MAE are considerable errors within a pasture system. Oklahoma and Texas have the minimum and maximum RMSE and MAE respectively. The Oklahoma D index is the greatest among States, demonstrating that Oklahoma has the smallest errors among individual states, but has the poorest fit for measured average soil loss.

One major limitation of this study was limited measured soil loss data. It is crucial to have more monitoring sites for grassland increasing the soil loss measured datasets (Sharpley et al., 2015) for a more robust model evaluation.

For pastures with and without litter application, the NSE and D also indicated a poor fit for this study as shown in Table 3.4.2. Thus, there is a need for a better understanding and representation of the mechanism of poultry litter fate and cycling in grassland settings. For some states, there is a requirement for more litter application due to the lower organic matter available in the soil, which contributes to diverse grassland environment. Hence, the effect of poultry application on biomass accumulation for various grass species needs to be holistically identified and quantitative correlation structures developed to formulate an understanding of the grassland bio-physical relationship. A more detailed understanding of this system is necessary. Sharpley et al. (2015) pinpointed an urgent need to focus on the development of more profound nutrient cycling models especially for this system.

The grassland system is analyzed into two vegetation type, tall fescue (*Festuca arundinacea*) which is a predominantly used bunch grass cultivar, and other vegetation, which consists of local bunch grasses as substitutes for the tall fescue (*Festuca arundinacea*) cultivar. In the other vegetation system both NSE and D are worse fit than tall fescue (*Festuca arundinacea*) as seen in Table 3.4.3. This further exemplifies the need to understand local grass system especially with its low soil loss. This is also consistent with sensitivity analysis for RUSLE 2 where it is not applicable to organic soils (NSRL, 2015) as there is an accumulation of organic matter in grassland system (Six et al., 1998), which presents difficulties in estimating soil loss correctly.

In RUSLE 2, ground cover plays a controlling role in rill and inter-rill erosion, where the decay constant, b, value of 0.025, is dominantly inter-rill erosion, and, as b increases so does biomass (NSRL, 2015). Therefore, the representation of biomass accumulation is vital in calculation of the effective ground cover which affects soil loss estimates within the field. Thus, the quantitative rate of change of biomass of various grass species pattern within a pasture system and various grass growth curves under different stocking rate capacity must be studied in order to be accurately represented. Hence, further research on the effect of grazing management on biomass rate is needed for tall fescue and other bunch grasses system in these eco-regions.

Figure 3.4.5 shows that the relative percent average soil loss errors for 27 sites across the Southeastern US are mostly under-prediction within a 100% relative error range. However, for Georgia UAN2 –UAN4, the rotational grazing operation produced the maximum relative errors of soil loss estimates ranging from 275 to 450%. Although Georgia has the largest magnitude of errors from the individual site, the NSE for each states revealed Arkansas had the worst prediction of soil loss. This might be the result from incorrect input of management and site information caused by the limited data from published literature sources.

Another possible error is the percent ground cover and surface residue information is needed when simulating the grazing operation in RUSLE2. There is a demand to quantitatively define various time- related grazing operations as a function of percent ground cover and surface residue particularly in county field scale. This research highlighted the lack of grassland soil loss information, the need for grazed site monitoring, and the challenges of diverse grazing systems across Southeastern U.S. when modelling soil loss in the RUSLE2 environment.

For example, the RUSLE2 environment simulates effective ground cover and surface residue over a daily time step with the following equations, where $G = \exp(-b)$ and b effectiveness coefficient of ground covered, as the surface residue and ground cover control soil loss across a field by providing protection of soil from rainfall impact and reduces detachment of soil particles (USDA ARS, 2003). Hence, relatively low soil loss occurs in grassland due to the increase of surface residue and ground cover. For instance, Dabney (2014) compared the herbage or biomass standing daily rate calculated by RUSLE2 to that of measured Pensacola bahiagrass (*Paspalum notatum*) in the Southern Piedmont in Georgia, using various harvest removal rates. The chronological forage mass for these operations indicated that RUSLE2 estimates followed the same time-related pattern and magnitude of the biomass present in the field. A similar validation is needed for other grassland regions to justify whether the grazing operation is correctly predicting biomass production over a given time. These validation and evaluation procedures will enhance the RUSLE2's quasi- deterministic modelling environment and improve its reliability of average soil loss estimates.

In addition, the new modelling concept and design for grassland systems to address the problematic predictions particularly for range and grassland conditions. For example, Rangeland Hydrology and Erosion Model, RHEM (http://dss.tucson.ars.ag.gov/rhem/), a processed based model on rangelands includes: infiltration rates, hydrology and erosional processes. This would be beneficial as soil loss models such as USLE and RUSLE were based on empirical cropping system data and are not sensitive to the low soil loss system (Nearing ,1998). Hence the new modelling environment of RHEM is based on a mechanistic representation of soil loss flux featuring grassland hydrological and erosional parameters (ARS, 2015), which tailors soil loss to rangeland conditions. But verification of soil loss from pastures and rangeland using (RHEM) is also needed in order to adopt it into pasture nutrient management planning tool.

3.6 Conclusions

Overall NSE and D were below 0.5 thus, RUSLE2 poorly predicted soil loss across different grasslands for previously published rain-fed pasture systems. There is a greater need for monitoring of soil loss at the field scale, biomass forage rates, and site conditions to update definitions and to determine RUSLE 2 validity. Clearly, an understanding in low soil loss system in native local grassland need further development in biomass accumulation for various grazing schemes as indicated by the poor fit between RUSLE2 estimates and measured soil loss. A defined and standardized grazing structure for fields and operations are needed for states in order to implement RUSLE2 successfully especially across diverse eco-regions.

RUSLE2 unsuccessfully modelled field conditions present in the humid- temperate grassland across southern U.S. Further investigations on grazing pattern and vegetation decomposition rates for various states are needed in order to effectively use the time integrated biomass production feature within RUSLE2 computational model, to increase the accuracy of the RUSE2 soil loss estimates. Therefore, more detail information on vegetation decomposition and growth in pasture setting are necessary.

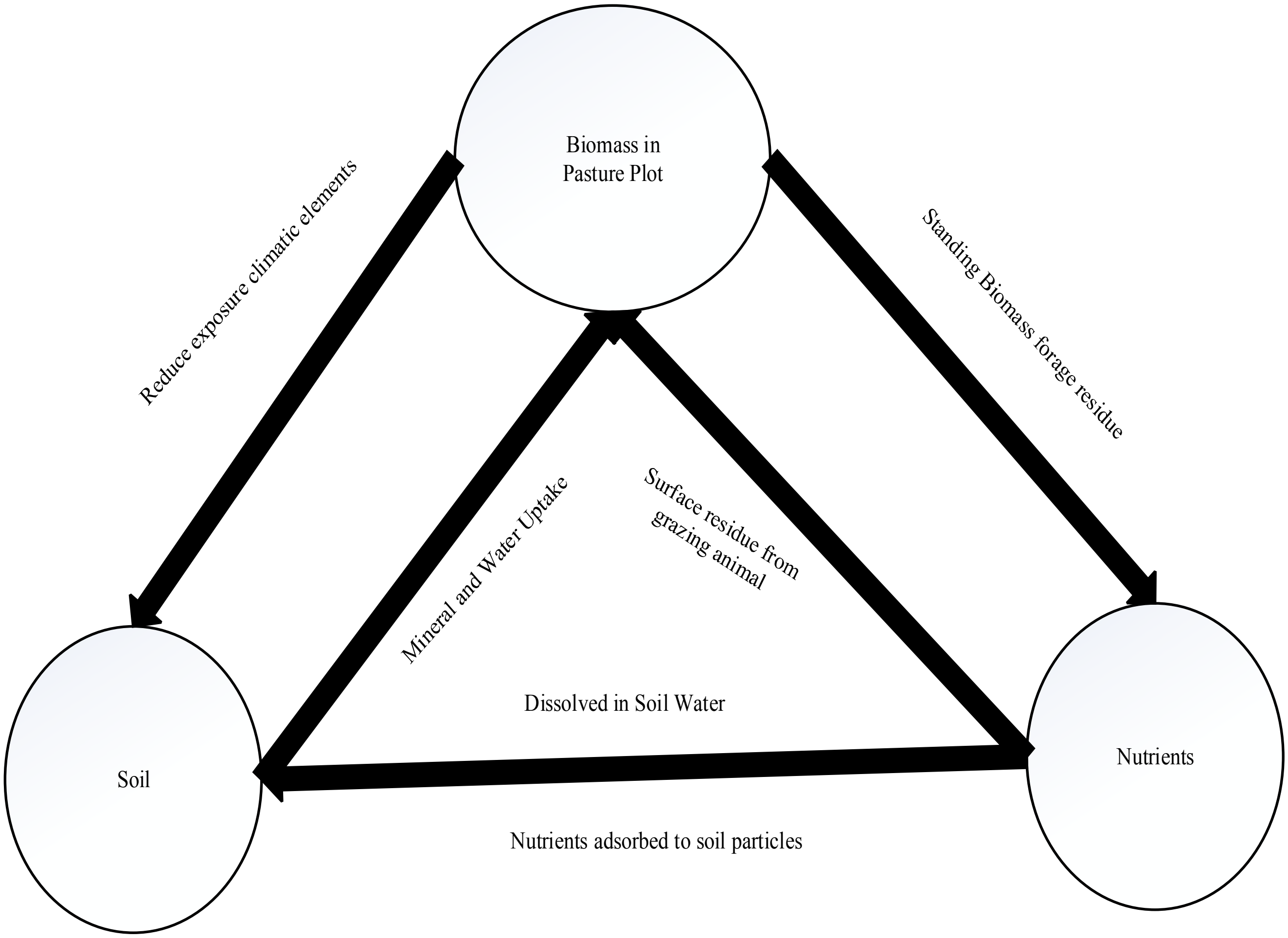

Figure 3.2.1 Cyclic conceptual path dynamics of three major components for biomass accumulation of grassland environment in Southeastern U.S.

Table 3.2.1 Watershed characteristics for hillslope profile used in RUSLE2

Watershed ID	County	Soil	Litter Application	Slope (%)	Slope Length (m)
			Texas		
			Black Prairie		
SW12	Mc Lennan	Houston Black Clay	None	1.2	110
SW17	Mc Lennan	Houston Black Clay	None	1.2	113
Y14	Mc Lennan	Houston Black Clay	Litter	2.3	109
W10	Mc Lennan	Houston Black Clay	Litter	8.0	170
			Georgia		
			South Piedmont		
UAN-1	Oconee	Cecil Sandy loam	Litter	7.0	100
UAN-2	Oconee	Altavita Sandy loam	Litter	7.0	100
UAN-3	Oconee	Helena Sandy loam	Litter	7.0	100
UAN-4	Oconee	Sedgefield Sandy loam	Litter	7.0	100
BA	Tifton	Tifton sandy loam	None	3.0	25
W1	Tifton	Esto sandy loam	Litter	1.0	67
W3	Tifton	Faceville sandy loam	Litter	3.5	67
			Oklahoma		
			Reddish Prairies Rolling Red Plains		
FR1	Canadian	Bethany Kirkland silt loam	None	3.0	196
FR2	Canadian	Bethany Kirkland silt loam	None	3.0	192
FR3	Canadian	Bethany Kirkland silt loam	None	3.0	193
FR4	Canadian	Bethany Kirkland silt loam	None	4.0	195
WW1	Woodward	Woodward and Quinlan loam	None	5.2	185
WW3	Woodward	Woodward and Quinlan loam	None	6.8	222
WW4	Woodward	Woodward and Quinlan loam	None	6.5	282
			Arkansas		
			Ozark		
RA	Washington	Johnsonburg Sandy loam	Litter	3.0	182
RA2	Washington	Captina silt loam	Litter	3.0	182
RB	Washington	Clerora sandy loam	None	2.0	188
WA	Washington	Linker Loam	Litter	4.0	257
WM	Washington	Hector Mountainburg Sandy loam	Litter	4.0	239

Table 3.2.2 Watershed Grazing Operation using MANAGE database

Watershed	Time Period	Litter Application	Average Measured Soil Loss kg/ha	Land Use	Vegetation	Source
Texas						
SW12	2000 -2003	None	60	Hay	Native prairie	Harmel et al. (2004)
SW17	2000 -2003	None	817	Grazing	Coastal bermuda	
Y14	2000 -2003	Litter	29	Hay	Kliengrass	
W10	2000 -2003	Litter	28	Grazing	Coastal bermuda	
Georgia						
UAN-1	1995-1998	Litter	21.5	Grazing	Tall fescue & bermuda grass	Pierson et al. (2001)
UAN-2	1995-1998	Litter	21.5	Grazing	Tall fescue & bermuda grass	
UAN-3	1995-1998	Litter	21.5	Grazing	Tall fescue & bermuda grass	
UAN-4	1995-1998	Litter	21.5	Grazing	Tall fescue & bermuda grass	
BA	1951-1954	None	378.3	No Grazing	Bahiagrass	Thomas et al. (1968)
W1	1994-1996	Litter	0	Hay	Tall fescue & bermuda grass	Vervoot et al. (1998)
W3	1994-1996	Litter	0	Hay		
Oklahoma						
FR1	1977-1989	None	95	Double stock/fair	Native tall grass	Smith et al. (1992)
FR2	1977-1989	None	99	Flash (heavy) poor	Native tall grass	
FR3	1977-1989	None	84	Moderate graze good	Native tall grass	
FR4	1977-1989	None	75	Moderate graze excellent	Native tall grass	
WW1	1977-1989	None	6	Moderate graze good	Native tall grass	
WW2	1977-1989	None	14	Moderate graze fair	Native tall grass	
WW3	1977-1989	None	98	Moderate graze excellent	Native tall grass	
WW4	1977-1989	None	54	Moderate graze excellent	Native tall grass	
Arkansas						
RA	1992-1994	Litter	76	Grazing	Tall fescue	Edwards et al. (1996)
RA2	1992-1994	Litter	76	Grazing	Tall fescue	
RB	1992-1994	None	30	Grazing	Tall fescue	
WB	1992-1994	Litter	68	Grazing	Tall fescue	
WM	1992-1994	Litter	117	Grazing	Tall fescue	

