This paper was peer-reviewed for scientific content.
Pages 747-750. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

TEAM: The Texas Tech Wind Erosion Analysis Model

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ABSTRACT

TEAM is a wind erosion simulation model that provides outcomes of soil movement or deposition for up to 10 sequential land segments. Land segments can vary in soil type and cover conditions. A windbreak can also be used at the end of each segment. The amount of suspended material (dust concentration) including a PM10 calculation is determined at various heights at the downwind end of each segment. The current TEAM program is being expanded to generate dust concentrations at various distances and heights for downwind estimates of dust loading into the atmosphere. TEAM is designed to evaluate soil conservation practices and to evaluate offsite damages from sediment and dust.

INTRODUCTION

Need for Wind Erosion Model

Wind erosion occurs at numerous locations on Earth and other planets, such as Mars. As a result, wind erosion impacts activities of man in a variety of settings including but not limited to construction sites, agricultural fields, space exploration, and military operations. Wind erosion affects air quality, health, visibility, highway safety, sediment deposition, crop production, and global circulation, especially in the case of Mars. Wind erosion certainly is more than just an agricultural problem.

Understanding the process of soil detachment by wind and the suspension of dust is an important scientific problem. Likewise, modeling the process with the prediction of outcomes associated with treatments is important to mankind.

Gregory, et al. (1999) describes the wind erosion process and the modeling of individual components. Soil erosion is an energy driven process that begins with detachment. Detachment occurs from drag and lift forces produced by wind flowing around and over particles or from impact forces from the kinetic energy of soil particles moving with the wind when they return to the soil surface. The second part of the soil erosion process is the movement of the detached particle downwind until it eventually settles out of the flow. Larger particles tend to settle back to the soil surface quickly after detachment and require a re-detachment for further movement. Small particles may settle at a velocity lower than the upward component of turbulence in the wind and, thus, go into suspension. Suspended particles eventually settle back to the soil surface; however, there is an opportunity or probability for some of these particles to travel great distances before returning the ground level.

The objective of this paper is to describe the computer program known as TEAM (**T**exas Tech Wind **E**rosion **A**nalysis **M**odel). This program simulates the wind erosion process and provides outcomes of soil movement and sediment deposition for a sequence of up to 10 segments of soil and cover (land management) combinations. TEAM also is structured to provide estimates of dust concentrations including PM_{10} (particle matter less than 10 microns in diameter) and length of visibility both at the field level, at various elevations above field level, and at locations downwind of eroding sites. By sequencing segments with representative soil types and land management, it is possible to generate a regional representation of dust loading into the atmosphere and the downwind outcomes of dust concentration, visibility, and air quality. TEAM, thus, is designed to analyze both onsite and offsite impacts of wind erosion associated with inputs of both nature and actions of man.

History of TEAM

The history of TEAM begins with the history of understanding and modeling the wind erosion process. Ralph Baghold, was a key individual in the early stage of this history providing two fundamental relationships: (1) that maximum transport at winds high above threshold velocity is controlled by the cube of the wind velocity and (2) that threshold velocity for dry conditions (low relative humidity) is controlled by the square root of particle size. The literature by Baghold is also filled with other treasures of understanding that help in "systems thinking" of the wind erosion process. Baghold focused on understanding the movement of loose soil, such as sands in desert environments.

A second individual of high importance in understanding wind erosion is William Chepil who worked with soils instead of sand and measured the influence of dry bonding or soil aggregates on the wind erosion process. Chepil made many measurements in agricultural fields documenting that soil type interacts with field length to determine the rate of soil erosion. While Chepil was not successful in developing a mathematical equation to accurately describe the length effect, Gregory (1984) used Chepil's data and derived a fundamental equation to describe the length effect.

