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The Wind Erosion Prediction System and its Use in Conservation Planning

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Abstract

Soil erosion by wind is a threat to sustainable agriculture as well as human, soil, air, and water resources. In the past, the development of wind erosion control systems for cultivated land has largely been a process of developing experience from repeated trial and error over many years by farmers to determine the best practices for their particular farm or with changing cropping systems or weather variability. The Wind Erosion Prediction System (WEPS) is a computer based model developed to provide an accurate, universal, and simple tool for simulating soil wind erosion. The Wind Erosion Prediction System incorporates 70 yr of wind erosion research by the United States Department of Agriculture (USDA) and utilizes advances in computer technology to provide a state-of-the-art research and decision-support system for producers as well as agricultural policy agencies. It is a multi-disciplinary model that simulates interactions between management operations, soil water dynamics, plant growth, residue decomposition, and soil erodibility. The model interface was designed for easy selection of inputs from provided databases and outputs that are straightforward to interpret. The strongest benefit of WEPS is its ability to provide producers a system to apply different "what-if" management scenarios to the land for developing and evaluating alternative wind erosion control practices. This paper provides a detailed description of the development, structure, and uses of the WEPS model including applications beyond farm conservation planning. We also present example scenarios of using WEPS to demonstrate the process of developing alternative erosion control strategies for common cropping systems of the U.S. Great Plains.

Wind erosion of soil not only affects agricultural productivity but also contributes to degraded human health as well as reduced soil, air, and water quality. Wind erosion physically removes the most fertile portion of the soil from the field and therefore, lowers the productivity of the land (Lyles, 1975, 1977). Soil blown by wind has been recognized as a serious health and environmental issue associated with reduced air quality and visibility (Chepil and Woodruff, 1957; Hagen and Skidmore, 1977; Gillette, 1986; Carvacho et al., 2001), soil nutrient loss

Abbreviations: MCREW, Management Crop Rotation Editor for WEPS; NRCS, Natural Resources Conservation Service; WEPS, Wind Erosion Prediction System; WEQ, Wind Erosion Equation.

Key words: Soil erosion, models and modeling, soil conservation

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Bridging Among Disciplines by Synthesizing Soil and Plant Processes
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(Zobeck and Fryrear, 1986; Larney et al., 1998), and nutrient and/or chemical loading on regional ecological systems (Leys, 1999; Leys and McTainsh, 1999). Dust has also been implicated as a factor in early melt of mountain snow packs (Painter et al., 2012) and global climate change (Prospero and Lamb, 2003; Lambert et al., 2008). In addition, soil particles entering water systems are one of the most costly off-site damage from wind erosion (Pimentel et al., 1995; Pimentel and Burgess, 2013; Larney et al., 1998).

Periods of long and severe drought have exacerbated the wind erosion problem and highlighted it as a threat to a sustainable agricultural food supply for the world's population (Lal, 2001; Guo et al., 2014). The prolonged drought of the 1930s in the U.S Great Plains, known as the Dust Bowl, as well as a similar 50 yr drought in southeast Australia had similar causes of overuse of the land prior to drought and comparable effects to the land and long distance transport of dust (Lee and Gill, 2015; Cattle, 2016).

In response to the long-term drought and resulting severe problems of wind erosion in the 1930s, the U.S. Department of Agriculture (USDA) established a research program to understand and combat this ever-present problem. As part of this program, the USDA-Agricultural Research Service (ARS) has focused considerable research effort into developing predictive models for wind erosion (Tatarko et al., 2013). This effort eventually resulted in the multidisciplinary WEPS model used in the United States for planning wind erosion control systems for soil conservation (Wagner, 2013).