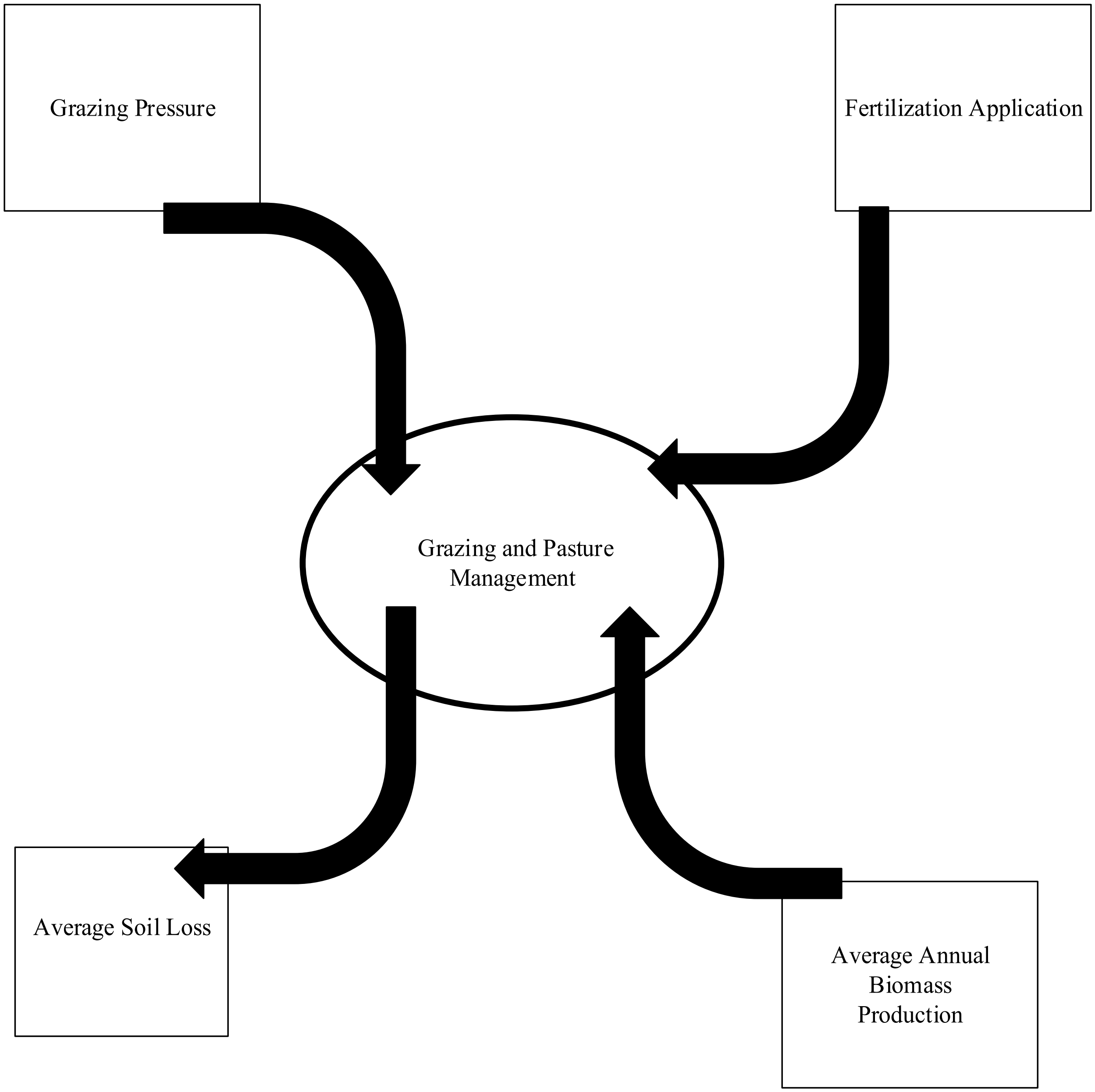

Figure 3.2.2 General schematic RUSLE2 version 2.0.4.0 simulating a Grazing Pasture Management with grassland setting inputs to compute hillslope soil loss

Table 3.3.1 Goodness to fit Indicator commonly used in hydrologic and water quality models adapted from Harmel et al. (2010).

Indicator	Mathematical Derivation	Units	Limitation
***E$_{NS}$**	$E_{NS} = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2}$	Dimensionless	Accepted and sensitive to extreme values
****d**	$d = 1 - \frac{\sum_{i}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(\lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}$	Dimensionless	Accepted and not as sensitive to extreme values as E$_{NS}$
*****RSME**	$RMSE = \sqrt{\sum_{i=1}^{N}(O_i - P_i)^2}$	For soil loss SI (Mg/ha or kg/ha)	Well accepted but sensitive to extreme values
*****MAE**	$MAE = \sum_{i=1}^{N}\lvert O_i - P_i\rvert$	For soil loss SI (Mg/ha or kg/ha)	Well accepted but not as sensitive to extreme as RMSE

* Nash and Sutcliffe (1970)

**Willmott (1981)

***Legates and McCabe (1999)

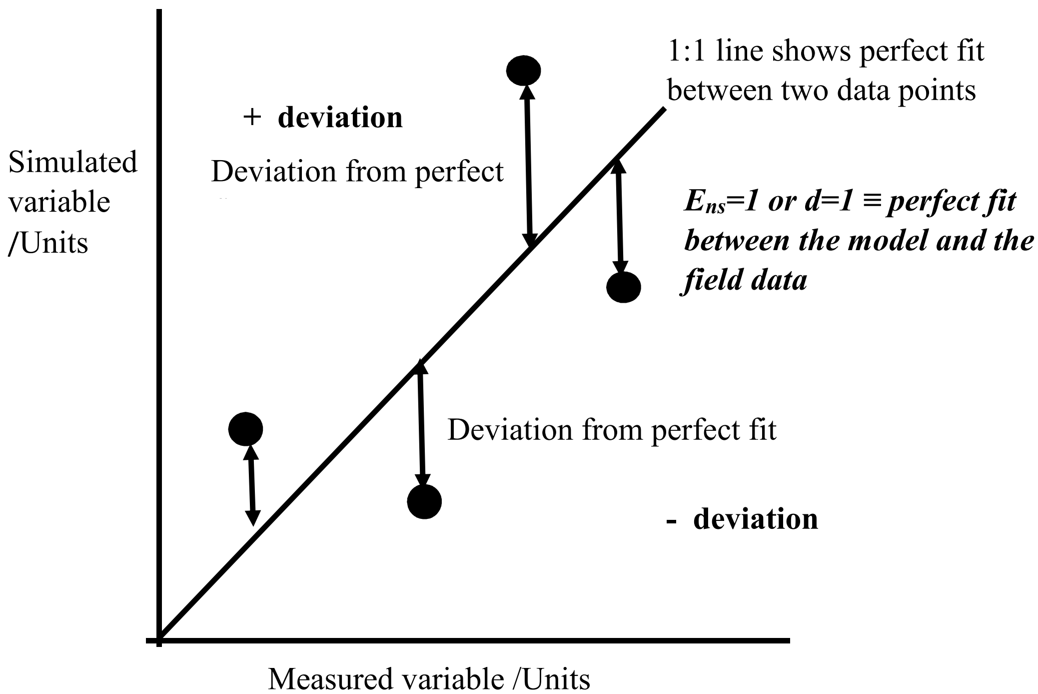

Figure 3.3.1. Graphical representation deviation of the simulated data from the measured data to indicate the model (RUSLE2) fit.

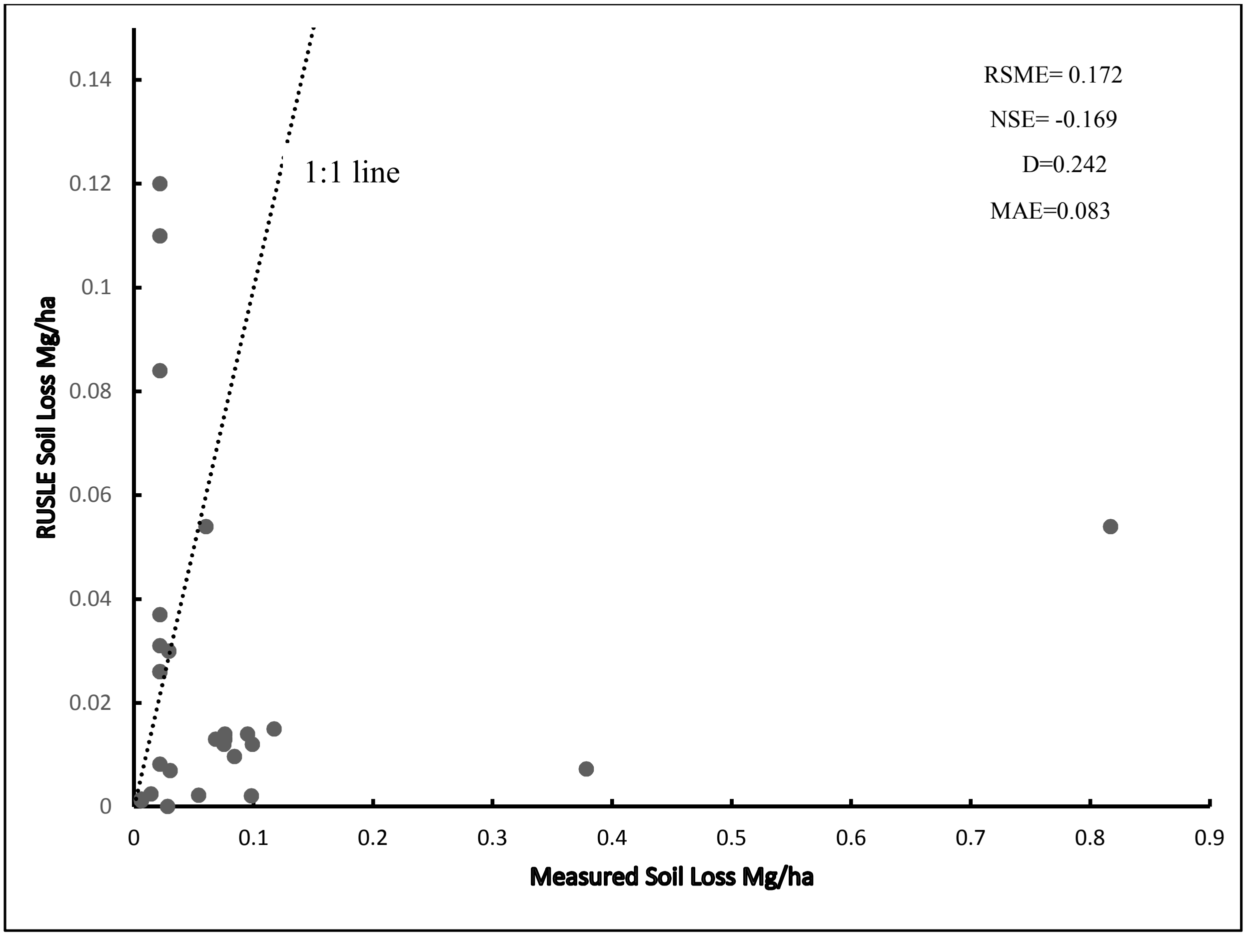

FIGURE 3.4.1 Average soil loss measured and predicted by RUSLE2 from rain-fed Southeastern U.S. grazed fields.

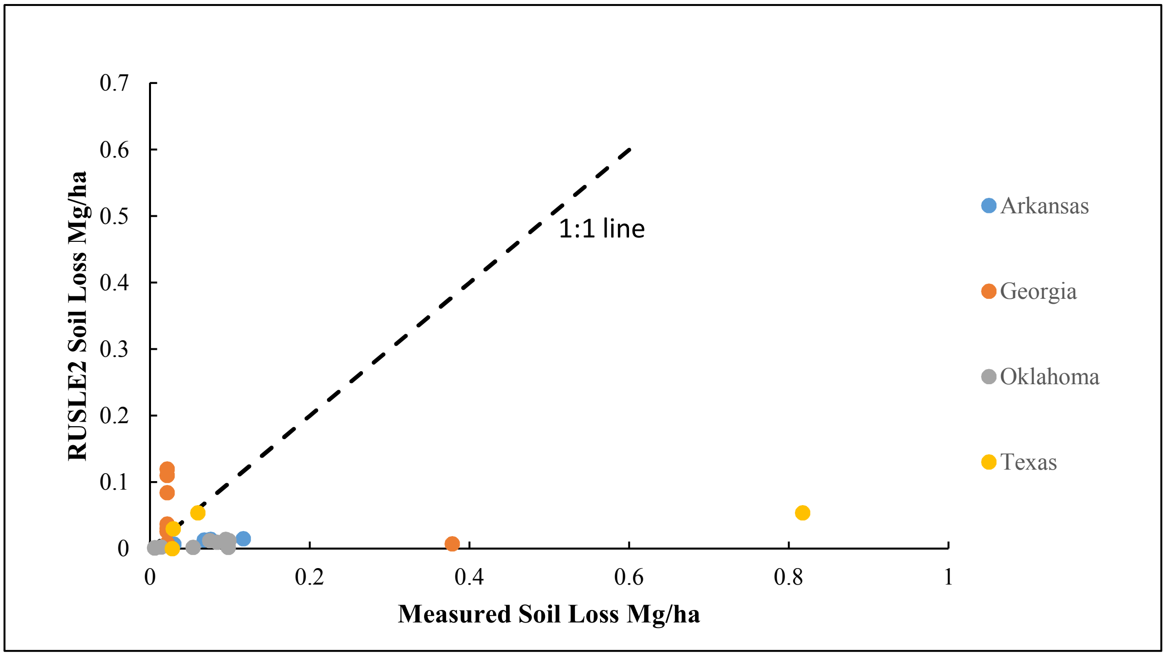

Figure 3.4.2 Average soil loss measured to RUSLE2 generated soil loss across four distinct eco-regions within each State. Arkansas- Ozark region, Georgia- South Piedmont, Oklahoma- Reddish Prairies Rolling Red Plain, and Texas-Black Prairie.

