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Advances in Soil Erosion Research: Processes, Measurement, and Modeling

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ADVANCES IN SOIL EROSION RESEARCH: PROCESSES, MEASUREMENT, AND MODELING



D. C. Flanagan, J. C. Ascough II, J. L. Nieber, D. Misra, K. R. Douglas-Mankin

ABSTRACT. Soil erosion by the environmental agents of water and wind is a continuing global menace that threatens the agricultural base that sustains our civilization. For over 70 years, ASABE members have been at the forefront of research to understand erosion processes, measure erosion and related processes, and model very complex sediment detachment, transport, and deposition. The ASABE Erosion Control Group (SW-22) and Erosion Control Research (SW-223) committees periodically sponsor international symposia to provide an avenue for exchange of ideas and information by engineers, scientists, and students from around the world. The two most recent symposia were the Soil Erosion Research for the 21st Century Symposium held in January 2001 in Honolulu, Hawaii, and the International Symposium on Erosion and Landscape Evolution (ISELE) held in September 2011 in Anchorage, Alaska. This article describes these two events, provides a description of major outcomes, and introduces a collection of papers that were presented as part of the 2011 ISELE in Alaska. The ISELE sessions focused on seven themes: water erosion process research; aeolian erosion and fugitive dust emission; highly disturbed, urban, and arid lands; erosion measurement and assessment; prevention and control of upland and in-stream erosion; soil erosion modeling; and impacts of global change on erosion and landscape evolution. More than 120 people from 16 countries attended the ISELE and gave 112 oral and poster presentations. From those presentations, 24 papers were accepted for publication in Transactions of the ASABE (22 papers, this issue) and Applied Engineering in Agriculture (two papers, next issue). The results from these symposia and in these papers show active and vibrant research to address soil erosion problems, particularly in the face of global environmental changes.

Keywords. Experimentation, Modeling, Research, Soil erosion.

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mining, and construction, can disturb or destroy vegetation, loosen soil, and greatly increase the risk of soil erosion losses from subsequent rainfall, runoff, and/or windstorm events. Soil erosion and sedimentation of eroded materials at locations away from the point of detachment are costly to individuals and society as a whole due to loss of productive topsoil and applied nutrients on croplands, damage to crops and crop yield, and pollution of water. In order of scale, erosion by water progresses from sheet to rills, to ephemeral gullies, and to classical gullies and channels as the contributing areas and amounts of runoff water increase (Flanagan, 2002). Erosion by wind may be very local in a single field, or it may encompass thousands of hectares impacted by a large wind storm front.

Soil erosion by water and wind is a serious problem both within the U.S. and throughout the world. Myers (1993) stated that about 75 billion tons of topsoil are lost from agricultural production areas worldwide every year. The Food and Agricultural Organization (FAO) of the United Nations reported that 16% of the total world land area (21,960,000 km² of 134,907,000 km²) is subject to significant soil erosion risk (FAO, 2000), and estimated soil loss rates were greatest in Asia, South America, and Africa, with averages of 30 to 40 t ha⁻¹ year⁻¹. Somewhat lower erosion rates were estimated for Europe and North America, at about 17 t ha⁻¹ year⁻¹, while a sustainable rate of soil loss (rate of soil loss that is equal to rate of soil formation) was reported to be about 1 t ha⁻¹ year⁻¹ (FAO, 2000).

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The USDA Natural Resources Conservation Service (NRCS) estimated in the 2007 National Resources Inventory (NRI) that about 1.7 billion tons of soil are lost each year in the U.S. from nonfederal rural lands due to sheet and rill erosion by water and by wind erosion, and that 28% of U.S. cropland is eroding at excessive rates (USDA-NRCS, 2009). The NRI actually understates soil erosion levels, as it does not include estimates of soil lost from channel erosion in ephemeral or classical gullies, nor does it report on erosion from public lands in the U.S.