From 1985 to present, a "systems thinking" approach has been used at Texas Tech University under the leadership of James Gregory to develop the current understanding and

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mathematical modeling used in TEAM. Gregory et al. (1999) provide a brief description of each component with reference to the original work. Most of this research has been theoretically based and associated with teaching a graduate level class on soil erosion. Some funding has been provided by the Army Corps of Engineers to study moisture effects on threshold velocity, the National Science Foundation to support graduate students, and the National Institute of Standards and Technology to support undergraduate students working as interns to convert the TEAM research model to the current user-friendly TEAM program. The United States Department of Agriculture has not funded the development of TEAM but funded a study to determine the loading of dust into the atmosphere. A follow up study was funded to determine the effects of changes of land use policy on the generation of dust in the Great Plains. Finally, at the request of environmental consulting firms working to clean up a nuclear materials processing plant and the area surrounding the plant, the Department of Energy funded a short course on TEAM in 1995 and adopted the TEAM model to perform the safety analysis for the "super site" cleanup. Also during Operation Desert Storm, funding was provided to develop solutions to stabilize sand barriers used in military operations. The result has been a focus on theoretical understanding and applications to real problems. Even counting applications work, the funding level has averaged less than one-fourth full time researcher per year during the last 14 years. During this period, four graduate students and two undergraduate students have been funded to work on wind erosion. The cost for the development of TEAM has been extremely low compared to other research tasks of a similar nature.

Structure of Code and Control of Process

TEAM is designed with a core wind erosion and dust generation model. The program is dimensioned to include up to 10 length segments. Each of these segments can be a source of wind erosion and dust. Any segment can have sufficient cover to prevent wind erosion. TEAM is also structured with the option to use a windbreak (snow fence, trees, grass and weeds in fencerow, etc.) that can vary in height and porosity. The windbreak, if used, is located at the end of each segment. When a windbreak is selected, TEAM reduces the wind behind the windbreak reducing the friction velocity in contact with the land surface. When transition is made from one length segment to the next, an iteration process is used to determine the length associated with the new conditions that give the same rate of movement as the previous conditions. If the previous rate of movement exceeds the maximum transport rate for the new conditions, the difference is calculated as deposition. The equation used to calculate the rate of soil movement is an integrated form of maximum transport rate and length effect. The resulting equation is the maximum transport rate times a length factor. Several advantages are associated with this integrated model compared to a differential equation for wind erosion. These advantages are (1) stable boundary conditions, (2) increased speed in executable computer code, (3) physical meaning for researchers and programmers developing the code, and (4) minimum data input required for calibrating the system to generate the desired outcomes.

The core computer code is programmed in C++ for speed and efficiency in computer usage. The current code runs on a 32-bit Windows platform (Windows 95, 98 or NT). Because of the complexity of the nested loops, the problem does not easily lend itself to a parallel structured computer code. The core, however, could easily be repeated and operated as a parallel code to generate dust occurring from multiple sources for input to global circulation models. A typical run time for a simulation over a year period of time and for three to five length segments ranges between 30 and 90 seconds depending on the speed of the computer processor.

The input and output to and from the core model is controlled with a Visual Basic code. Output is provided as a text document and as graphs using Excel. The user simply selects the output graphs to be generated from the output data.

For input, the user sees several "Forms" or input boxes and makes a selection of location to get wind, relative humidity, and rain day data. A similar box is used for soil type to get soil particle size distribution (clay percentages is included as a variable). Another box is used for cover selection (bare soil, grass, and crop rotations).

The input boxes provide information that directly controls the erosion process. The physical process is modeled as follows. TEAM adjusts the maximum transport rate based on both particle size and particle size distribution. Rate of movement increases as particle size increases until the particle size is too heavy to move. Rate of movement is also highest for mixed particle sizes. Rate of movement is reduced as relative humidity increases because of the increased forces resisting particle detachment from surface tension and viscosity effects of water around the particles. Increasing fraction of cover or height of cover reduces the rate of movement. For small amounts of cover, however, the benefits of cover are countered by an increase of wind velocity at the land surface associated with an increase in aerodynamic roughness. TEAM also adjusts calculations for field conditions compared to wind tunnel conditions using a wind gust factor. Movement for field conditions is higher than for wind tunnel conditions.

TEAM also allows the user to generate new soil types and cover conditions. The user can also select English or metric units for either input or output. Because of the flexibility in use of units and the minimum requirements for data input, TEAM is flexible and relatively easy to use.

Because TEAM is stable at boundary conditions, outcomes can be predicted for sand as found in sand dune areas on Earth and Mars as well as for soil conditions at construction sites and agricultural fields. The current TEAM code also allows the user to select an analysis for a normal or drought year. A drought year selection results in reduced soil strength, increased soil erodability, and increased soil erosion associated with weakening of soil bonds. The basis for this adjustment is the historical dust-hour record at Lubbock, Texas. The probable cause for the increased erosion for the same wind and relative humidity conditions is the weakening of soil bonds from a large number of cycles of high and low relative humidity associated with night and day temperature changes. Drying after light rainfall will also weaken soil strength. During normal years a few large rain events typically occur which saturate the soil and re-establish strong bonding between soil particles causing aggregate formations.