A common metric of what is considered acceptable loss is the "soil loss tolerance" or "*T*-value" assigned to each soil map unit by NRCS. The *T*-values represent the average annual erosion rate (mass per area per year) that can occur and still permit a high level of crop productivity to be sustained economically and indefinitely (Wischmeier and Smith 1978). The *T*-values vary among U.S. soil types from 0.224 to 1.12 kg m^{-2} yr^{-1} (1 to 5 tons $acre^{-1}$ yr^{-1}). However an adjacent field with a growing crop that is sensitive to wind erosion sandblast damage may require lower than soil *T*-value erosion rates. The USDA-NRCS (2000) has defined the maximum wind erosion that various growing crops can tolerate, from crop emergence to field stabilization, without an economic loss to stand, yield, or quality.

Throughout the history of cultivated agriculture, wind erosion of soil and its control has been a constant problem (Lal, 2001). The development of wind erosion control systems on cultivated land has been a process of developing experience from trial and error over many years by farmers to determine the best practices to control this problem. Our objectives are to describe the WEPS model development, structure, and uses and to demonstrate its use, its outputs, and associated tools for exploring alternative conservation planning scenarios for reducing wind erosion soil loss from cultivated agricultural fields. A series of simple example scenarios are presented with the evaluation of model outputs directing the application of increasing erosion controls until the soil loss is below the *T*-value.

The WEPS Model

The wind erosion research program, established by the USDA-ARS as a response to the Dust Bowl of the 1930s, has contributed 70 yr of research into wind erosion processes, control practices, and the development of simulation models (Tatarko et al., 2013). A project that utilized this vast knowledge base to development of a state-of-the-art wind erosion simulation model was begun in 1985 (Wagner, 2013) with the goal to provide accurate, universal, and simple simulations of soil loss by wind (Hagen, 1991) and utilize advances in computer technology to provide a powerful research and decision-support tool for researchers, producers, and policymakers (Wagner, 2013). The WEPS model was developed at the request of the USDA-National Resources Conservation Service (NRCS) to replace the empirical Wind Erosion Equation (WEQ), which was published in 1965 by Woodruff and Siddoway (1965). In 1985, the NRCS requested that ARS develop an eventual replacement for WEQ (Wagner, 2013), one that takes advantage of increasing computer power, improved simulation modeling techniques, and the latest research of the physical processes of wind erosion, the effects of management operations, soil water dynamics, plant growth, residue decomposition, and soil erodibility. The resulting WEPS model was released to the NRCS in 2010. In the U.S. alone, WEPS is currently installed on approximately 15,000 NRCS computers nationwide to: i) assist land managers in controlling wind erosion; ii) establish acceptable field-level plans to conserve the soil; and iii) determine wind erosion susceptibility as part of the Conservation Reserve Program (CRP) to conserve the soil resource and other national programs. National Resource Conservation Service considers WEPS a critical component of the USDA strategy to reduce particulate emissions from cultivated agricultural lands through improved land management (Tatarko et al., 2013). Because of its improvements over WEQ, the U.S. congress stipulated that NRCS use the WEPS model "… where wind erosion is the primary causal factor for comparing the annual level of erosion before conservation system application to the expected annual level of erosion after conservation system application." (Federal Register Vol. 75, No. 234; 7 Dec., 2010: pp. 75961–75962; http://www.gpo.gov).

The most recent USDA-National Resources Inventory (USDA-NRCS, 2015) estimates that erosion due to wind on 125.6 million hectares of U.S. non-federal cultivated cropland in 2012 was approximately 4.35 Mg ha^{-1} yr^{-1} with an average of 5.82 Mg ha^{-1} yr^{-1} since 1982 (USDA-NRCS, 2015). National Resource Conservation Service considers WEPS an essential tool for planning crop management systems for soil conservation and uses the model to evaluate erosion potential (i.e., high or low), on 14 million hectares where soil conservation practices are applied through conservation programs. From October 2012 to June 2013 alone, NRCS applied WEPS for planning cropland conservation practices on over 2 million hectares nationally where wind erosion potential was found to be high (personal communication, Joel Poore, USDA-NRCS Wind Erosion Specialist). In addition to wind erosion planning, NRCS uses WEPS for nutrient management applications to improve water quality as well as soil quality and energy efficiency assessments. The USDA Climate Change Program Office also uses WEPS to estimate carbon loss for green house emissions estimates.