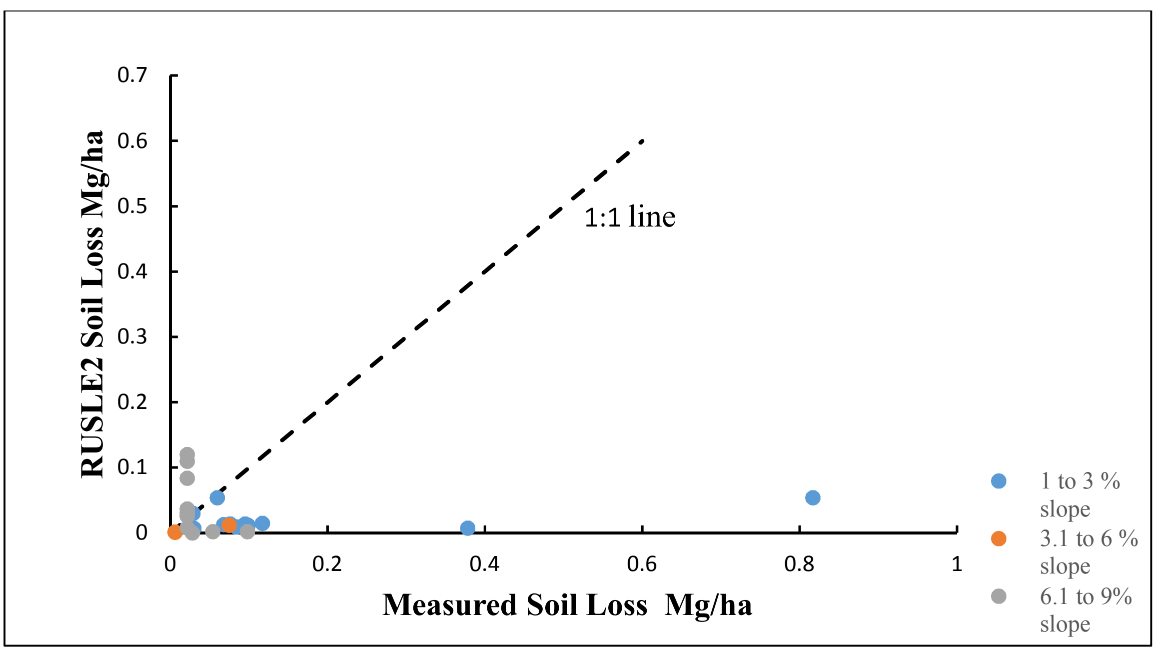

Figure 3.4.3 Comparison between the RUSLE2 and measured soil loss using three slope classes for grassland across the Southeastern U.S.

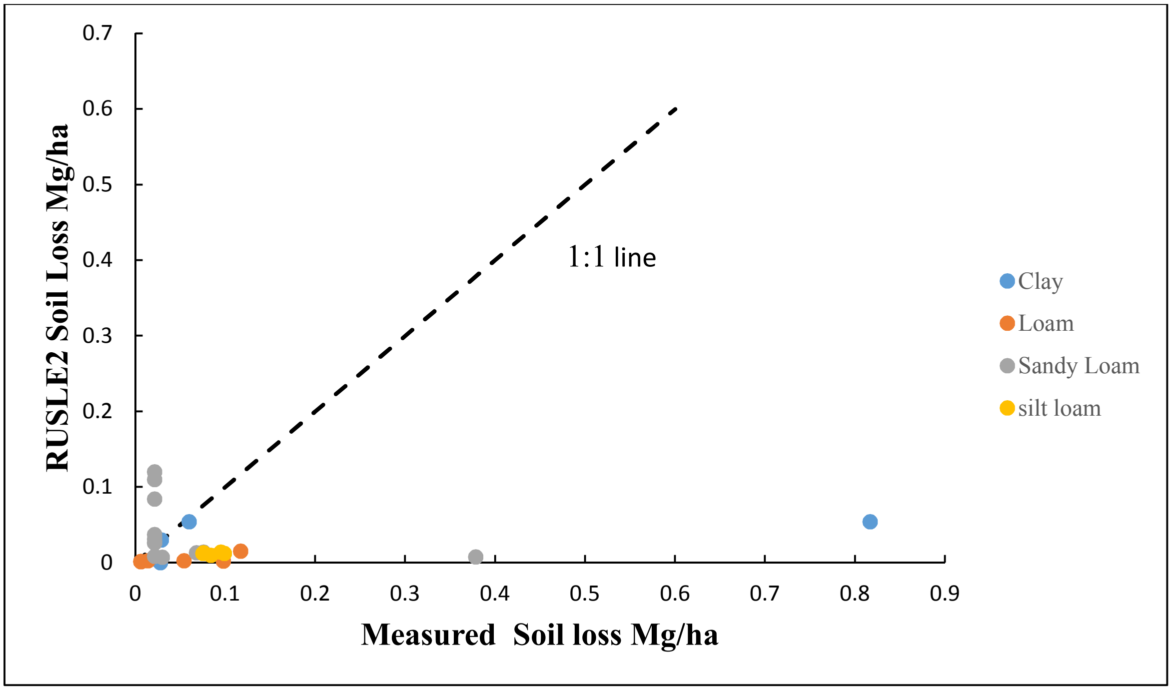

Figure 3.4.4 Comparison between the RUSLE2 and measured soil loss using four soil textural classes for grassland across the Southeastern U.S.

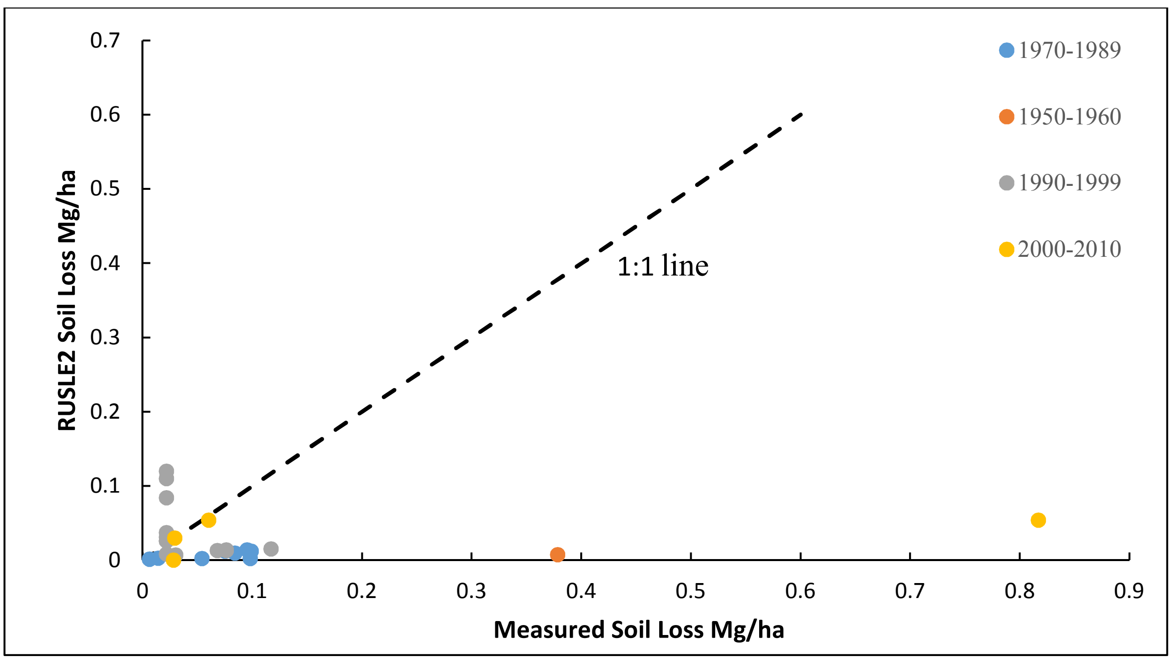

Figure 3.4.5 Comparison between the RUSLE2 and measured soil loss using four time spans across the Southeastern U.S. grassland.

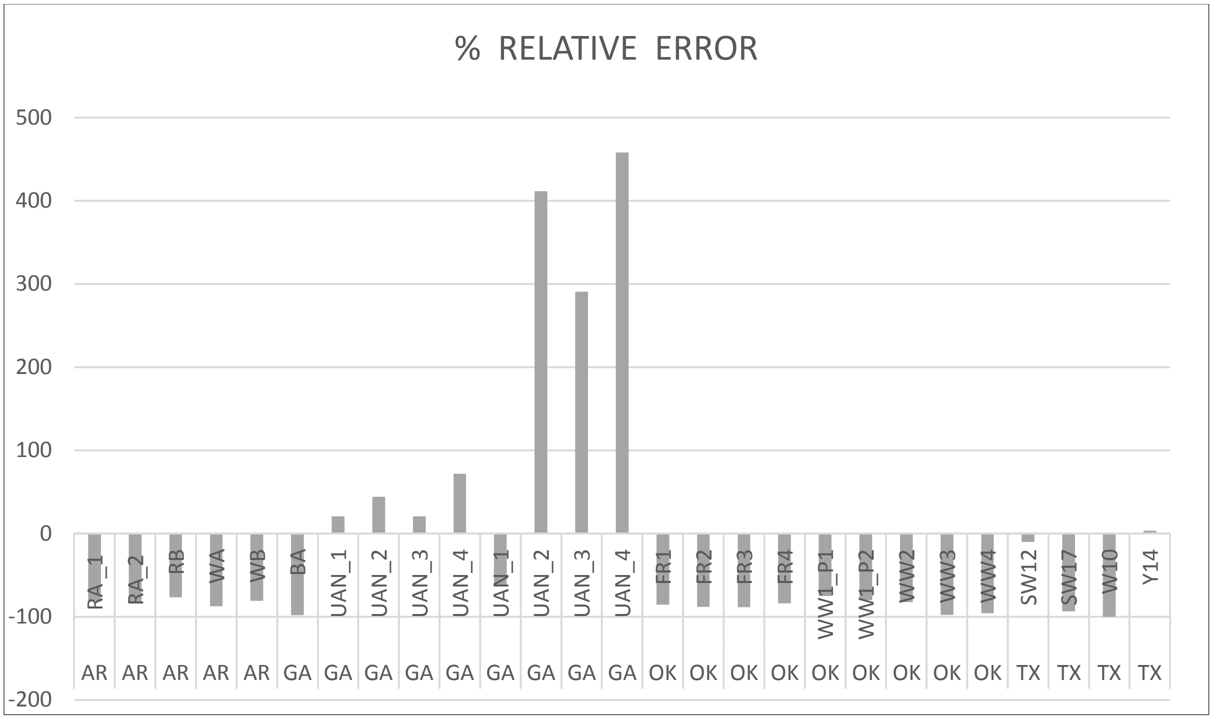

Figure 3.4.5 Relative average soil loss RUSLE2 errors for each fields runs categorized by States.

Table 3.4.1 Statistical Indictors for Fit of RUSLE2 estimates for grassland systems.

	n	*RMSE	*MAE	*NSE	*D
All State	27	0.172	0.083	-0.169	0.242
AR	6	0.066	0.061	-94.681	0.417
GA	8	0.133	0.074	-0.409	0.173
OK	9	0.063	0.057	-1.751	0.501
TX	4	0.382	0.199	-0.394	0.453

*RSME- Root Mean Square Error; MAE-Mean Absolute Error; NSE- Nash-Sutcliffe Efficiency Index; D -Index of Agreement

Table 3.4.2. Statistical Indictors for RUSLE2 soil loss estimate for litter and non-litter grassland.

	n	*RMSE	*MAE	*NSE	*D
Litter	15	0.054	0.042	-43.893	0.163
No Litter	12	0.251	0.134	-0.275	0.398

*RSME- Root Mean Square Error; MAE-Mean Absolute Error; NSE- Nash-Sutcliffe Efficiency Index; D -Index of Agreement

Table 3.4.3. Statistical Indictors for RUSLE2 soil loss estimates for different grassland vegetation .

Vegetation	n	*RMSE	*MAE	*NSE	*D
Other Grass	12	0.120	0.073	-8.125	0.377
Tall Fescue	15	0.204	0.091	-0.089	0.195

*RSME- Root Mean Square Error; *MAE-Mean Absolute Error; *NSE- Nash-Sutcliffe Efficiency Index; *D -Index of Agreement

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Chapter 4

Evaluation of RUSLE2 to estimate soil loss from Natural Rain-fed Field scale in North West Arkansas

4.1 Abstract

RUSLE2 modelling testing is a critical component of its applicability in the Phosphorus Index, as an agricultural fertilizer management measure. The reliable estimation of soil loss by RUSLE2 is crucial in capturing the runoff characteristics of the pasture fields, and thereby transporting phosphorus (P) from these fields into neighboring water bodies. This study was conducted using plots and field data from University of Arkansas Field Station and Harmon fields, respectively. Natural runoff data span from 2009 to 2012 for 3 plots, and from 2009 to 2013 for 5 fields with various manure and grazing structure. RUSLE2 input files for climate, soil, slope and crop management were compiled based on measured data. An overall of 164 storm events were evaluated using the log Nash Sutcliffe Efficiency Index with an overall value of 1.4; HW2, rotational grazing with broadcast manure field was the best field prediction (NSE=1.09) while, HE1, hayed manured injected field, was the worst field prediction (NSE=1.98). Temporal sediment delivery runoff characteristics were investigated via monthly comparison of sediment events recorded and simulated from RUSLE2 for the various haying and grazing field operations at Harmon. Generally, the RUSLE2 over predicted the number of sediment delivery events but recorded majority of the measured sediment delivery events. RUSLE2 sediment delivery predicts reasonably for grassland conditions, but a lower threshold limit should be investigated to increase the reliability of RUSLE2 estimate and to more accurately simulate temporal sediment delivery pattern.

4.2 Introduction

Sharpley (2012) identified the demand to standardize the federal Nutrient Management Farm Program particularly in Farm Program, hence the redevelopment of the NRCS 590 Standard. RUSLE 2 was chosen as the soil loss model, due to extensive database, usability and over 80 years of erosion technology in the U.S. In northwest Arkansas, conflicts over water quality degradation from over-fertilized manure pasture fields, and elevated Phosphorus (P) in streams are presently source of interest. P Index, a P management tool for agricultural system, was used to determine environmentally sound rates of manure application, but in Oklahoma and Arkansas reported difference between both state P Indices on the application of manure in the Eucha-Spavinaw Watershed henceforth, a Eucha-Spavinaw Index was developed (DeLaune et al., 2006). Clearly, there is a need for consistency in the P Index to regulate manure application to fields especially for watershed and fields around and within State boundaries. Thus, a standardized the P Index involves implementing RUSLE2 as transport calculation for runoff and soil loss within a field plot scale is necessary.