Finally, TEAM is designed with a Help button where definitions and information about the wind erosion process and the program can be found. This Help section provides graphical relationship of trends as well as text information.

Example Output

As a means of illustrating the utility of TEAM, a few examples of output will be presented. The text output is long: 12 page (one page per month) for each segment. Therefore, only graphical output will be included in this paper. The effect of changing cover conditions on the rate of soil movement is shown in Fig. 1 for a sequence of bare soil, grass, and fallow-wheat. Note that the strip of grass stopped the soil movement. Fig. 2 illustrates the buildup of soil

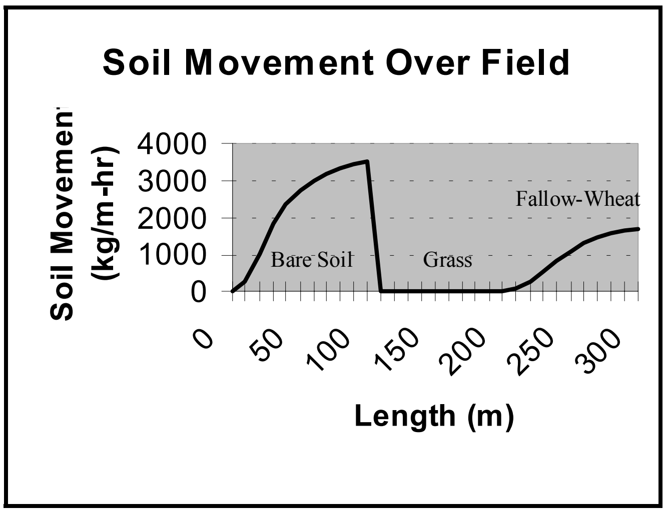

Figure 1. Simulations of changing cover effects on rate of wind erosion.

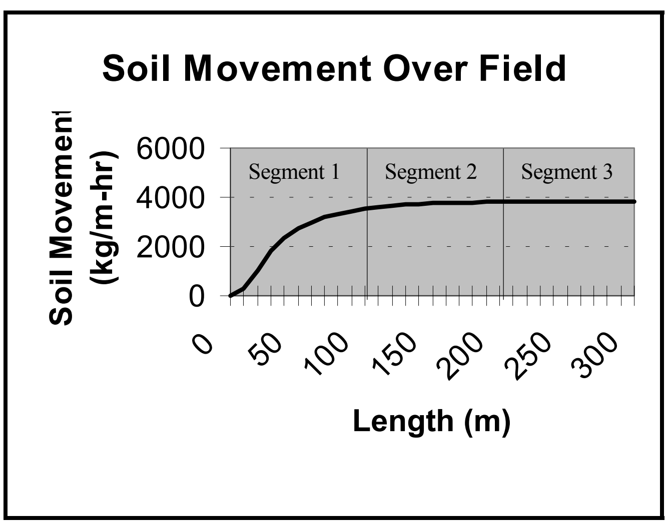

Figure 2. Simulation for three length segments of bare soil with same clay content.

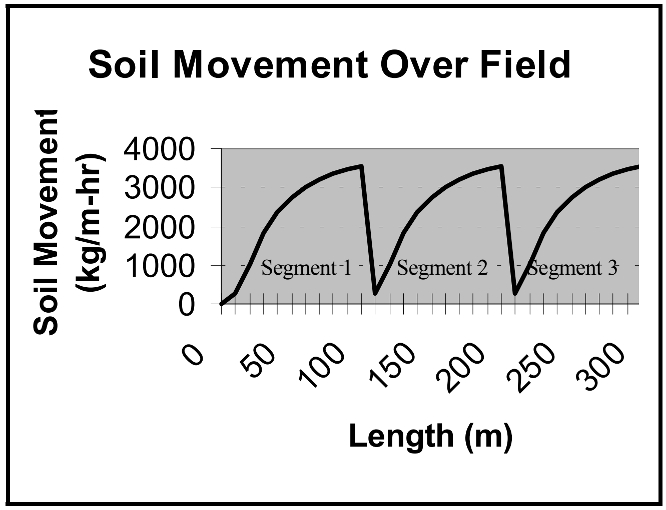

Figure 3. Effect of windbreaks on soil movement.