The Wind Erosion Prediction System has been used for a variety of research and other applications including mapping wind erosion risk in Canada (Coen et al., 2004), predicting dispersion of fine particulates over a large region in Mexico (Diaz et al., 2010), development of wind erosion control strategies for a contaminated soil storage facility (Hagen et al., 2009), regional wind erosion estimates via GIS applications of WEPS (Gao et al., 2013; Chung et al., 2013), assessing biomass removal effects on wind erosion (Muth and Bryden, 2013; Nelson et al., 2015; Blanco-Canqui et al., 2016), wind erosion estimation under climate change (Sharratt et al., 2015), and predicting soil loss from military training activities (van Donk et al., 2003; Meeks et al., 2015). Research involving WEPS has been published by users in Argentina, Burkina Faso, Canada, China, Germany, Mexico, and Sweden (Buschiazzo and Zobeck, 2008; Chen et al., 2013, 2017; Coen et al., 2004; Diaz et al., 2010; Funk et al., 2004; Jia et al., 2014; Liu et al., 2013; Li et al., 2015; Maurer and Gerke, 2011; Visser et al., 2005; Zhang et al., 2017). Since its release, more than 560 copies of WEPS have been downloaded by users in 31 countries. Numerous universities also use WEPS for extension and education purposes.

The Wind Erosion Prediction System technology allows government agencies, researchers, and individual farmers to apply knowledge from research findings to specific tracts of land to simulate and assess wind erosion and develop improved control strategies. The WEPS model, combined with a simple-to-use interface provides a means to input a basic field description, calculate soil loss, and display outputs for designing erosion control strategies (a typical simulation is 50 yr in < 1 min of runtime). The Wind Erosion Prediction System models the surface state and wind erosion as physically based processes as much as possible (Hagen, 2004a). Process-based models use equations derived from observations to calculate the values for a given set of input values and a given amount of time. The WEPS innovative modular design allows for continual model updating as new knowledge is gained through research. It is designed as a complete stand-alone package allowing a simulation using only the input of field dimensions with the location, soil, and management practices selected from pre-developed lists for the area. Some modification of site specific inputs are possible at the users' discretion.

WEPS Science Development

The WEPS project is the result of synthesizing research from multiple disciplines including climatology, hydrology, soil science, agricultural engineering, crop science, computer science, and wind erosion. The WEPS development project had a multi-agency commitment including the ARS, NRCS, and the Forest Service from the U.S. Department of Agriculture, along with the Environmental Protection Agency, the Army Corps of Engineers, and the Bureau of Land Management. A detailed description of the development of the WEPS model is provided by Wagner (2013).

Numerous field and laboratory studies were conducted to develop relationships between surface conditions and erosion. Field and laboratory experimental data were collected to support the simulation of weather (Skidmore and Tatarko, 1990; van Donk et al., 2005), hydrology (Durar et al., 1995), crop growth (Retta and Armbrust, 1995; Retta et al., 2000), residue decomposition (Steiner et al., 1994; Schomberg et al., 1996), soil processes (Lyles and Tatarko, 1987; Potter, 1990; Zobeck and Popham, 1990, 1992; Layton et al., 1993), field management (Wagner et al., 1992; Wagner and Ding, 1993; Wagner and Nelson, 1995), and erosion (Hagen, 2004b; Hagen, and Armbrust, 1992; Hagen et al., 1999, 2010).

The resulting WEPS is a physically-based model that simulates weather, field surface conditions, and erosion on a less than daily (e.g., hourly) time-step (Hagen, 2004a; Wagner, 2013). As shown in Fig. 4–1, the WEPS structure consists of a user interface (programmed in Java), a science model (programmed in Fortran) with a main controlling routine and six science submodels (hydrology, management, soil, plant growth, residue decomposition, and erosion), and five databases (soil, plant growth and residue decompositions, operations, wind barriers, and climate). The technical documentation of WEPS provides a detailed description of each of the wind erosion science submodels within the model (USDA-ARS, 1995).