RUSLE 2 is a computational engine which interface with an extensive database and RUSLE 2 Science. RUSLE2 Science is second generation erosion technology of RUSLE for hillslope overland flow (USDA, 2003). RUSLE 2 is limited to only sheet, rill and inter rill soil loss (USDA, 2003). This model defines the sediments transport along a hillslope profile into segments as:

$$g_{out} = g_{in} + \Delta x\, D \quad Equation\ 1\ (USDA, 2003)$$

Where–g_{out} is the lower end of segment of the slope

– g_{in} sediment load entering the upper segment of the slope

– Δx length of the segment

– D detachment.

Equation 1 follows the conservation of mass for each segment within the hillslope until deposition, which occurs in RUSLE 2 environment when sediment load exceeds transport capacity as indicated in Equation 2 (USDA, 2003).

$$T_c = K_T\ q\ s \quad Equation\ 2\ (USDA, 2003)$$

Where: $T_c - T$ransport capacity

$K_T -$ Transport coefficient

$q -$ overland runoff

$s -$ sine of the slope angle in degree

The transport coefficient takes into consideration the shear stress applied by runoff whereby the coefficient is a function of Manning's n. It is noted as hydraulic coefficient of roughness (Manning's n) is governed in RUSLE 2 by standing live and dead vegetation, ground cover and surface roughness (USDA, 2003). Unlike USLE, where cover management is independent of slope length, RUSLE2 cover management impacts on slope length since soil cover interacts with slope length, and provide retardation force on rill and inter-rill erosion. This correlation between cover management and slope is particularly important in biomass systems such as pastures (USDA, 2003). It is noted that for each segment within the hillslope the transport capacity (T_c) is a differential to the length of the segment (USDA, 2003) which gives the model a spatial attribute of soil loss along a hillslope.

Overland flow, q, is a function of sheer stress and is defined as Equation 3 for RUSLE2 modelling environment.

$$q = q_{i-1} + \sigma(x - x_{i-1}) \; Equation\ 3\ (USDA, 2003)$$

Where q- runoff rate (volume per time interval)
$\sigma -$ excess rainfall (rainfall greater than infiltration rate)
$q_{i-1} -$ previous segment discharge rate

Overland flow, q, integrates the model with the temporal aspect of soil loss along the slope. It considers the dynamics of antecedent soil moisture plays in runoff within the RUSLE2 framework. Hence, the factor of K_T and q variable address the complexities of spatio-temporal variation associated with soil loss.

The soil loss in RUSLE 2 is a daily time step calculation for each segment, in which each segment represents a discontinuity in the hillslope profile, be it change in soil, change in crop management or change in topographic relief. The daily time step is new approach of calculating soil loss from using the same mathematical construct as average annual soil loss developed by Wischemier and Smith (1978). Hence using a finer temporal scale for soil loss would better capture sediment delivery since sediment delivery studies usually in the order of time scale: daily, hourly and every minute (Efta and James, 2014; Wagenbrenner and Robichaud, 2014; Morgan et al., 2013). Foster et al. (2003) attributed the overestimation of soil loss by 20% when compared to its predecessor RUSLE is due to the daily step algorithm than the average annual soil loss. Also, for the pasture system Dabney et al (2006) recognized the problem of overestimation of soil loss with RUSLE2 and sort to correct the overestimation problem by introduction of a new vegetative descriptions and operations for pasture systems (Dabney et al., 2014). However, there is no validation of a field and plot scale under natural storm event analysis for pastures in northwest Arkansas or whether the sediments delivery given by RUSLE2 is a realistic interpretation.

This paper aims to validate storm event based on plot and field conditions in norhtwest Arkansas using the available measured sediment delivery to that of RUSLE 2 values. For RUSLE 2 to be a successful P transport based model for conservation measures like P Index, it must meet the following requirements: (1) follows the temporal pattern of sediment delivery of the measured results (2) RUSLE2 sediment delivery coefficient of variation is similar to that measured sediment delivery coefficient of variation and (3) within reasonable prediction or acceptable goodness to fit test range.

4.2 Modelling storm event in RUSLE 2

Across the U.S., monthly precipitation and erosivity climatic data are readily available and recorded. To generate the runoff sequence within RUSLE2 environment, Dabney et al. (2011) developed a runoff driven based approach which disintegrates the monthly climatic factors into daily sequence using the concepts of Curve Number (CN) and Storage Index (S) where:

$$S = \frac{25400 - 254\ \mathrm{CN}}{CN}\ Equation\ 4\ (ASCE, 2009)$$

S =Storage Index in mm and

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}\ Equation\ 5(ASCE, 2009)$$

Q- Runoff (mm)

P-Precipitation (mm).

RUSLE2 internally calculates the daily CN for a given soil, climate, and management, which varies with daily changes in soil biomass, soil consolidation, soil roughness, and soil residue cover, which affects infiltration. It is noted that in this approach is modelled for long term average events since CN does not necessarily vary with storm rainfall intensity (Dabney et al., 2011). The RUSLE2 is a long term soil loss model estimator such that the CN approach should be adequate. The RUSLE2 predicts long term average of soil loss in a year, or rotation cycle, and uses a vast empirical database to generate gamma distribution shape and location parameters for its erosivity factor in various climatic regions mapped across the U.S. These are downloaded from http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm and integrated into RUSLE2 database.

The daily erosivity is a representation of a weighted value of a day step of a storm events that accrued from 10 years, 24- hours' precipitation. Hence this weighted value is a ratio known as Erosivity Density Multiplier (edm_{ev}) and is represented in the erosivity calculation as:

$$EI_{30ev} = P_{ev}E_{ev}edm_{ev} \; Equation\ 6\ (Kinnell, 2014)$$

P_{ev} factor is added into the calculation to account for rainfall between erosivity events that does not contribute to base event erosivity but, contribute to runoff (Kinnell, 2014; Dabney et al., 2010). This improvement captures runoff and sediment delivery under hillslope profile setting, and is a benefit for conservation planning.

RUSLE2 version 2.5.7.7. ARS Science Access gives the option to add in real- time rainfall intensity and erosivity data from a particular site. Figure 3.2.1 showed the process in which the data was transformed and entered within the RUSLE2 computing environment. Rainfall gauged data must be pre-processed into precipitation depth, erosivity, duration and maximum 30-

minutes intensity for each storm event. A storm event is defined as a rainfall event such that there is no rainfall 6 hours prior and 6 hours after the rain event. Kinetic energy for each storm event calculated using the Mc Gregor et al. (1995) equation:

$$E = 0.29[1 - 0.72 \exp(-0.08\, I)\ \mathit{Equation}\ 7\ (\mathit{Mc\ Gregor\ et\ al.}, 1995)$$

Where

E- Kinetic energy
I –Intensity of the storm event

Also, the maximum 30- minutes intensity (I_{30}) event was obtained and multiplied by the kinetic energy of each storm event to give the respective based erosivity value for a storm event. Field data and soil loss plot rainfall intensity data was obtained from the period of 2008-2013 within 0.5 measured second interval and 2009-2012 increments of 30 minute respectively.

4.3 Materials and Methods

4.3.1 Site Characteristics and RUSLE2 Modelling Scenario

For this study, the general field characteristics is described in Table 4.2.1 in which the operations are outlined in Table 4.2.2. These fields are located in Washington County Arkansas, US (36º 04′ N, 94º 16′ W). The general operation is cattle grazing on tall fescue (*Festuca arundinacaea*) with varied poultry litter amendments in Captina silt loam soils. These monitored fields runoff samples were collected and recorded using surface water sampler from the period 2009-2013. There was recorded 172 storm events during the period of May 2008-December 2013, further information is provided in Appendices.

For the runoff plot study, the characteristics are described in Table 4.3.1. The period of the study lies from 2009-2012. Total storm events collected from the weather station at the plot site was eight but 4 of these storm events the rainfall depth was too low to calculate the erosivity such that these were eliminated in the storm analysis. From the period 2009-2012, there is a noted low rainfall intensity and averaging annual precipitation of 1130mm with the lowest annual rainfall of 813.6 mm in the year 2012.

Each storm event is correlated to a sediment yield and a runoff event. RUSLE2 estimates were compared to the measured sediment yield for both spatial scale of field and runoff plot. A modified NSE for event soil loss was used since the residuals are logarithmically distributed (Kinnell, 2014; Kinnel and Risse, 1998). The calculation for the effectiveness of the RUSLE2 model estimates for event runoff situations follows equation 8.

$$Z = 1 - \frac{\sum_{e=1}^{N}(ln y_o - ln y_c)^2}{\sum_{e=1}^{N}(ln y_o - ln y_m)^2} \quad Equation\ 8\ (Kinnell, 2014)$$

Where: y_o – observed sediment loss

y_c – RUSLE2 sediment loss

y_m- the mean of the observed sediment loss

N - numbers of events

4.4 Results and Discussion

4.4.1 Plot Analysis

Table 4.4.1 shows that there was 8 storm event for the plot data from RUSLE2 output during the period of 2009-2013. From the rain gauged data, only 1.59% were recorded rainfall intensity with a maximum of 62.2 mm/hr.; therefore, storm events are few and sediment delivery would less likely occur under these conditions. RUSLE2 predicted that the annual soil loss increased across these plots as shown in Table 4.4.1, as the rate of manure application increases.

4.4.2 Field Analysis

Table 4.4.2.1 indicates that RUSLE2 over-predicted the number of storm events that lead to runoff. Normally, the number of storm events in these fields lie within 20-30 range during the period 2009-2013. Noticeably in 2012, across all field there was a decrease in measured runoff events in which HE2 there was no recorded runoff. In generating the storm sequence, all storms were included, normally there is a limit of 78.2 mm hr^{-1} intensity used for erosivity calculation in the U.S. (Wischemier and Smith, 1978) and is updated throughout varying climatic regime in the U.S. by McGregor et al. (1995) and Brown and Foster (1987). Runoff is a complex process, which depends on prior field conditions such as antecedent soil moisture affecting infiltration rates hence, the field–field variability is inherent to the variability of field-infiltration related factors. Not all storm events produced a runoff event, as demonstrated in the number of measured runoff events from the field to number of storm events. This potentially leads to an overestimation of soil loss and sediment delivery since these storm events sequence is modelled to produce a runoff sequence. Therefore, a lower rainfall intensity threshold should be established that eliminates rainfalls that do not result in soil displacement or runoff when calculating base erosivity values for a given storm event. This threshold should be co-related to a particular rainfall- runoff regime and requires at least 10- years of rainfall and runoff to gain a better understanding of storm pattern and to produce a more realistic representation of eco-climatic area runoff.

For 2012, there was a lower number of rainfall days with a total an annual rainfall of 784.6 mm. however, there were 19 generated storm events for 2012, which is similar to the number of storm events when compared to the other years (Table 3). The incorrect number of storm events is attributed to the fact Rainfall Intensity Summarization Tool (RIST) program generated 24 erosivity values for 2012 (see Appendices), resulting in an unrealistic representation of storm events sequence., For the other years, such as 2011 which has the highest number of measured runoff events has 30 storm events. In 2012, an extreme year, re-emphasized the need for a threshold to eliminate storm events that does not produce a measured field runoff event especially for extreme analysis evaluation. The number of storm events inducing runoff events can be improved by establishing a lower threshold that corresponds to analysis for measured storm event generation runoff to a particular eco-climatic region.

However, most of the runoff storm events were predicted in RUSLE 2 with a hit rate ranging from 0.95 to 1.0 is expected since the user entered rainfall intensity data are from in situ rain gauge. Since, RUSLE2 used the same rainfall data it is expected that RUSLE2 usually predicted within ± a day or, 2 days. Table 4.4.2.1 indicates that field HE2 has highest prediction for the same day event to measured runoff ratio, highlighting the soil manure treatment and grazing structure impact on same day storm prediction despite the rainfall pattern being the same among fields regarding event date runoff sequence.

Most of the RUSLE2 generated storm runoff events have a lag of one day after the measured runoff events for all fields. The lag can be explained that the measured storm runoff event was collected on the following day. Fields HE3, HW1, HW2 and HW3 are broadcast litter operations and RUSLE2 runoff event have a day lead when compared to the measured counterpart. Hence, a possible explanation for the day lead in these fields can be explained by the soil moisture conditions of the soil moisture content and its interaction with poultry litter, but further investigation on RUSLE 2 runoff and poultry litter is needed to ascertain whether there is a significant lead day in RUSLE2 simulation for runoff events. Gilley and Risse (2000) found that runoff was reduced from 2 to 62 % for manured fields in North Eastern US region supporting reduction of runoff and possible delay in the day for the storm event.

4.4.2.1 Temporal pattern of sediment delivery

Figures 4.4.2.1.1 to 4.4.2.1.7 show the monthly comparison variation of RUSLE2 modelled and measured sediment delivery annually for each field. Generally, RUSLE2 captured the peak monthly runoff as seen from these figures, suggesting that RUSLE2 represents the monthly variation of runoff. This is critical since monthly temporal variation in runoff is considered in the design of water quality management tools such as P Index (Sharpley et al., 2003). A realistic representation of monthly variation is necessary to effectively implement conservation measures and the timing of these measures.

As expected the field HE1 for 2011 yielded the largest sediment delivery for both RUSLE2 and measured sediment delivery since there are more storm events occurred during 2011 as compared to the others years in this study. There is a general trend where RUSLE2 sediment delivery is numerically larger than that of the measured years' data. But for the year 2011 the primary peak was lower in RUSLE2 estimate than the measured sediment delivery in April.

HE2 measured sediment delivery ranged from 0-0.2 Mg/ha, indicating that the treatment hayed with injection of poultry litter has reduced sediment delivery in runoff. For the monthly distribution of sediment delivery runoff events were less compared to RUSLE2, as seen in Figure 4.4.2.1.2. Hence, for this reason explains why there is an overestimation of soil loss since there are higher sediment delivery monthly values in RUSLE2 than in the measured monthly sediment delivery.