Erosion removes the top fertile layers of the soil, resulting in loss of organic matter, nutrients, and water holding capacity that can lead to an overall decrease in crop productivity from the soil. In some cases, erosion from flow in gully channels can be so massive that it becomes impossible for agricultural equipment to traverse the gullies, resulting in loss of entire areas of land for crop production. In addition to this on-site degradation, sediment detached during the erosion process can be transported away in the wind or water fluids, causing a variety of offsite impacts and problems. Sediment is the largest pollutant by volume of waterways, and deposition of sediment in ditches, streams, rivers, lakes, and harbors can impede navigation, reduce storage capacity, and increase risks of flooding. Dredging of sediment from these water bodies is often necessary, and conducted at large costs. Pimentel et al. (1995) reported that the combined on-site and off-site costs of soil erosion in the U.S. were as great at \$44 billion per year. Uri (2000) estimated total annual costs to society of wind and water erosion in the U.S. at \$37.6 billion per year, ranging from \$27.9 billion to \$73.8 billion per year.

Regardless of the exact costs, there is no disagreement that soil erosion is a serious, continuing environmental and economic problem of global proportions. For over 70 years, ASABE members have been conducting research to understand, predict, and control soil erosion processes. In particular, the members of the ASABE SW-22 Erosion Control Group and SW-223 Erosion Control Research committees conduct research in these areas and provide an international forum in which to present and exchange current scientific knowledge through the ASABE annual meetings and specialty conferences. In 2001 and 2011, the SW-223 committee organized and hosted international symposia on soil erosion research. This introductory article provides information on the two symposia and introduces the peer-reviewed journal articles that constitute a special collection of papers originally submitted to the International Symposium on Erosion and Landscape Evolution held in Alaska in September 2011.

SOIL EROSION RESEARCH FOR THE 21ST CENTURY SYMPOSIUM

On January 3-5, 2001, over 200 erosion scientists from 30 countries met in Honolulu, Hawaii, at the Soil Erosion Research for the 21st Century International Symposium and Exhibition, sponsored by ASAE (now ASABE) and the SW-223 Technical Committee. Major themes of the meeting were: erosion by wind (processes, modeling, and control);

erosion by water (processes, modeling, and control); and quantification of soil erosion by wind and water. Keynote speakers were Dr. John Stout, Dr. Gerard Govers, and Dr. Samir El-Swaify, who addressed the three topic areas, respectively. In addition to over 180 oral and poster presentations, time was allotted during this meeting for small and large group discussions of future research needed to better understand soil erosion processes and ways to control this erosion. A mid-week field tour (fig. 1) highlighted erosion and water quality concerns on the Hawaiian island of Oahu. The products from this conference included a Proceedings book (Ascough and Flanagan, 2001), CD-ROM (Flanagan and Ascough, 2001), and Symposium Statement document (Flanagan, 2001). ASAE also published a position paper (ASAE, 2002) based on the symposium statement, which is available at: www.asabe.org/news-public-affairs/ public-affairs/position-statements/soil-erosion-program.aspx. Other information from this symposium, including the program, photographs, and the full symposium statement, are available at the National Soil Erosion Research Laboratory (NSERL) website: http://topsoil.nserl. purdue.edu/~flanagan/ erosymp/. The meeting papers are also available via the ASABE Technical Library (http://elibrary.asabe.org/ conference.asp?confid=se2001).



Figure 1. (a) Local arrangements chair and keynote speaker Dr. Samir El-Swaify (right) led a field tour of the island of Oahu during the Soil Erosion Research for the 21st Century symposium that highlighted erosion and water quality problems and solutions, and (b) a serious soil erosion area on Oahu seen during the field tour.

INTERNATIONAL SYMPOSIUM ON EROSION AND LANDSCAPE EVOLUTION

On September 18-21, 2011, over 120 scientists from 16 countries met in Anchorage, Alaska, as part of the International Symposium on Erosion and Landscape Evolution (ISELE). The program consisted of 2.5 days of oral and poster presentations, as well as a half-day field tour of important erosion and landscape features in the Anchorage area (fig. 2). Keynote speakers were Dr. Grant McTainsh, Dr. John Wainwright, and Dr. Des Walling. Dr. McTainsh spoke on "Wind Erosion, Dust and their Environmental Impacts: An Australian Perspective" on the first day of the symposium, leading into several technical sessions on aeolian research later that day. Dr. Wainwright provided a discussion of "Small Steps and Giant Leaps? Thoughts for the Future Based on a Decade of Progress in Understanding and Modeling Hydrologic and Erosion Processes," highlighting erosion research findings from his career. Dr. Walling's keynote presentation on the final day of the meeting covered "Research on Erosion and Landscape Evolution: Current Status and Future



Figure 2. (a) Susan Karl (center), USGS Anchorage, describes to the ISELE field tour participants what happened during the 1964 Good Friday earthquake, as this area of Anchorage sustained enormous damage due to soil liquefaction and subsequent landslides, and (b) Professor Tom Ravens (left), University of Alaska Anchorage, speaks at Beluga Point in the Turnagain Arm (background) about a range of engineering research projects.