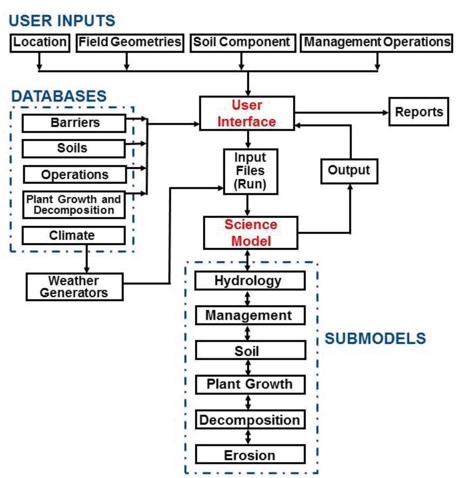


Fig. 4–1. The fundamental structure of the WEPS model.

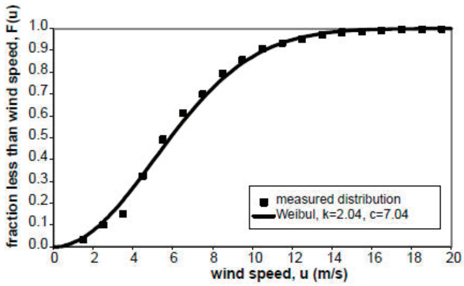


Fig. 4–2. Cumulative distribution of measured wind speed data and fitted Weibull curve for Sidney, Nebraska, for December with winds coming out of the northwest (from van Donk et al., 2005). The Weibul distribution parameter "*k*" is the shape parameter (dimensionless) and "c" is the scale parameter (m s^{-1}).

Weather is the primary driver of changes in soil surface physical processes, plant growth, and residue decomposition. The WEPS weather generators simulate the needed weather data through two separate weather models. The CLIGEN model is a stochastic generator of climate (weather) data, simulating daily estimates of precipitation (amount, duration, peak intensity), temperature (maximum, minimum, dewpoint), wind (direction and speed), and solar radiation. It generates these for a single geographic point, using monthly statistical parameters (means, standard deviations, skewness, etc.) derived from historic measurements. The wind parameters in CLIGEN are not of sufficient detail for WEPS and so the WINDGEN model was created to provide the needed wind parameters. Similar to CLIGEN, WINDGEN is a stochastic wind generator that uses the frequency distributions of historic subdaily (i.e., hourly) wind speeds by direction for each month to generate wind parameters, providing the unique requirements of hourly wind speeds and daily wind direction for each day of simulation. Two different methods were used to summarize wind speed statistics: i) fitting the two-parameter WEIBULL model to the measured wind speed distribution by direction for each month (e.g., Fig. 4–2), and ii) for improved representation of the upper wind speed distribution tails, the measured wind speed distribution histogram, by direction, was used directly with linear interpolation between histogram wind speeds classes when necessary. Since WINDGEN bases its generations on historical statistics of wind, it reflects the past wind histories at a given location. Station parameter files (summary statistics) to run both generators are available for several thousand U.S. locations. CLIGEN and WINDGEN data were often not collected at the same location, making the data sets for each generator distinct.

The hydrology submodel of WEPS simulates soil energy dynamic changes, including soil temperature and water content at the surface, including snow, and in soil layers, including the effects on the growing plants and standing and flat surface residue decomposition. This submodel maintains a continuous, daily, soil water balance and flow accounting for water in the soil profile, daily precipitation and irrigation, snow depth and melt, runoff, evapotranspiration, and deep percolation. Evapotranspiration is partitioned into evaporation at the soil and/or snow atmospheric interface and crop transpiration, accounting for standing and flat crop residue evaporation suppression effects. Two methods of solving the soil water balance are implemented. In the first, the one-dimensional Darcy equation is applied to a thinly layered soil profile and solved as a system of ordinary differential equations. The soil water content at the soil-atmosphere interface is then estimated using the functional relationship between surface-soil wetness and the evaporation ratio. The second, faster, method uses the Water Erosion Prediction Project (WEPP) hydrology model adapted to the WEPS modeling system. For this, the soil water content at the soil-atmosphere interface is estimated using the water content of a very thin surface layer. An example comparison of the simulated evaporation by each method is shown in Fig. 4–3.