In 2011, HE3 has the most measured monthly runoff event, with a noticeable peak in RUSLE2 simulated event in September but was not present in the September measured runoff. This trend is emphasized further in 2009, 2010, 2012 and 2013; where there is only 2 measured events but RUSLE2 at least have 11of these events. This trend of more runoff events in RUSLE2 simulations seen in Figure 4.4.2.1.3 and is also reflected in Figure 4.4.2.1.4, site HE4. This overestimation of storm events was previously explained the need for a lower threshold limit to give a reasonable representation of runoff events from these field.

As previously seen from the other sites HE1to HE4, HW2 to HW3 followed the general pattern as demonstrated in Figure 3.4.2.1.6 to 3.4.2.1.7, where there is an overestimation of monthly runoff events. Nevertheless, HW reported underestimated for RUSLE2 sediment delivery in October 2009 and then in April 2012 (Figure 4.4.2.1.5). Similarly, only HE 1 reported an underestimation of RUSLE sediment delivery in April 2011.

4.4.2.2 Goodness to fit test and Consistency

Figures 4.4.2.2.1 and 4.4.2.2.2 show NSE ranging from 1.22 to 1.979 for Harmon fields. Overall, NSE for all fields is 1.4 indicating a good performance of RUSLE2 event sediment runoff prediction together with the consistent scatter around the 1:1-line seen in Figure 4.4.2.2.1 and Figure 4.4.2.2.2. The closer the scatter to the 1:1 line, less variation in the RUSLE2 simulations to the measured event sediment delivery runoff thus, the closer the NSE value is to 1 as seen in Figure 4.4.2.2.1 and Figure 4.4.2.2.2. The ascending order of NSE values for the predictions for the fields are HE1, HE2, HE3, HW3, HE4, HW1 and HW2. The grazing and poultry litter operations have the best predictions for event runoff, while injected manured hayed operations had the worst predictions. RUSLE2 predicts flash grazing better than continuous grazing, and continuous better than non- (grazing and manured) field for event sediment delivery for northwest Arkansas grazing fields. Thus, with the cattle-grazing fields, where these are the normal conditions, RUSLE2 prediction for sediment delivery runoff is acceptable when site rainfall data is used.

The representation of the variability in the measured event sediment runoff should be reflected in the RUSLE2 simulations. Table 4.4.2.1 showed the tendency to realistically represent field variation; where HE 2 has coefficient of variation ratio of 1.1625 indicating similar variability in RUSLE2 as in the measured sediment runoff. Whilst in a natural fescue (*Festuca arundinacea*) field plot, HE4, the coefficient of variation ratio of 102.5 indicates a poor RUSLE2 variability representation. For HE4, RUSLE2 showed higher variability, when in fact the field is more stable as seen in measured field data. Normally, an increase in the coefficient of variation indicates that there is more variation in sediment runoff event from the average sediment runoff and thus, the field is less stable to the mean sediment runoff and possibility of extreme sediment runoff events are occurring.

4.5 Conclusion

RUSLE2 generally predicted within the acceptable range for runoff sediment events using user-entered rainfall dataset. For the northwest Arkansas cattle-grazing operation, realistic model performance on an event-based sediment delivery, is critical identifying, assessing, and implementing effective conservation measures. From this study, the monthly variation of event sediment delivery indicates that most of the sediment delivery around April and August-

September which was well- represented in RUSLE2. However, RUSLE2 overestimated sediment runoff events in turn caused overestimation in sediments runoff events in monthly temporal distribution where no event actually occurred. A proposed lower threshold rainfall-runoff limit should be implement to correct overestimation of sediment runoff events in RUSLE2, and further research is needed to determine the value of this threshold.

Field variability indicated HE2 is closer to actual field variability while, HE4 indicated 102 times the variability obtained from measured sediment runoff. Hence, in HE4 RUSLE2 is predicting a less stable grassland than it actually present. This could lead to potential problems in assessing the non-grazed and non- litter grassland, since these variabilities are essential in the understanding of sediment delivery to a particular management setting. Care should be taken in extrapolating these findings since the period of this study is 5 years starting in 2009. Therefore, a more comprehensive assessment of the climatic runoff sediments yields a better understanding of long-term management impacts on sediment delivery runoff event thus gives better land management decisions.

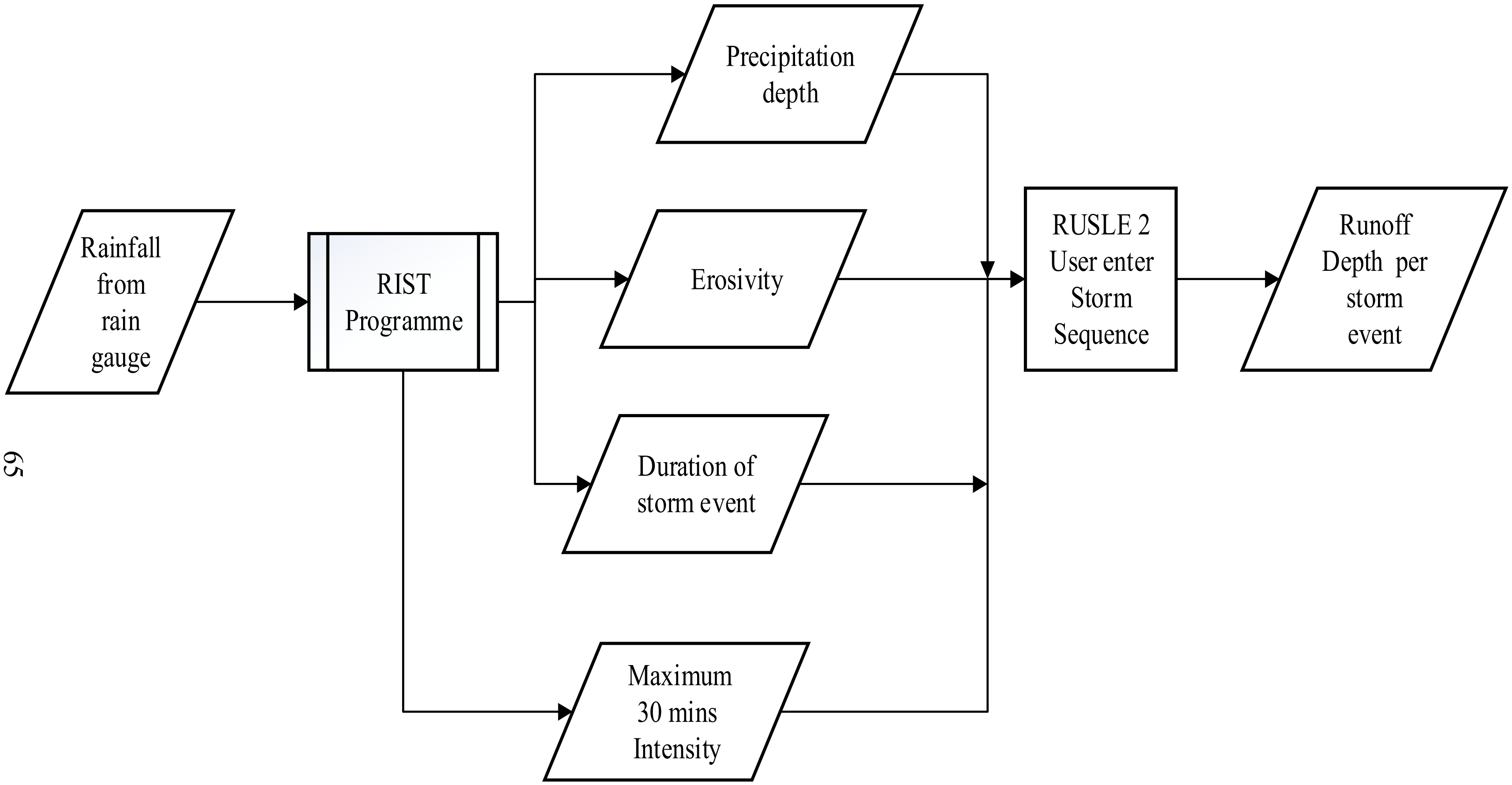

Figure 4.2.1. The flowchart representation of the RUSLE2 data entry to produce user specified runoff sequence using measured rain gauged data from a particular site.

Table 4.2.1 General characteristics of the field study at North West Arkansas.

Watershed ID	Length (m)	Slope (%)	Grazing	Area/ha
HW1	105	2.6	Continuous	0.4
HW2	105	2.3	Rotational	0.4
HW3	105	2.4	Hay	0.4
HE4	105	2.8	None	0.4

HE1, HE2, HE3 has the same length and slope characteristics for field HW1, HW2 and HW3 respectively but all HEs are hayed fields. All Soil are the Captina Silt Loam

Table 4.2.2 The Litter and Biomass Input into RUSLE2 Management Database hillslope profile.

Watershed ID	Litter Application (ton/ac)	RUSLE2 Litter (ton/ac)	Stocking Rate AUM	Biomass Forage Removal	Area/ha
HW1	1.5	0.1125	6	0.9716	0.4
HW2	1.5	0.1125	1.5	0.7287	0.4
HW3	1.5	0.1125	-	-	0.4
HE4	-	-	-	-	0.4
HE1	1.2	0.09	-	-	0.4
HE2	2.4	0.18	-	-	0.4
HE3	1.2	0.09	-	-	0.4

Table 4.2.3 General characteristics of field plot at North West Arkansas, Washington County

Field Plot ID	Length (m)	Slope (%)	Poultry litter	Vegetation
B1	6.09	5	11.2	Tall Fescue
B2	6.09	5	5.6	Tall Fescue
B3	6.09	5	0	Tall Fescue

Table 4.4.1.1 RUSLE2 Soil Loss characteristics for manured treated plot at North West Arkansas, Washington County.

Field Plot	N	Soil Loss Mg/ha/yr				Rainfall mm
		2009	2010	2011	2012	
B1	12 (8)	0.0052	0.0052	0.0052	0.0052	1400
B2	12 (8)	0.0021	0.0021	0.0021	0.0021	1400
B3	12(8)	0.0018	0.0017	0.0017	0.0017	1400

N- total no of storm events recorded from 2009-2012, (8) recorded rainfall storm events to produce base erosivity.

Table 4.4.2.1 Measured and RUSLE 2 runoff characteristics for field study in North West Arkansas.

Field	# of measured runoff event	No. of RUSLE generated runoff event	Hit rate	False negative rate	# of Runoff events predicted on the same day	Lead Predicted runoff event			Lag predicted runoff event		
						1 Day	2 days	>2 days	1 Day	2 Days	>2days
HE1	19	168	1.0	0.43	11			1	5	1	1
HE2	23	168	0.96	0.42	16				6		
HE3	20	168	1.0	0.42	12	1		1	5	1	
HE4	28	168	0.95	0.41	16				10	1	
HW1	31	168	0.97	0.41	20	1			8	1	
HW2	22	168	0.96	0.42	15	1			6	1	
HW3	34	168	0.97	0.41	23	1			9		

HW1 -Continuous grazing at 1.5 ton/ac litter, HW2-Rotational grazing at 1.5 ton/ac litter, HW3- hay at 1.5 ton/ac litter. HEs are all hayed fields with HE1 and HE3 – 1.2 ton/ ac, HE2 – 2.4 ton/ac and HE4- no litter application rates

Table 4.4.2.2 Comparison of Annual Distribution of Runoff Events from RUSLE2 and Measured Field Data for Various Grazing and Litter Treatment

Field	# of Measured Runoff Events					# of RUSLE2 Runoff Event				
	2009	**2010**	**2011**	**2012**	**2013**	**2009**	**2010**	**2011**	**2012**	**2013**
HE1	3	2	9	1	4	32	28	32	25	27
HE2	7	5	7	0	5	32	28	32	25	27
HE3	2	2	8	2	6	32	28	32	25	27
HE4	7	5	9	2	5	32	28	32	25	27
HW1	12	5	7	3	5	32	28	32	25	27
HW2	8	5	8	2	2	32	28	32	25	27
HW3	15	4	8	2	6	32	28	32	25	27

HW1 -Continuous grazing at 1.5 ton/ac litter, HW2-Rotational grazing at 1.5 ton/ac litter, HW3- hay at 1.5 ton/ac litter. HEs are all hayed fields with HE1 and HE3 – 1.2 ton/ ac, HE2 – 2.4 ton/ac and HE4- no litter application rates.