Prospects," with a large focus on erosion by water and sediment yield processes, measurement, and prediction in the U.K. and elsewhere.

Materials provided at the symposium in Anchorage included a printed book of abstracts (Ascough and Flanagan, 2011) and a CD-ROM (Flanagan et al., 2011) with all of the extended abstracts and papers. The ISELE abstracts and papers are also available via the ASABE Technical Library (http://elibrary.asabe.org/conference.asp? confid=isel2011), and the NSERL website hosts a large amount of information, including many photographs, the final program, and all of the on-site oral and poster presentations given in Alaska (http://topsoil.nserl.purdue. edu/~flanagan/isele2011).

The ISELE oral and poster sessions were focused on seven themes: water erosion process research; aeolian erosion and fugitive dust emission; highly disturbed, urban, and arid lands; erosion measurement and assessment; prevention and control of upland and in-stream erosion; soil erosion modeling; and impacts of global change on erosion and landscape evolution. The meeting attendees provided 112 presentations. From those presented papers, 22 are now published as peer-reviewed articles in a special collection in this issue of *Transactions of the ASABE*, with another two articles in the next issue of *Applied Engineering in Agriculture*. Each of the articles is described briefly here, under the appropriate research area from the ISELE.

WATER EROSION PROCESS RESEARCH

Wilson et al. (2013) report on the state of the science on internal erosion during soil pipeflow. There has been little consensus on how piping affects embankment failures, landslides, and gully erosion, and this article attempts to clarify the terminology related to piping processes, describe previous experiments on these processes, and assess current modeling approaches to describe pipeflow and erosion. Different environmental conditions can result in soil pipes stabilizing the soil when acting as drains or destabilizing the soil when there is positive pore pressure, causing gully formation. Experimental studies described here cover slope destabilization due to clogging of soil pipes, gully formation resulting from mass failures due to water flow in discontinuous soil pipes, and gully initiation following tunnel collapses when soil pipes were enlarged by internal erosion. Pipeflow is most often predicted using numerical models based on the Richards (1931) equation, while internal erosion in the soil pipes is estimated using analytical solutions of the excess flow shear stress equation. Gaps in understanding of these processes as well as needed future research are presented.

Results from *in situ* soil pipeflow experiments on streambank soils are discussed by Midgley et al. (2013). An innovative constant-head trench system was used to conduct experiments on a sandy loam streambank in northern Oklahoma and on a clay loam streambank in northern Mississippi. Two types of experiments were run: open pipes where the soil pipe was directly connected to the trench and open at the streambank face, and clogged pipes where the pipe outlets were plugged with excavated soil materials. Flow and sediment samples were collected

with pans during pipeflow events, and soil water pressure was measured on the streambank face with a tensiometer network. The Bonelli et al. (2006) pipeflow erosion model was applied, and observed flow and sediment data were used to estimate erosion parameters, which were compared to values obtained from jet erosion tests. At both locations when the pipes were clogged, the pore water pressure in the soil increased, and either turbulent pipeflow occurred after these pores burst or the pores were manually punctured to establish pipeflow. At the sandy loam streambank, sediment concentrations ranged from 10 to about 45 g L⁻¹, while much lower values, below 4 g L⁻¹, were observed on the clay loam streambank, even at large hydraulic gradients. The Bonelli et al. (2006) model matched flow and sediment data from the clay loam streambank but appeared to not be applicable on the highly erodible sandy loam.