User-prescribed management practices, including but not limited to, tillage, planting, harvesting, and irrigation, are simulated in the WEPS management submodel (Wagner and Fox, 2013). The management submodel simulates individual management operations as a set of physical processes (Table 4–1). Those processes include: i) surface modification (i.e., creation or removal of oriented roughness such as ridges and dikes, changes in surface random roughness, and removal of soil crust); ii) soil layer mass changes (i.e., soil aggregate size distribution and porosity, mixing of soil and residue in and between soil layers, and soil layer inversion); iii) biomass manipulation (i.e., bury and resurface residue, flatten standing residue, kill live crop biomass, and biomass removal); and iv)

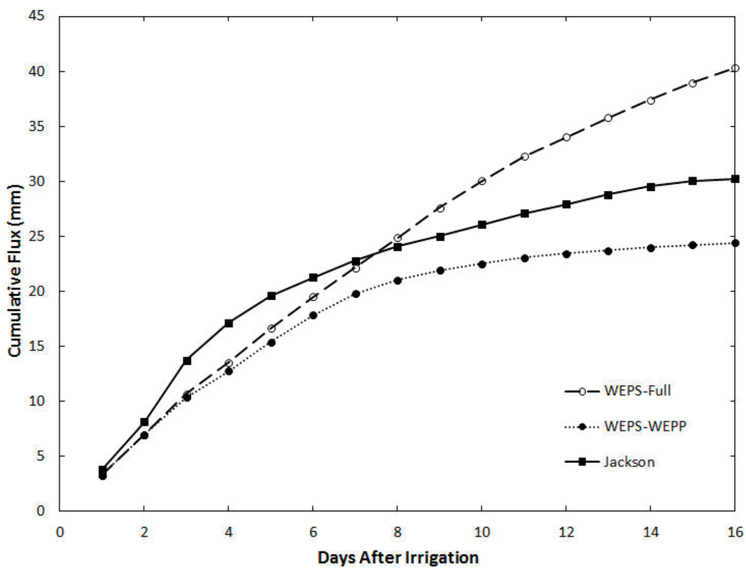


Fig. 4–3. Comparison of cumulative evaporation flux as measured by Jackson (1973) and simulated by WEPS using Darcian-based hydrodynamic simulation (WEPS-full) and WEPP hydrology (WEPS-WEPP).

Table 4–1. Management processes of WEPS.

Action	Process	Description
Soil surface manipulation	Crust	Process of modifying the soil surface crust characteristics.
	Roughen	Process of modifying the random surface roughness.
	Ridge/Dike	Process of creating or destroying ridges or dikes (oriented surface roughness).
Soil mass manipulation	Crush	Process of applying forces to the soil that modifies the aggregate structure by breaking down soil aggregates.
	Loosen	Process of decreasing the soil bulk density and increasing the porosity (incorporation of air), or the inverse process of increasing the soil bulk density by removing air from the soil, e.g., compaction.
	Mix	Process of uniting or blending of soil layer properties, including biomass.
	Invert	Process of reversing the vertical order of occurrence of the soil layers within the current specified tillage zone.
Biomass manipulation	Flatten	Process of converting standing biomass to flat biomass.
	Bury	Process of moving surface biomass into the soil.
	Re-surface	Process of bringing buried biomass to the surface.
	Change standing biomass fall rate	Process that adjusts the standing biomass fall rate to account for the accelerated change in standing residue due to roots being loosened or cut from the standing stalks due to tillage.
	Cut/Remove	Process of cutting standing biomass to a prescribed height and placing the cut material on the surface or, optionally, removing (harvesting) the cut material.
	Thin population	Process of reducing the number of standing biomass stems or stalks by a fraction of the total or to a specified number per unit area and placing the thinned material on the surface or, optionally, removing (harvesting) it.
	Kill/Defoliate	Process of killing or defoliating live (or dead) biomass.
	Remove	Process of removing biomass from the system (harvest, grazing and burning).
	End biomass manipulation	Process that transfers the killed crop biomass to the residue decomposition pools.
Soil amendments	Plant	Process of adding seeds/plants to the soil.
	Irrigate	Process of adding water on or into the soil.
	Add biomass	Process of adding biomass (residue, manure, wood chips) to the surface or into the soil.