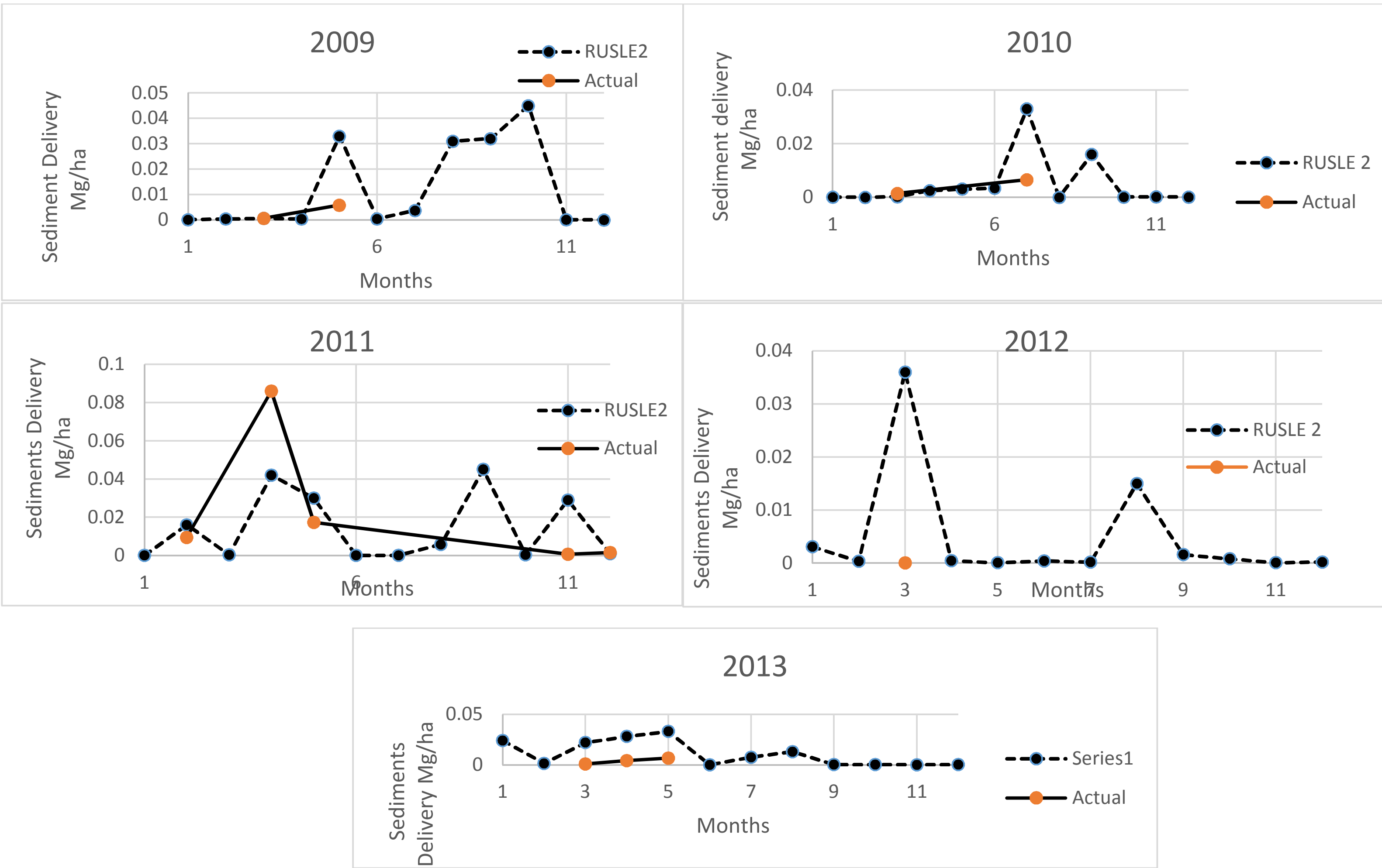

Figure 4.4.2.1.1 Comparison of the temporal variation of RUSLE 2 and Measured Sediment Delivery for Site HE1

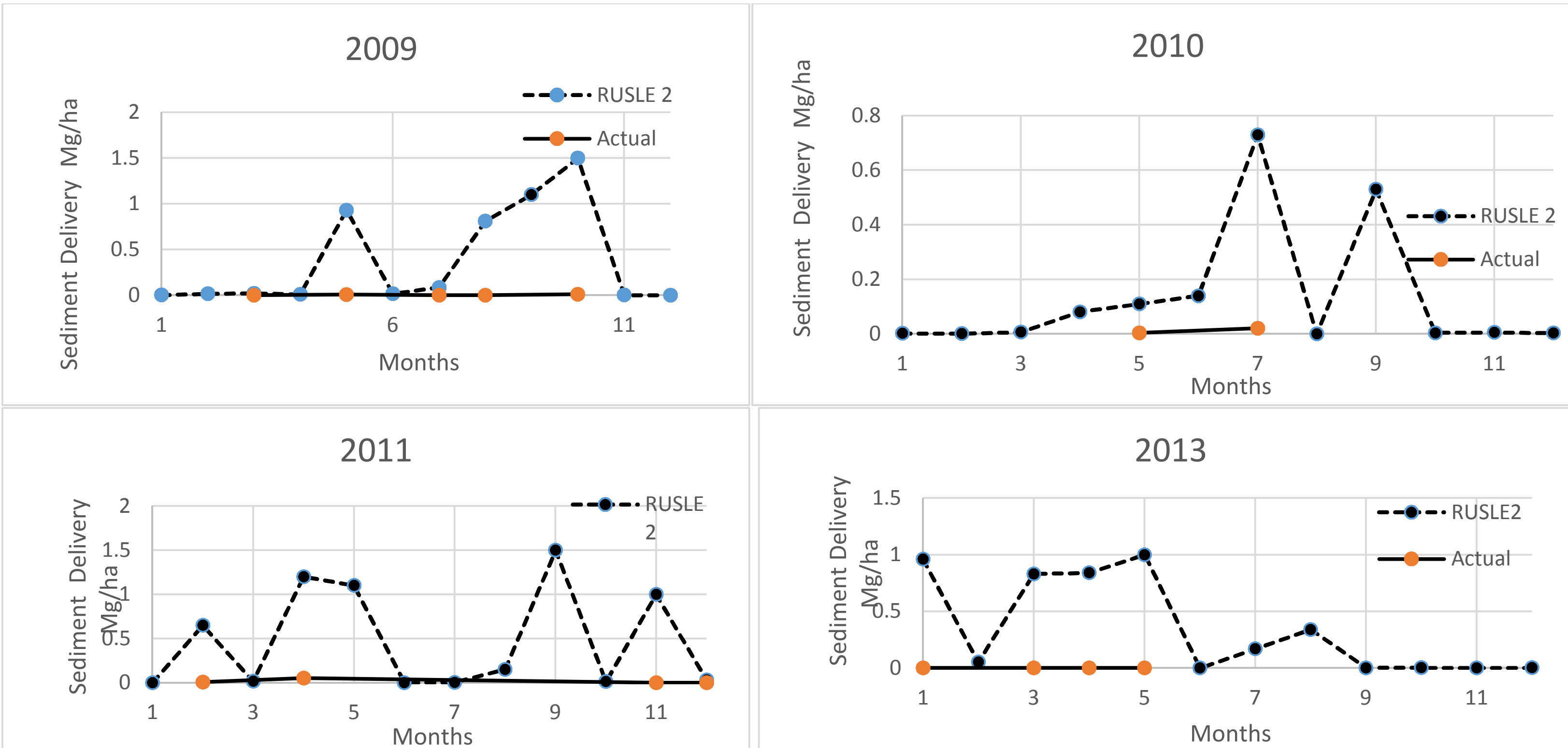

Figure 4.4.2.1.2 Comparison of the temporal variation of RUSLE 2 and Measured Sediment Delivery for Site HE2

Figure 4.4.2.1.3 Comparison of the temporal variation of RUSLE 2 and Measured Sediment Delivery for Site HE3

Figure 4.4.2.1.4 Comparison of the temporal variation of RUSLE 2 and Measured Sediment Delivery for Site HE4

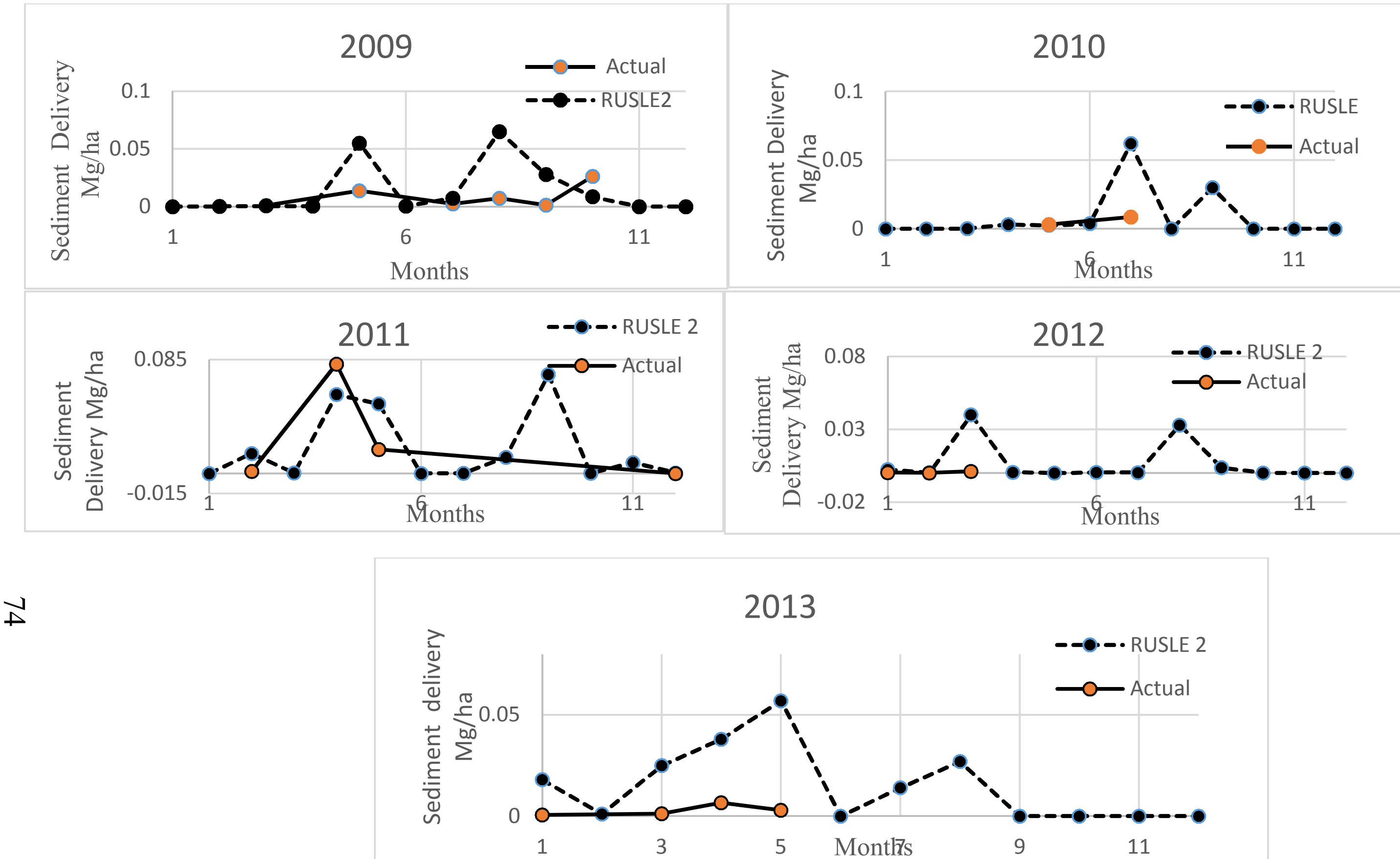

Figure 4.4.2.1.5 Comparison of the temporal variation of RUSLE2 and Measured Sediment Delivery for Site HW1.

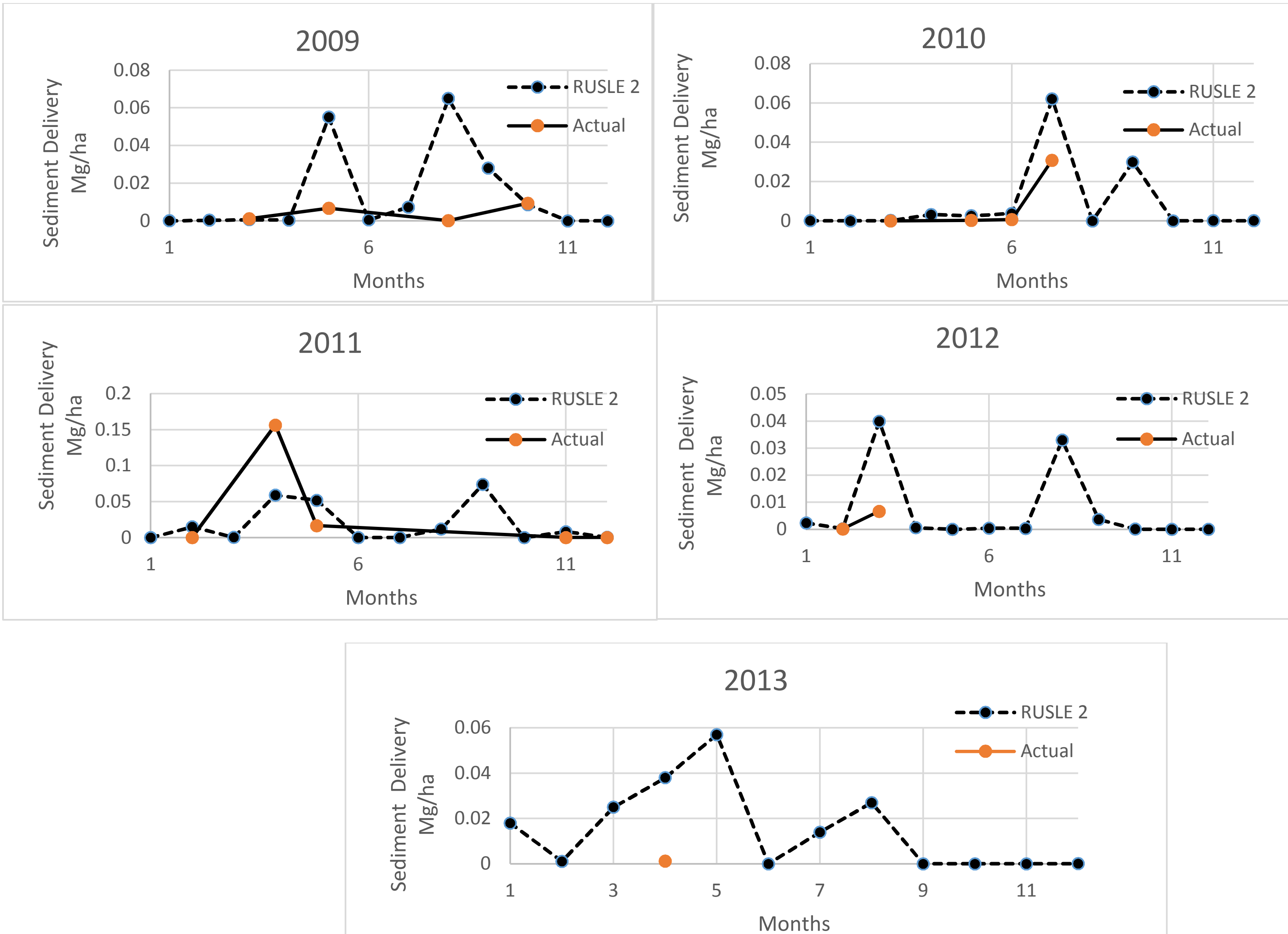

Figure 4.4.2.1.6 Comparison of the temporal variation of RUSLE2 and Measured Sediment Delivery for Site HW2