Results of flume and jet erosion tests to determine parameters for two erosion prediction methods are reported by Al-Madhhachi et al. (2013). Detachment of cohesive soils is commonly quantified using the excess shear stress equation, with the parameters of critical shear stress and an erodibility coefficient. The Wilson model (Wilson, 1993) is a more mechanistic approach and is proposed for use here as a good alternative. This study used flume experiments, submerged jet tests (JET, Jet Erosion Test), and a new "mini" JET test to determine parameters for the excess shear stress equation and the Wilson model for two cohesive soils (silty sand and clayey sand soils). Results from the experiments could not detect differences in the parameters determined by the two experimental procedures for the two predictive methods, except for one parameter (b_1) when using the original JET method. This showed that the jet tests (which can be applied in field settings) can be a satisfactory approach for determining erosion model parameters. In addition, the more mechanistic Wilson model predicted soil detachment as well as or better than the excess flow shear stress equation.

One of the dominant factors affecting runoff and interrill erosion is soil surface roughness. In the article by Vermang et al. (2013), the objective was to compare several existing soil surface roughness indices and to test the revised triangular prism surface area method (RTPM) for calculating the fractal dimension as a roughness index. A silty clay loam soil was sieved to four aggregate sizes, packed into soil trays, and subjected to rainfall simulations for 90 min at 50 mm h⁻¹ average intensity. A laser scanner was used before and after the rainfall to determine soil surface elevations and microtopography. Random roughness, variogram sill and range, fractal dimension and fractal length using a fractional Brownian motion (fBm) model, variance and correlation length according to a Markov-Gaussian model, and fractal dimension using the RTPM were computed for the before and after rainfall cases. The best predictor of surface roughness classes was found to be random roughness. The variogram sill was the best alternative approach when spatial dependency was considered. Based on results from this study, Vermang et al. (2013) concluded that the fractal dimension from the RTPM provides good estimates of overall roughness.

Römkens et al. (2013) report results of sediment

transport in shallow flows conducted at the USDA-ARS National Sedimentation Laboratory in Oxford, Mississippi. Sand-sized material was fed to the upper end of a 7 m long \times 10 cm wide channel under super-critical flow conditions (Fr > 1), and experimental measurements included particle velocities and concentrations using photonic probes. Sediment discharge from the channel was collected at the downstream end. Particle types used were coarse sand (1.0 mm < d < 1.4 mm), medium sand (0.6 mm < d < 1.4 mm)0.85 mm), and glass beads (0.6 mm < d < 1.0 mm). Observations indicated three types of sediment transport: saltation at lower sediment concentrations, regularly spaced sediment waves, and meandering. The last two modes of transport were caused by particle interactions, which were shown to greatly reduce equilibrium sediment transport rates compared to the grain addition rate (40% reduction for waves, and up to 64% reduction for meanders). The sediment transport rate was found to have curvilinear increases with increases in seeding rate until a critical saltation limit was reached. Römkens et al. (2013) provide a relationship describing the transition from saltation mode to wave mode as a function of a critical solid concentration.

Identification of gully channels and their initiation points is a critically important current research topic, and Momm et al. (2013) provide results on the effects of topographic characteristics on gully initiation location based on the compound topographic index (CTI). The likelihood of gullies developing can be evaluated using spatially derived stream power estimates from proxy topographic information that combines local slope, upslope drainage area, and planform curvature into a CTI. Evaluations were conducted that examined the impact of varying relief, overall watershed size, and DEM grid cell size on calculated CTI values, and results showed that CTI was linearly related to changes in relief variance and overall slope. However, there was an inverse power relationship observed between grid cell size and CTI. Use of a normalized CTI (CTI_n) for positive CTI values produced matching distribution curves when overall slope and relief variance were varied. Additional simulation studies using three observed field locations and use of the CTI_n improved comparisons between the different sites. Results from this study indicate a critical CTI_n between 1 and 2 can be used to identify areas having high potential for gully channel initiation.

Risk assessment of erosion from concentrated flows on arid rangelands, which occasionally occur and detach large amounts of sediment, is presented by Al-Hamdan et al. (2013). They examined the conditions under which flows transition from sheet to concentrated flow and developed equations that estimate the effective flow shear stress acting on the soil using Darcy-Weisbach friction factor partitioning based on experimental data. Concentrated flow formation was positively correlated with slope gradient, ground cover, and flow discharge per unit width. One of the equations developed can be used to estimate the risk of concentrated flow occurring at a specific site and under particular field conditions, and another equation can be used to estimate the risk of the concentrated flow generating erosion. A risk index as a function of slope gradient can then be plotted versus the amount of bare soil.