soil amendments (i.e., manure and residue additions, planting, and irrigation). The individual processes and their order of simulation, along with each process parameter value uniquely describe the specific operation effect on the soil, surface, and vegetation present.

The soil submodel simulates temporal changes in soil physical properties of soil layers and the surface due to weathering processes between management events. Weathering processes affecting change include precipitation (raindrop impact), wetting, drying, freezing, thawing, and freeze-drying. The soil submodel updates the relevant temporal variables by simulating the effects of these processes on ridge, furrow, and dike height; random roughness height; crust thickness; crust cover fraction; crust stability; loose erodible material on the crust; dry aggregate stability; aggregate size distribution; bulk density; crust and aggregate density. A temporal variable to be updated is generally a function of more than one driving process as well as intrinsic soil properties.

Two approaches are used in updating the variables affecting soil erodibility. For the first approach, a simple, typical case is illustrated in Fig. 4–4, where the individual effects of Process A and Process B on ridge height are known. In the field, however, these driving processes, A and B, may occur in many combinations of sequences. It is assumed that an explicit relationship (Eq. [1]) is known from field data or other experiments.

$$Y = f(X_j) \quad [1]$$

where Y = a dependent soil temporal variable, and X_j = an independent driving process variable which changes Y. Now, in principle, one can express X_j in terms of Y, that is:

$$X_j = f(Y) \quad [2]$$

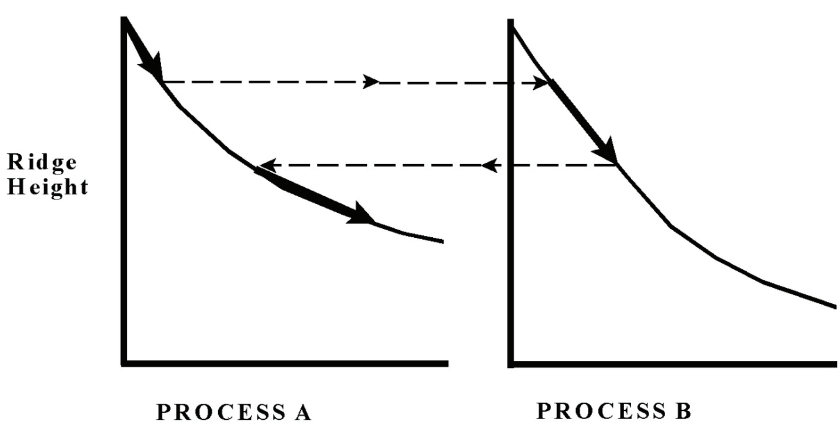


Fig. 4–4. Conceptual example of a temporal variable (e.g., ridge height) affected by two processes (e.g., soil wetness and raindrop impact).