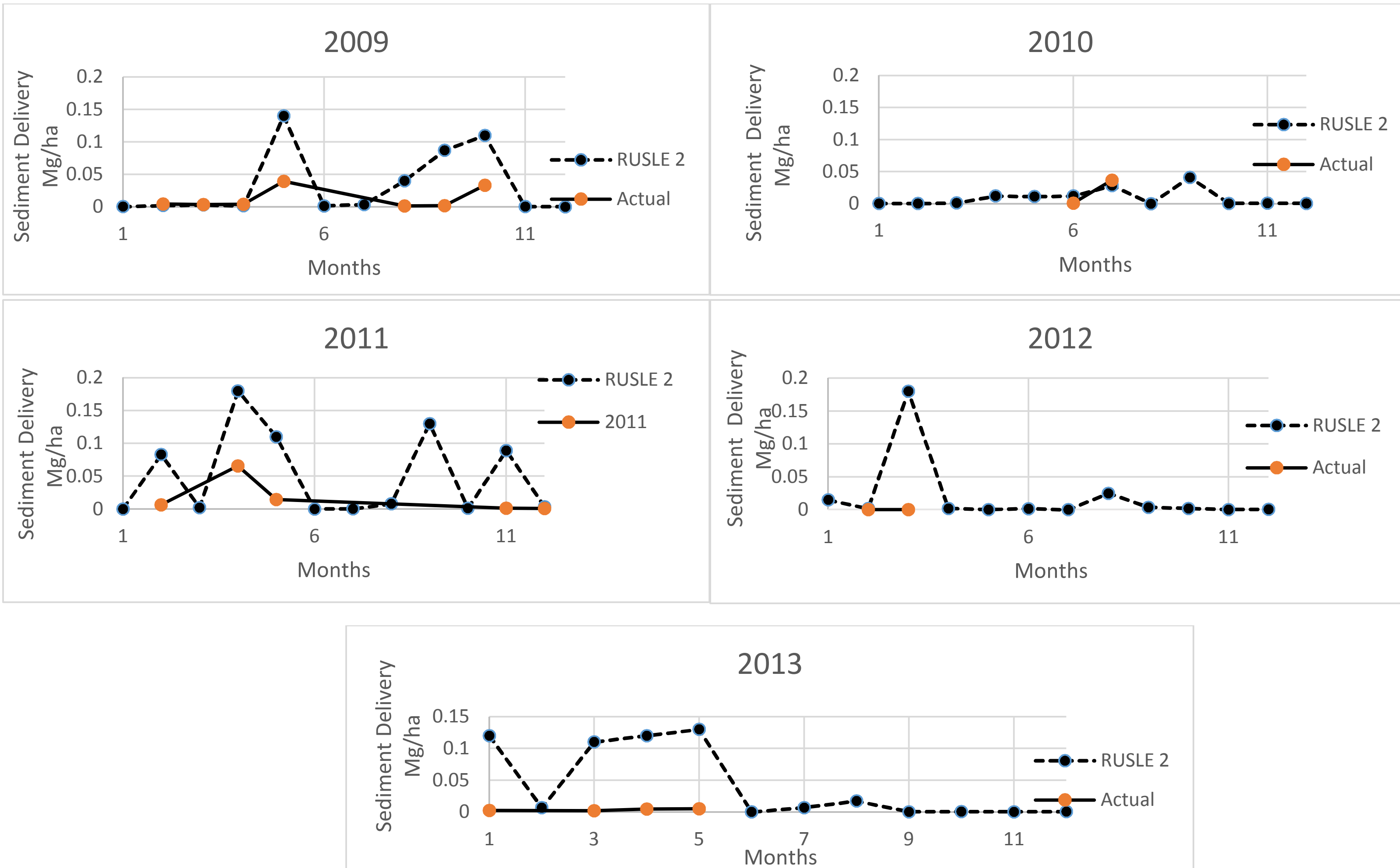

Figure 4.4.2.1.7 Comparison of the temporal variation of RUSLE 2 and Measured Sediment Delivery for Site HW3

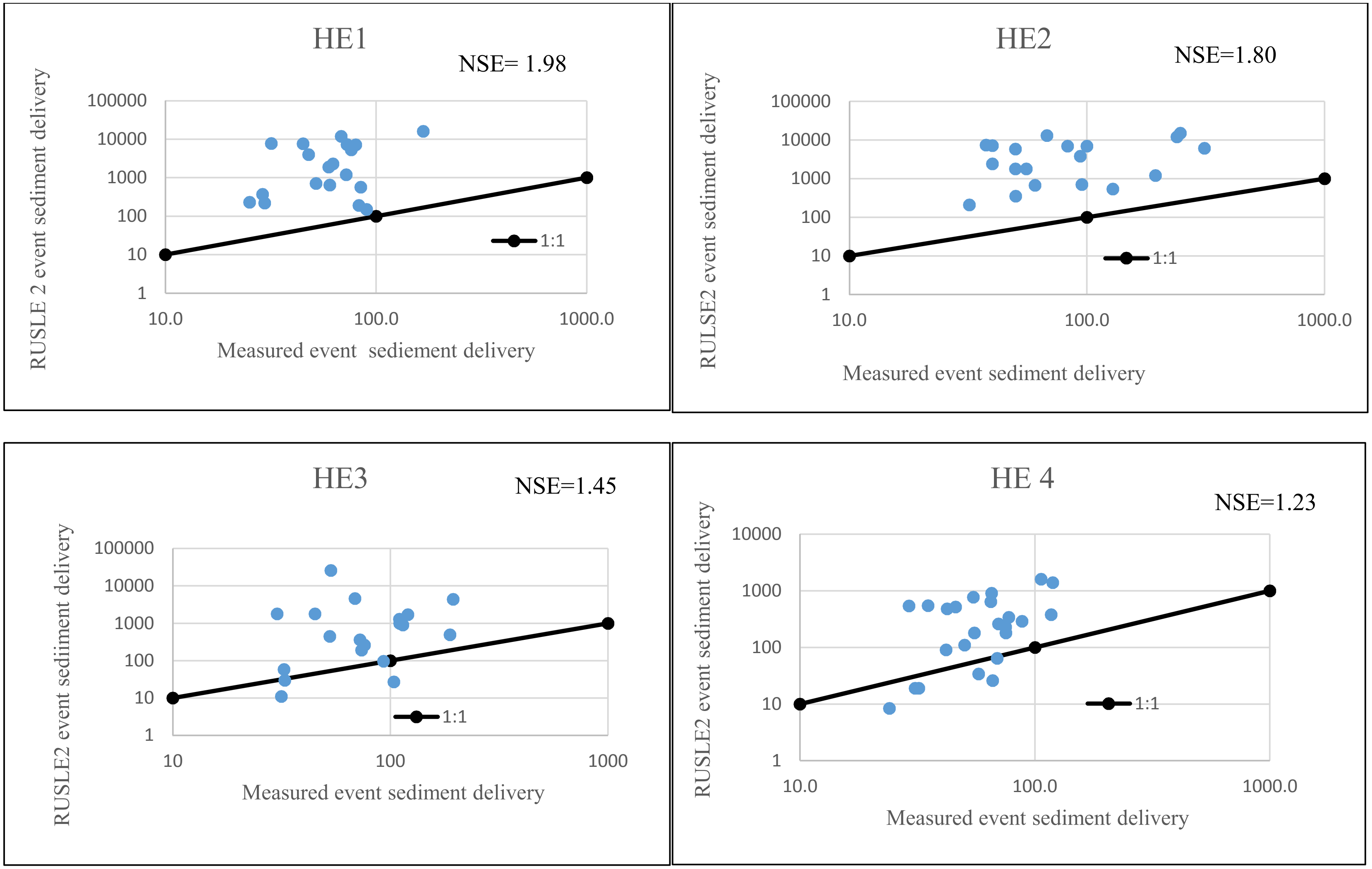

Figure 4.4.2.2.1 Relationship between the Measured and RUSLE2 for Harmon fields HE1to HE4.

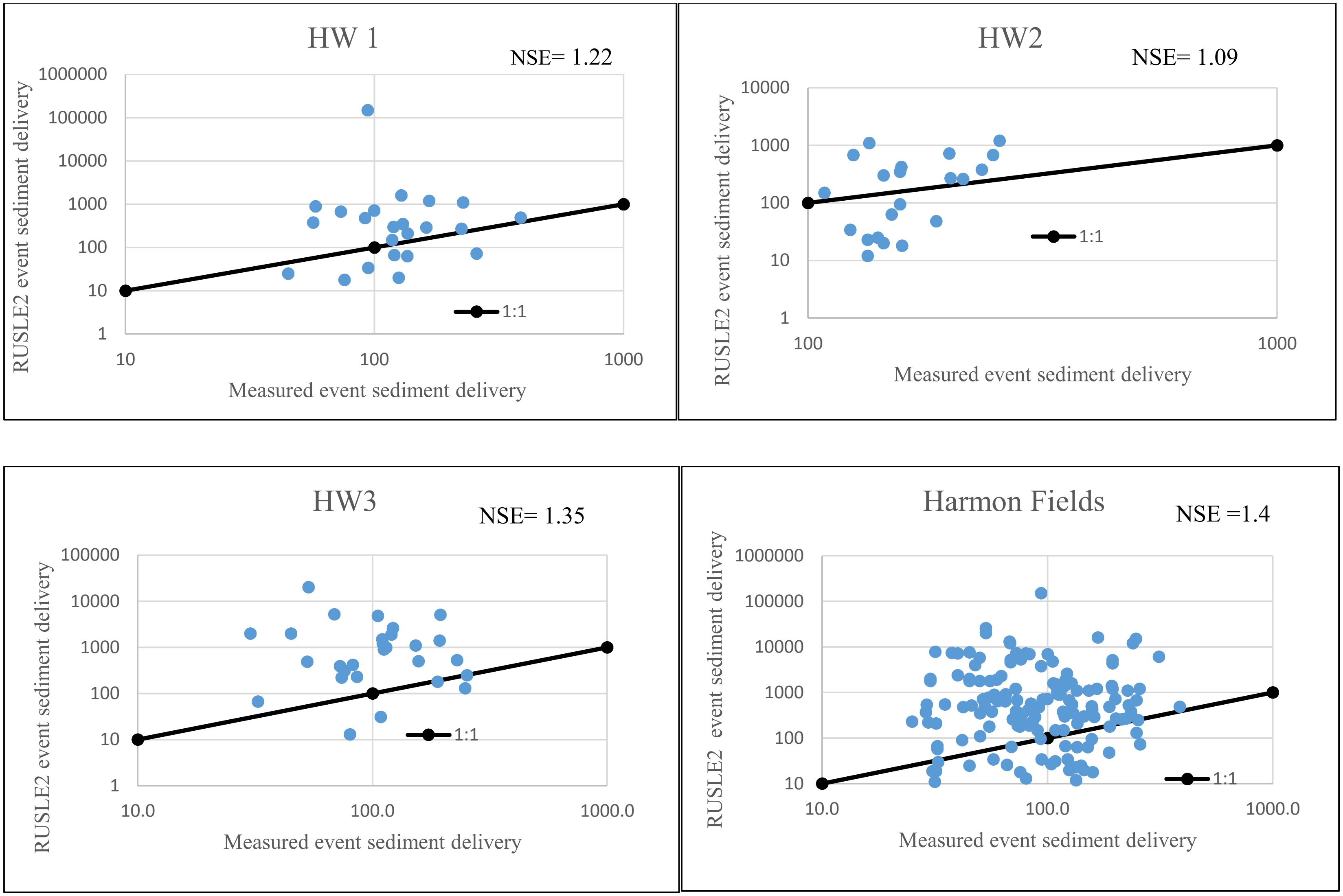

Figure 4.4.2.2.2 Relationship between the measured and RUSLE2 for HW1 to HW3 and overall Harmon Fields.

Table 4.4.2.3. The variability of runoff events for measured and RUSLE2 simulated sediment delivery.

Field	n	Measured Sediment Delivery				RUSLE2 Sediment Delivery				CV Ratio
		Mean/ ppm	Std Deviation/ppm	Range /ppm	CV %	Mean	Std Deviation/ppm	Range	CV %	RUSLE: Measured
HE1	19	65.1	4583.7	25.1-167.3	**7044**	3983.7	4583.7	150-16000	**115**	**0.0163**
HE2	19	104.1	82.9	32-312.2	**80**	4935.3	4579	210-15000	**93**	**1.1625**
HE3	20	62.5	48.6	29.8-194.5	**60**	2273.6	5743.2	0-26000	**253**	**4.216**
HE4	27	138.1	25.2	24-119	**40**	357.1	14646.6	0-1600	**4102**	**102.5**
HW1	24	138.1	76.4	45-386.4	**55**	6642.1	30538.1	0-150000	**460**	**8.363**
HW2	23	168	43.3	108.4-256	**26**	297.7	357.8	0-1200	**119**	**4.57**
HW3	32	114	61	29.8-252.4	**54**	1701.3	3645.1	0-20000	**214**	**3.962**
Overall	164	106	65.7	24-386.4	**62**	2715.1	12151	0-150000	**448**	**7.225**

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Chapter 5

Conclusions and Implications

Use of RUSLE2 to estimate soil loss, plays a vital role in conservation planning measures. For example, RUSLE2 is an integral component of P Indices, which are used throughout the U.S. to determine the risk of P loss in runoff and on which P use and management (as mineral fertilizer and manure) are now based. RUSLE 2 version 2.0.4.0 produced a general overestimation of soil loss from humid US grassland and poor performance using published data collated in the MANAGE database. Several studies in this database could not be used due to inadequate information that were needed to populate and run the model.

Parameterization and operation of RUSLE2 is very data and labor intensive with various sub-routines that control soil loss according to management conditions. For instance, the rotational grazing structure within the Forage Management database and growth scheme highlighted a gross over-prediction of soil loss with a relative accuracy of over ±300%. Further, users must be cognizant to the effects of management inputs in RUSLE2 on the output results. When used in a P Index, these overestimated errors in soil loss are translated into overestimated risk of P loss. The consequences of this over prediction is the recommendation of conservation or best management practices that are more restrictive to a farmer than actually needed. This over-prediction can also limit manure applications, which can in turn reduce the productivity of the field. Further validation across a larger humid U.S. grassland database is needed to justify the claim of over-prediction across this particular region.