Lenhart et al. (2013) describe channel changes in the lower Minnesota River that are being driven by hydrologic, geomorphic, and ecological factors. Most of the sediment in this river comes from bank or bluff erosion, and the authors examined the impacts of recent streamflow increases, channel straightening, and reduced floodplain access on increasing channel sediment load and decreasing deposition. Aerial photographs were used to document changes in the river geometry. Since 1938, the river has widened by 50% to 100% between St. Paul and Mankato, Minnesota, resulting in sediment losses of 280,000 tonnes year⁻¹, and it has also shortened by 7%, resulting in increased stream power and bankfull shear stress. Sediment problems farther downstream in the Minnesota River and sediment filling of Lake Pepin in the Mississippi River have resulted from this channel evolution. Point bar deposition in the lower Minnesota River has declined, most likely due to loss of woody vegetation on the sand bars because of recent summer flows that keep the bars submerged. Since European settlement. floodplain sediment deposition rates have increased.

Elliot (2013) presents information on current soil erosion research being conducted in forests in the U.S. When undisturbed, sediment losses from forested areas are typically very low. However, disturbances from wildfires, forest road networks, and all-terrain vehicle (ATV) trails can result in increased risks of erosion and sediment delivery to streams. If forest streams are themselves not disturbed, they tend toward an equilibrium condition in which sediment entering a channel reach is balanced by sediment leaving the reach downstream. Large amounts of sediment delivered to streams following forest disturbance may deposit there and take a long time before leaving a reach during a subsequent high runoff event. The USDA Forest Service has developed a number of online predictive tools using the Water Erosion Prediction Project (WEPP) model (Flanagan et al., 2007; Flanagan and Nearing, 1995) to estimate soil erosion and sediment delivery from wildfires, timber harvest, forest roads, and other disturbances. Current work is underway to enhance online watershed interfaces to better simulate spatial variability, channel processes, and road networks, some of which are reported in this collection by Dun et al. (2013), Flanagan et al. (2013), and Srivastava et al. (2013).

AEOLIAN EROSION AND FUGITIVE DUST EMISSION

Wind erosion and associated dust emissions from agricultural land management systems can have large impacts on air quality. Gao et al. (2013) describe spatial application of the Wind Erosion Prediction System (WEPS) model (Hagen, 1991) for estimating wind erosion in the Pacific Northwest. WEPS was originally designed to only run wind erosion simulations on single field-sized areas, but in this study it was extended to allow independent simulation of multiple fields to cover a large region. The WEPS model source code was modified so that it could run for multiple grids, and the internal parameter values of the model at the end of a simulation period could be saved to an external file, which could then be used as initialization for subsequent runs. The 1 km × 1 km grid cell WEPS model output results from three-year simulations, covering the entire state of Washington, were aggregated into 12 km × 12 km grid cells for better visualization of surface wind erosion rates, suspension, and PM₁₀ concentrations. The ultimate goal of this work was to use WEPS predictions of PM₁₀ and PM_{2.5} (airborne particulate matter less than 10 and 2.5 microns in diameter, respectively) emissions as input to the chemical transport model (CMAQ) used in the AIRPACT (Air Indicator Report for Public Awareness and Community Tracking) regional air quality modeling framework developed for the Pacific Northwest (Chen et al., 2008).

Chung et al. (2013) describe the use of the WEPS model (Hagen, 1991) within AIRPACT. The wind erosion submodel from WEPS was used as the PM_{10} emissions generator within the CMAQ of AIRPACT and applied regionally to areas divided into Euclidean grid cells. Results from application of the combined system to two observed dust storms in Washington State in 2009 and 2010 are presented, and the predicted occurrence and spatial extent of the dust storms and dust plumes matched the observed data well. The magnitude of elevated PM_{10} concentrations downwind of the sources was very sensitive to surface soil moisture and wind speeds.