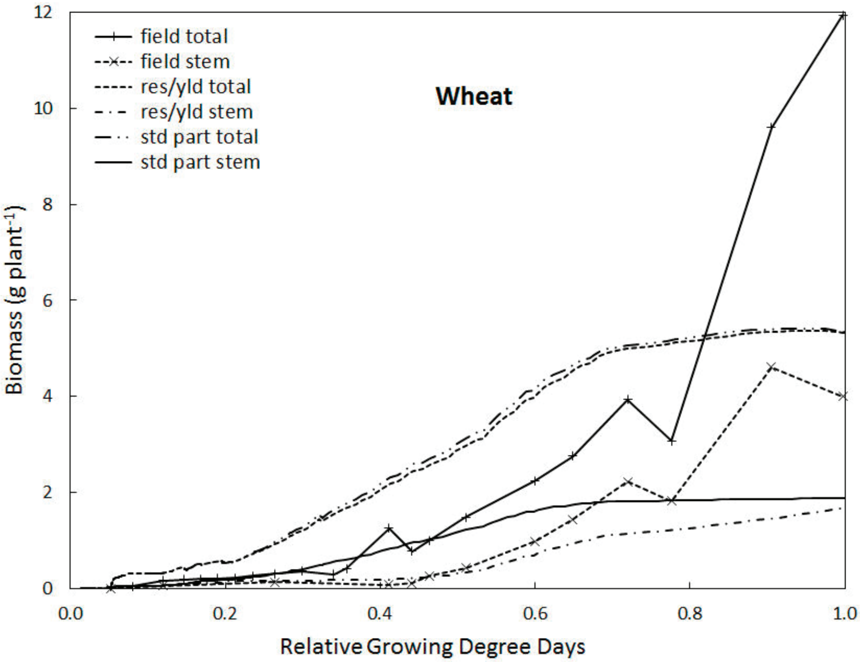


Fig. 4–5. Comparison of measured wheat total biomass and stem mass from Retta et al. (1995) (field total, field stem), with WEPS using a residue yield ratio (res/yld total, res/yld stem) and WEPS using standard partitioning.

Equation 2 often can be derived from Eq. 1 algebraically. However, some solutions may not be analytic, so numerical values for X_j must be obtained using an iteration scheme.

A second approach used to update some of the variables is to determine the average and standard deviation of a given variable from field measurements. Prediction equations were then developed to relate these results to intrinsic soil properties such as the sand, silt, and clay fractions. Next, each temporal variable for each soil was given a non-dimensional range of zero to one bounded by the average ± two standard deviations. Over the non-dimensional range, process effects on individual variables were assigned. On a daily basis, the prior-day non-dimensional variables were calculated and processes for the current day were applied to update the non-dimensional variables. Finally, the non-dimensional updated variables were converted to dimensional values for use by other submodels.

The plant growth submodel simulates the growth of plants (e.g., crops) moderated by daily water and temperature stresses. The presence of live biomass on the soil surface influences the energy of the wind interacting with the soil surface and thus the quantity of soil that can be removed by wind erosion. This model was originally derived from the Erosion Productivity Impact Calculator (EPIC) plant growth model (Sharpley and Williams, 1990) but has been heavily modified to meet the WEPS requirements for vegetation influences on wind erosion. The leaf mass and the stem mass interact differently with the wind; therefore, the plant biomass accumulation is divided into the stem, leaf and reproductive components (e.g., Fig. 4–5).

The plant growth submodel is designed to i) estimate daily biomass production; ii) partition biomass into fibrous root, storage root, leaf, stem, and reproductive mass pools; iii) obtain estimates of leaf and stem area growth; and iv) at physiological maturity, calculate economic (i.e., grain or other yield) and noneconomic (i.e., chaff) parts. Harvesting of non-grain crops removes reproductive material, leaves, stems, storage roots, or combinations of these plant parts. Plants may regrow after these kinds of harvest events depending on crop type and the availability of biomass reserves.