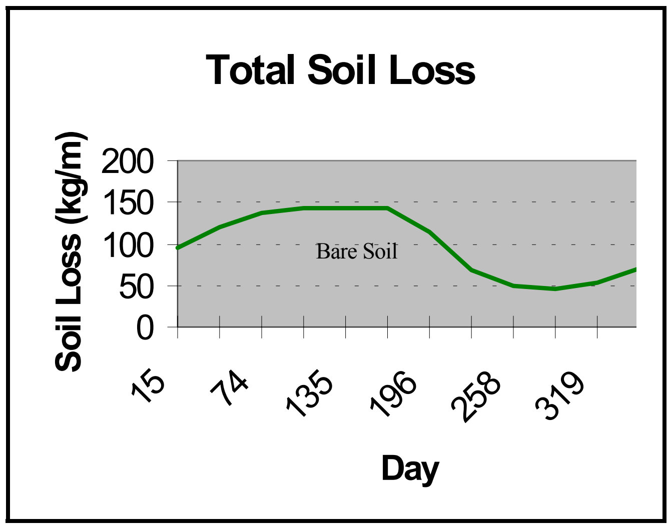

Figure 4. Output for bare soil as a function of time.

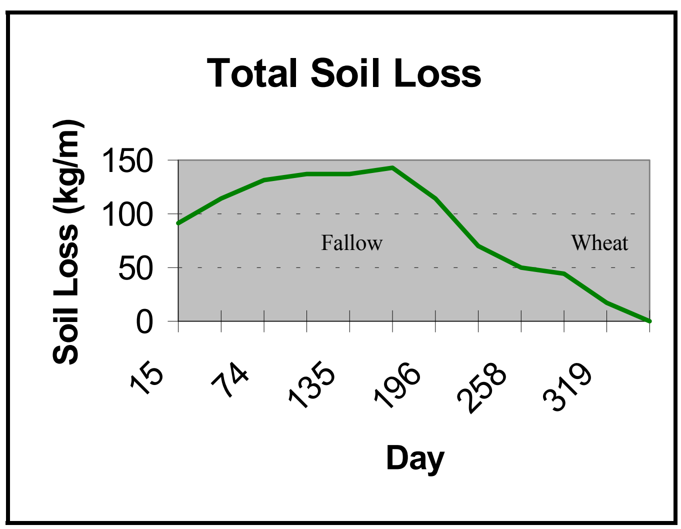

Figure 5. Effect of tillage associated with fallow and growing wheat crop on rate of soil erosion.

movement over bare soil for three length segments. Note that the buildup across segments is relatively smooth. The same conditions are shown in Fig. 3 except with windbreaks 2 m in height and 40 percent porosity. Note that the windbreaks caused the erosion process to start over.

The rates of movement shown in Figures 1-3 are for the highest wind velocities expected in Lubbock, Texas excluding extreme winds associated with tornadoes and thunderstorms. The total soil movement in TEAM is calculated by calculating the rate of movement for 1, 3, 5, and 7, etc m/s velocities times the probability of winds being at each of these levels. This calculation is made for each hour of the day and summed over the whole day. The average rate of movement is much less than the high-wind movement shown in these figures.

Fig. 4 illustrates the variation in soil movement associated with season of year for bare soil conditions. Note the smooth cycle associated with wind and relative humidity changes. The effect of crop growth is shown in Fig. 5. Note how the shape of the cycle has changed due to the crop cover changes throughout the year.

SUMMARY AND CONCLUSIONS

A process-based wind erosion and dust generation model has been developed at Texas Tech University with minimal cost for the research. The TEAM program is a computer code that enables a user to determine outcomes associated with management and variations in natural input, such as wind and relative humidity.

The TEAM program is designated with a core code written in C++ language to minimize computer time for the many calculations necessary to complete a simulation. The input and output components of TEAM are written in Visual Basic to provide an easy to use interface with the user.

While the current TEAM program is useful to compare management systems on the rate of soil movement and dust concentrations, more work is planned to expand the utility of TEAM, as funding becomes available.

ACKNOWLEDGEMENTS

Funding for the programming of TEAM in its current form was provided from the National Institute of Standards and Technology.

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