A detailed description of the WEPS (Hagen, 1991) management submodel is provided by Wagner and Fox (2013). This submodel simulates the effects of agricultural cropping operations, including tillage, planting, harvesting, residue removal, and irrigation. Operations affect soil surface conditions that then impact the amount of any subsequent wind erosion. Physical processes involved with each operation are identified, and for those with multiple processes a sequence set is created. Process categories include surface modification, soil mass manipulation, biomass manipulation, and soil amendments. Whenever possible, the processes are simulated on a physical basis using conservation of mass principles. Some of the many processes that are simulated within the submodel are soil ridging and flattening, changes in soil random roughness, changes in soil aggregate size distributions, mixing of crop residues into the soil layers, killing live crops, and crop residue removal or addition. New operations can be easily created and used within WEPS to represent new tillage tools or residue management practices.

EROSION MEASUREMENT AND ASSESSMENT

Military training within the U.S. is conducted at over 5000 installations comprising an area of about 12 million ha, and this training can seriously degrade soil surface cover and increase risks of erosion and off-site sediment and other pollutant losses. Howard et al. (2013) provide results of regression analyses of land condition at the Fort Riley military installation in Kansas. Independent variables (total training days per year, ground cover, landscape fragmentation, distance to a road, slope gradient, and Landsat TM bands 1, 2, 3, 4, 5, and 7) were used in linear and nonlinear regressions to predict a RUSLE (Revised Universal Soil Loss Equation; Renard et al., 1997) cover factor that was computed based on observed ground and

canopy cover and canopy height. Coefficients of determination (r^2) ranged from 0.42 to 0.70 for all models, and nonlinear regression was more accurate than linear regression. Ground cover and training days were most correlated with the cover factor, and adding historical land condition variables increased prediction accuracy. Use of the TM images only slightly improved predictions. A combination of stepwise nonlinear regression was the best approach seen in this study.

The Water Erosion Prediction Project (WEPP) model is a state-of-the-art process-based erosion modeling system, developed initially for application to hillslope profiles and small watersheds up to about 260 ha in size (Flanagan et al., 2007; Flanagan and Nearing, 1995). However, there is an increasing need to make detailed WEPP erosion assessments on larger watersheds, particularly those under forest management where large portions of streamflow can come from subsurface water movement. Srivastava et al. (2013) describe the application of WEPP combined with a linear reservoir baseflow component to allow simulation of groundwater flow into streams. They applied this combined model to the Priest River Experimental Forest and found that, when baseflow was considered, WEPP reasonably predicted streamflow, with a Nash-Sutcliffe (Nash and Sutcliffe, 1970) model efficiency value (NSE) of 0.67, and 7% deviation of runoff volume (D_{ν}) , compared to NSE = 0.57 and $D_v = 47\%$ with the original WEPP model.

HIGHLY DISTURBED, URBAN, AND ARID LAND

Military training exercises can negatively impact soil surface vegetation and soil properties, putting training locations at risk of increased wind and water erosion and subsequent sediment losses. The effects of military vehicle traffic on vegetation and soil bulk density were evaluated by Retta et al. (2013). They conducted a field experiment at Fort Riley, Kansas, on two dominant soils (silt loam and silty clay loam) using a Humvee and an Abrams M1A1 tank to represent wheeled and tracked military vehicles. Existing site vegetation and soil bulk densities were measured before and after traffic at three times in 2010-2011. Experimental treatments included the two vehicle types as well as three levels of vehicle passes (curved, straight, cross-over sections in a figure-eight pattern). Retta et al. (2013) found that soil bulk density was significantly greater under the M1A1 tank compared to the Humvee, and increased passes by the tank resulted in significant increases in bulk density. Plant cover and biomass reductions were greater in the curved sections of the track than in the straight sections. This information will be useful for parameterizing process-based erosion models such as WEPS (Hagen, 1991) for military vehicle traffic impacts on soil and vegetation during erosion simulations.