The principal design of RUSLE2 follows a storm-event modeling approach for hillslope sediment delivery, from which the long-term annual average soil loss can be determined. To better understand RUSLE2, sediment delivery estimates from version 2.5.7.7 RUSLE2 were used to assess the temporal characteristics of the collected storm data for various treated fields in northwest Arkansas. Performance NSE index suggested that this version of RUSLE2 provided an improved prediction of runoff sediment delivery.

Runoff sediment plays an active role in legacy P and P input from edge of field into nearby water bodies. The ability of RUSLE2 to predict soil loss on an individual storm event basis would enhance RUSLE's ability as a conservation and planning tool. However, there is a need for real-time rainfall intensity data in order for RUSLE2 to estimate soil with an acceptable accuracy. In fact, RUSLE2 over-predicted soil loss on a storm-event basis and a threshold limit correction is proposed to address the problem with individual storm event estimations. Further research on the value of this threshold is necessary and would need to consider the extreme rainfall conditions and climatic changes experienced in northwest Arkansas area both in hourly, daily and annual temporal scale.

RUSLE2 models estimates should reflect the changes in soil loss from the present and changing rainfall pattern in order to effectively implement as a national conservation planning model, especially for water degradation assessment. If the model does not depict field conditions that would significantly impact soil loss, then use of the RUSLE2 model could be detrimental to the outcomes of conservation planning. Policy managers should be aware of the limitations and assumptions when using models in its conservation program to increase model effectiveness and applicability.

RUSLE2, second generation soil erosion technology, included the dynamic nature of vegetation growth stages and time related ground cover in order to model the temporal variation of soil loss or sediment delivery for a particular crop or pasture management. The need to accurately describe the effect of rotational grazing on ground cover in relation to time, to produce an accurate vegetative growth pattern is crucial for the accuracy of RUSLE2 estimates. Noticeably, in the humid southeastern U.S., the quantitative growth curve of tall fescue (*Festuca arundinaea*) and their relation to manure rates need to be investigated to model the effects and outcome of soil loss and runoff in fields. In Georgia, recent efforts in fescue production with litter application provided the basis of modelling inputs into the RUSLE2 to resolve overestimation errors in pasture and hay-land from earlier versions of RUSLE. This work led to the development of process-based functions, consisting of 12 process parameters for forage removal. There is a need for other States to establish similar studies on tall fescue (*Festuca arundinaea*) growth curves and manure amendments effects with soil loss or runoff. Hence, to improve the modelling capability of RUSLE2, accurate temporal information on ground cover must be developed and incorporated each particular eco-region or State.

6 Appendices

University Field Station Rainfall Data output from RIST for calculating storm erosivity input into RUSLE2 S.I. format.

PERIOD	DEPTH_mm	EI30_SI MJ.mm/ha.hr	Duration_hr	Max_Intensity_30_mm/hr	Start_Time_hr	Time_to_Peak_hr
01/01/2009	1511.41	291.12	2974.08	1.524	0.5	2855.833
05/05/2009	0.25	0	0.08	0.5	23	0.042
05/04/2009	2938.36	565.979	5784.08	1.524	23.5	5088.833
01/01/2010	1511.41	291.12	2974.08	1.524	0.5	2855.833
05/05/2010	0.25	0	0.08	0.5	23	0.042
05/04/2010	2938.36	565.979	5784.08	1.524	23.5	5088.833
01/01/2011	1511.41	291.12	2974.08	1.524	0.5	2855.833
05/05/2011	0.25	0	0.08	0.5	23	0.042
05/04/2011	2938.36	565.979	5784.08	1.524	23.5	5088.833
01/01/2012	1523.35	293.356	2998.08	1.524	0.5	2879.833
05/05/2012	0.25	0	0.08	0.5	23	0.042
05/04/2012	2938.36	565.979	5784.08	1.524	23.5	5088.833

Harmon Field Station Rainfall Data output from RIST for calculating storm erosivity input into RUSLE2 U.S. format

Date	Precipitation (inches)	EI 30 (US) Hundreds offoot.tonf.inch/acre.hr	Duration (hrs)	Maximum Intensity(30mins) (inches/hr)
07/05/2008	0.53	0.87	12.7	0.31
10/05/2008	0.66	6.62	5.57	1.00
14/05/2008	0.62	0.82	7.11	0.23
24/05/2008	0.57	5.31	1.87	0.99
26/05/2008	0.8	5.11	4.21	0.82
27/05/2008	0.98	6.09	6.63	0.88
01/06/2008	1.37	204.07	7.71	1.18
09/06/2008	1.93	306.61	15.81	0.55
15/06/2008	1.35	438.46	1.35	2.62
28/06/2008	0.54	2.91	6.86	0.65
03/07/2008	0.86	7.60	12.25	1.06
09/07/2008	2.19	849.85	13.81	1.11
12/07/2008	0.73	3.68	5.62	0.72
07/08/2008	1.06	3.26	5.79	0.48
09/08/2008	1.73	0.61	97.63	0.10
02/09/2008	3.79	988.30	49.16	0.42
13/09/2008	2.11	594.54	14.68	0.86
06/10/2008	0.6	2.09	4.8	0.51
22/10/2008	0.93	2.98	5.98	0.46
06/11/2008	0.44	3.41	0.66	0.82
10/11/2008	0.8	0.75	12.41	0.20
27/12/2008	1.35	204.97	3.81	1.16
29/01/2009	0.52	0.69	5.61	0.23
30/01/2009	1.13	2.02	8.33	0.28
10/02/2009	1.2	5.46	17.16	0.67

Date	Precipitation (inches)	EI(30) Hundreds offoot.tonf.inch/acre.hr	Duration	Maximum Intensity (30 mins) Inches/hr
20/03/2009	1.34	5.41	14.49	0.61
24/03/2009	1.04	5.33	1.69	1.50
27/03/2009	0.81	1.21	24.92	0.28
12/04/2009	1.51	3.57	19.43	0.39
18/04/2009	1.07	4.69	14.52	0.60
01/05/2009	2.04	760.13	30.09	1.08
03/05/2009	1	7.60	12.24	0.99
05/05/2009	0.99	2.38	11.83	0.38
08/05/2009	0.56	4.94	2.14	0.95
08/05/2009	0.44	2.93	7.56	0.75
12/05/2009	1.32	305.44	5.13	2.00
13/05/2009	0.55	5.55	1.38	1.03
23/05/2009	0.96	13.40	1.83	1.48
12/06/2009	0.83	10.04	1.44	1.28
14/06/2009	1.12	9.13	14.27	0.94
20/07/2009	1.32	49.47	10.4	1.10
27/07/2009	1.13	120.71	2.89	1.92
05/08/2009	1.74	868.83	0.86	2.84
10/08/2009	1.41	243.98	6.81	1.94
20/08/2009	1.22	59.98	7.54	1.18
27/08/2009	0.72	6.31	4.19	1.03
02/09/2009	0.93	3.85	4.79	0.61
05/09/2009	0.75	10.91	1.44	1.44
09/09/2009	1.93	209.13	25.16	0.70
15/09/2009	0.53	0.69	22.98	0.24
21/09/2009	1.88	486.67	7.58	1.12
06/10/2009	0.52	3.15	5.8	0.74
08/10/2009	4.64	955.25	25.64	1.98
25/10/2009	0.84	0.86	44.35	0.24

Date	Precipitation (inches)	EI(30) Hundreds offoot.tonf.inch/acre.hr	Duration	Maximum Intensity (30 mins) Inches/hr
15/11/2009	0.74	2.59	9.57	0.50
20/01/2010	0.82	1.64	9.9	0.33
23/01/2010	0.51	0.35	18.56	0.16
21/02/2010	0.59	0.64	14.61	0.22
20/03/2010	0.8	0.88	12.37	0.23
21/03/2010	0.51	0.74	13.34	0.20
24/03/2010	1.24	2.20	20.33	0.31
02/04/2010	0.9	4.76	13.2	0.67
05/04/2010	0.95	32.93	0.14	1.90
21/04/2010	0.81	14.24	0.12	1.62
24/04/2010	1.1	3.16	14.66	0.43
09/05/2010	0.84	4.12	8.23	0.64
13/05/2010	0.58	1.76	8.59	0.42
14/05/2010	0.91	12.74	2.09	1.46
16/05/2010	0.5	4.26	5.35	0.90
19/05/2010	0.55	0.31	5.58	0.12
25/05/2010	2.08	108.89	7.5	1.87
07/06/2010	1.15	167.73	1.51	2.10
08/07/2010	0.77	2.90	18.47	0.59
12/07/2010	4.57	680.25	17.95	2.19
26/07/2010	1.92	940.95	7.19	2.68
01/09/2010	0.43	2.96	2.74	0.76
02/09/2010	0.66	5.50	5.32	0.97
08/09/2010	3.15	270.71	23.92	0.78
24/09/2010	1.25	89.70	5.16	1.16
19/10/2010	0.74	1.90	11.94	0.43
23/10/2010	0.65	1.19	8.37	0.30
25/11/2010	1.29	5.03	12.06	0.55
31/12/2010	0.61	3.80	1.82	0.64

Date	Precipitation (inches)	EI(30) Hundreds offoot.tonf.inch/acre.hr	Duration	Maximum Intensity (30 mins) Inches/hr
27/02/2011	1.42	416.98	10.15	1.84
04/03/2011	0.64	5.23	4.88	0.90
13/03/2011	0.92	3.68	14.2	0.58
10/04/2011	1.45	77.95	7.35	0.70
14/04/2011	0.5	0.76	3.14	0.26
21/04/2011	1.86	644.43	7.47	0.70
22/04/2011	0.87	11.05	7.04	1.28
23/04/2011	10.84	436.31	64.87	1.94
27/04/2011	0.65	1.47	4.76	0.35
29/04/2011	0.52	5.83	0.12	1.04
01/05/2011	1.42	31.64	12.63	0.56
12/05/2011	0.76	10.11	1.47	1.34
20/05/2011	2.06	541.32	14.29	0.89
23/05/2011	2.9	675.28	12.17	1.63
24/05/2011	0.47	3.53	1	0.83
22/07/2011	0.67	5.52	4.72	0.90
10/08/2011	1.65	206.01	33.12	0.52
12/08/2011	1.2	4.67	12.59	0.53
16/09/2011	0.88	3.32	25.73	0.54
18/09/2011	1.78	631.82	13.54	1.54
22/09/2011	1.82	357.87	10.13	0.99
12/10/2011	0.55	3.78	2.87	0.81
22/10/2011	0.77	4.90	2.68	0.80
27/10/2011	0.79	1.31	16.94	0.31
07/11/2011	3.42	887.85	14.65	1.60
15/11/2011	0.29	1.61	0.48	0.58
21/11/2011	1.34	5.28	10.26	0.55
03/12/2011	0.71	1.27	8.1	0.32

Date	Precipitation (inches)	EI(30) Hundreds offoot.tonf.inch/acre.hr	Duration	Maximum Intensity (30 mins) Inches/hr
19/12/2011	0.59	0.95	5.99	0.29
25/01/2012	1.81	120.373	18.41	0.41
03/02/2012	1.01	8.136	7.2	0.94
05/02/2012	0.41	3.603	0.1	0.82
29/02/2012	0.37	2.673	0.46	0.74
11/03/2012	0.61	1.606	13.45	0.42
19/03/2012	2.58	755.125	26.63	0.99
21/03/2012	0.75	1.305	10.05	0.333
15/04/2012	0.98	7.602	7.25	0.88
30/04/2012	0.77	4.385	3.46	0.76
31/05/2012	0.4	2.944	5.79	0.78
03/06/2012	0.99	15.858	1.27	1.804
04/06/2012	0.63	1.601	4.7	0.428
21/06/2012	0.51	3.027	2.55	0.72
26/07/2012	0.77	8.5	3.15	1.17
08/08/2012	0.77	6.676	1.66	0.944
16/08/2012	1.27	283.543	2.19	1.68
26/08/2012	1.3	176.244	2.54	0.98
26/08/2012	1.07	7.685	7.09	0.86
07/09/2012	1.07	34.06	8.26	0.96
14/09/2012	0.84	1.968	7.45	0.4
05/10/2012	0.61	5.243	4.18	0.88
12/10/2012	1	5.304	3.73	0.724
13/10/2012	1.07	11.046	5.54	1.244
11/11/2012	0.7	2.563	6.14	0.545
04/12/2012	0.97	6.459	2.83	0.747
31/12/2012	0.84	0.721	14.5	0.2
29/01/2013	2.38	872.105	10.64	1.14

Date	Precipitation (inches)	EI(30) Hundreds offoot.tonf.inch/acre.hr	Duration	Maximum Intensity (30 mins) Inches/hr
25/02/2013	1.11	0.618	22	0.12
09/03/2013	2.02	215.792	15.9	0.41
02/04/2013	0.72	0.466	11.62	0.144
10/04/2013	0.82	6.086	14.92	0.92
18/04/2013	1.94	710.202	11.21	1.42
26/04/2013	0.53	2.317	7.04	0.56
26/04/2013	1.06	12.049	7.53	1.33
09/05/2013	1.72	690.739	2.8	1.74
10/05/2013	0.42	2.229	1.61	0.65
20/05/2013	2.34	532.961	28.52	0.964
24/05/2013	0.31	2.01	0.15	0.62
30/05/2013	0.74	8.312	1.12	1.128
16/07/2013	0.58	5.669	3.09	1.028
23/07/2013	1.58	343.069	6.61	1.584
26/07/2013	0.75	1.446	10.65	0.304
30/07/2013	0.49	2.991	4.06	0.72
03/08/2013	0.89	5.7	3.6	0.76
08/08/2013	1.61	482.62	9.9	1.09
20/09/2013	1.14	0.654	9.5	0.12
28/09/2013	0.53	0.301	4.42	0.12
05/10/2013	1.22	0.699	16	0.12
14/10/2013	0.77	2.112	19.2	0.424
21/11/2013	1.11	0.666	19.15	0.135
13/12/2013	0.67	0.555	7.53	0.18
20/12/2013	1.93	2.516	22.18	0.268