PREVENTION AND CONTROL OF UPLAND

AND IN-STREAM EROSION

Use of plastic mulch (plastic-covered ridge-furrow cultivation systems) can greatly affect hydrologic and erosion processes, and its impact in combination with slope topography is reported by Arnhold et al. (2013). They measured runoff and sediment transport on two

mountainous fields in South Korea, one with a concave topography and one with a convex topography, during monsoonal rain events. Subsequently, the EROSION 3D model (Von Werner, 2009) was applied to compare flow and sediment transport between the fields with plastic mulch, uncovered ridges, and a smooth soil surface. The greatest runoff and erosion rates were from both of the fields with plastic mulch, due to the impermeable surfaces. Uncovered ridges had 140% greater erosion than smooth surfaces on the concave field, but 20% less erosion on the convex field. Simulated sediment routing showed that the ridge-furrow system concentrated overland flow on the concave field, resulting in higher erosion rates. On the convex field, however, the ridge-furrow system prevented flow accumulation and erosion. These experimental and modeling findings impact watershed conservation planning and design of ridge-furrow systems with plastic mulch, so that erosion and sediment losses can be minimized.

SOIL EROSION MODELING

Flanagan et al. (2013) describe mathematical approaches and interfaces that have been developed for geospatial application of WEPP. All current WEPP Geographic Information System (GIS) interfaces utilize the TOPAZ (TOpographic PAramateriZation; Garbrecht and Martz, 1997) automated digital landscape analysis tool for topographic evaluation, drainage identification, watershed segmentation and subcatchment parameterization, as well as custom software built to process information into and out of the GIS used and the WEPP model. GeoWEPP (Renschler, 2003) is an ArcView/ArcGIS extension allowing detailed WEPP model applications with custom user data. Web-based WEPP watershed interfaces have most recently been developed using the MapServer web GIS combined with Google Maps and OpenLayers technologies. Real-world geospatial WEPP model applications are presented by Flanagan et al. (2013).

Dun et al. (2013) used the WEPP model (Flanagan et al., 2007) to assess forest watershed hydrology using long-term observed hydrologic data from two mature forest watersheds in the Fernow Experimental Forest in West Virginia. Model applications were conducted using both the desktop WEPP Windows interface as well as the new online web-based GIS interface (http://WEPPOnlineGIS. bsyse.wsu.edu). When detailed observed climate inputs were used within desktop WEPP, annual runoff predictions with the model were not significantly different from observed runoff for both watersheds at $\alpha = 0.01$. NSE model efficiency values for annual runoff were greater than 0.93 for both watersheds. The online WEPP version using stochastic climate data and more default model settings predicted somewhat lower average annual precipitation and runoff for one watershed and slightly greater precipitation and runoff for the other watershed.

Improvement of an earlier saturation excess erosion model and results of its application to five watersheds in Ethiopia and the U.S. are presented by Tilahun et al. (2013). The Saturation Excess Erosion Model (SEEModel) is based on a semi-distributed hydrology model that calculates saturation excess runoff, interflow, and baseflow, and in the erosion model a linear relationship between surface runoff velocity and sediment concentration is assumed, with zero interflow and baseflow sediment concentrations (Tilahun et al., 2012). The SEEModel was applied to the Anjeni (1.1 km²), Andit Tid (4.8 km²), Enkulal (4.0 km²), and Blue Nile basin (174,000 km²) watersheds in Ethiopia, and to the upper Esopus Creek watershed (493 km²) in New York State. Over all the Ethiopian data sets, NSE model efficiency values for daily stream discharge were greater than 0.77. The NSE value for daily sediment concentrations exceeded 0.56 over all five watersheds examined.

Pinto et al. (2013) present results from an application of the SWAT (Soil and Water Assessment Tool; Arnold et al., 1998; Douglas-Mankin et al., 2010; Tuppad et al., 2011) model to the headwater Lavrinha Creek watershed (LCW) in the Mantiqueira mountain range in eastern Brazil. Climate data, streamflow, and suspended sediment concentrations for the LCW were monitored beginning in January 2006. Observed data from 2006 to 2010 were used in SWAT model calibration and validation exercises. NSE values for streamflow were 0.81 for the calibration period and 0.79 for the validation period. For sediment concentrations, the NSE values were 0.68 for calibration and 0.74 for validation. Based on these results, the SWAT model was an acceptable tool for water resources management at this location in Brazil.

The process-based WEPP model (Flanagan et al., 2007) currently predicts runoff, soil erosion, and sediment losses, but there has been considerable interest in expanding its capabilities to also allow simulation of agricultural chemical transport. Saia et al. (2013) describe linkage of WEPP with a pesticide module adapted from Steenhuis and Walter (1980) and evaluation of this coupled model with data from the Goodwater Creek Experimental Watershed (GCEW) in northeastern Missouri. Runoff and atrazine concentrations predicted with the coupled model were compared to observed values from field plots under no-till (NT) and mulch till (MT). WEPP predicted the occurrence and magnitude of runoff well, with event NSE values of 0.79 and 0.84 for NT and MT, respectively. The pesticide module predicted dissolved atrazine concentrations well, with event NSE values of 0.71 and 0.59 for NT and MT, respectively. Seasonal NT atrazine losses were greater than MT atrazine losses.

McCool et al. (2013) provide information on extensive evaluations of observed runoff and erosion from events at the Palouse Conservation Field Station (PCFS) in southeastern Washington State and determination of soil hydraulic and erosion input parameters for the WEPP (Flanagan et al., 2007) model. Data from 1984-1990 from two continuous bare fallow plots were used in multiple WEPP model simulations, and optimized values for effective hydraulic conductivity, rill erodibility, and critical hydraulic shear stress were determined. Results indicate that the internal WEPP adjustment factors for rill erodibility and critical hydraulic shear stress could be improved to simulate soil freeze and thaw impacts.

IMPACTS OF GLOBAL CHANGE ON EROSION AND LANDSCAPE EVOLUTION

Global environmental change is often associated with changes in rainfall occurrence and intensities. Klik and Konecny (2013) report on changes in calculated rainfall erosivity values using 15 min breakpoint rainfall data from 51 long-term (9 to 53 years) recording rain gauges in northeastern Austria. The rainfall-runoff (R) erosivity factor for the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997) was determined for each of the 51 stations, and spatial and temporal trends were evaluated. The study divided the region into Lower Austria (LA) with rain gauge elevations between 150 and 917 m asl, and Upper Austria (UA) having rain gauges at elevations between 235 and 635 m asl. The average R factor was 884 MJ mm ha⁻¹ h⁻¹ in LA (range 273 to 1599) and 982 MJ mm ha⁻¹ h⁻¹ in UA (range 637 to 1697). There was a significant increasing temporal trend observed in LA for rainfall intensities, R factor, and number of storms at 90% of the stations with data records longer than 25 years. This magnitude of temporal changes in rainfall characteristics was not seen in the UA data. These results indicate changes in rainfall patterns in eastern Austria and increasing erosion risk there.

Dabney et al. (2013) discuss the effects of topographic feedback on soil erosion and sediment deposition predictions through development and application of a spatially distributed version of the RUSLE2 (USDA-ARS, 2008) model combined with the Tillage Erosion and Landscape Evolution Model (TELEM; Vieira and Dabney, 2009). These models were applied to a 6.6 ha research watershed near Treynor, Iowa, having observed daily runoff and sediment yield data from 1975-2002. A 3 m raster DEM was used to delineate the watershed boundary, and RUSLE2 hillslope profiles ended at channels with contributing areas that exceeded 600 m². Average monthly runoff and sediment delivery to the channels from representative RUSLE2 hillslopes were compared to measured values at the watershed outlet, and under conventional tillage (1975-1995) the predicted monthly runoff matched observed values well. However, RUSLE2predicted watershed sediment losses were much greater than those observed, which was most likely due to sediment in the field depositing in the grass waterway channels. The period of no-till cropping and management (1995-2002) greatly reduced the RUSLE2 estimates of sediment loss but had much less impact on the observed watershed sediment yields. The predicted spatially distributed patterns of soil loss appeared reasonable, and grass hedges (1991-2002) reduced both the predicted soil loss and the observed watershed sediment yield. Impact of sediment deposition above the grass hedges on projected future erosion rates was determined by modifying the slope gradients from a simulation of 50 years of conventional tillage, which resulted in reduced gradients and reduced future erosion rates.

SUMMARY

Soil erosion by wind and water continue to threaten world agricultural lands, but research by engineers and scientists allows better understanding of the physical processes involved and development of practices and methods to reduce and control soil losses. ASABE members are leaders in these areas, as evidenced by the 24 articles of this special collection. International meetings, such as the symposium that generated these articles, allow exchange of ideas and addressing soil erosion problems as rapidly as possible with the most current technologies.

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