The residue decomposition submodel of WEPS simulates the decrease in plant residue biomass due to microbial activity. Decomposition in WEPS is a function of decomposition days where, under optimum temperature and moisture, one decomposition day per day is accumulated, but only a fraction of a decomposition day is accumulated if less than optimum conditions occur. Biomass remaining after harvest is partitioned into five age pools between standing, flat, and buried position pools. For standing residue, the moisture function is (Steiner et al., 1994):

$$\mathrm{MF}_s = P/4 + 0.4\ \mathrm{MF}_{s,t-1} \quad [3]$$

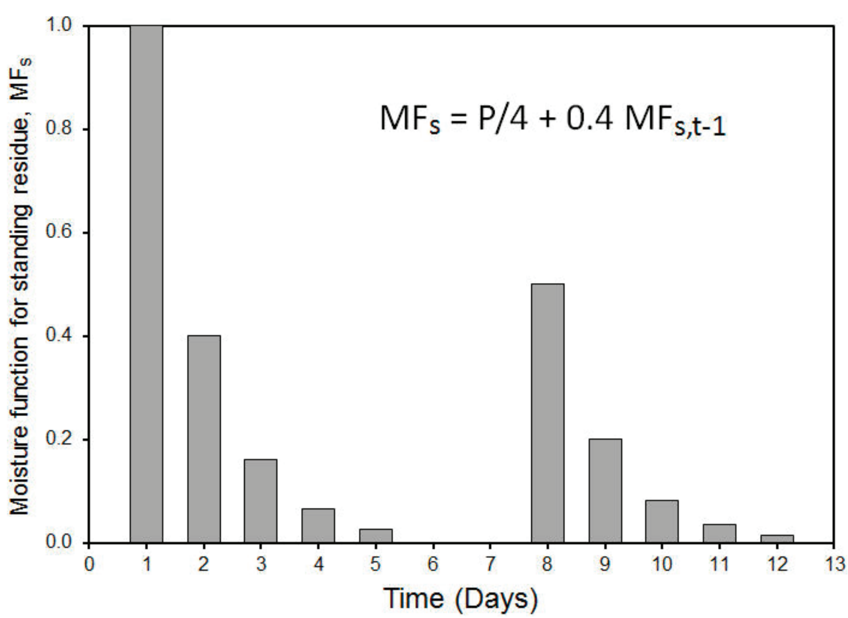


Fig. 4–6. Behavior of the moisture function for standing residue if precipitation were equal to or greater than 4 mm on Day 1, equal to 2 mm on Day 8, and all other days were dry (after van Donk et al. 2008).

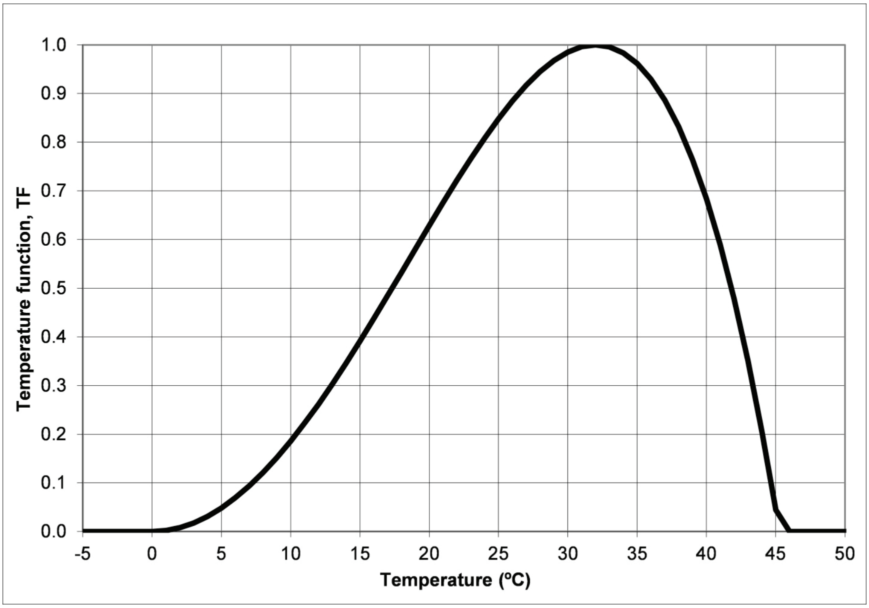


Fig. 4–7. Plot of the temperature function, TF (Eq. [4]) with T_b = 0°C and T_o = 32°C (after van Donk et al., 2008).

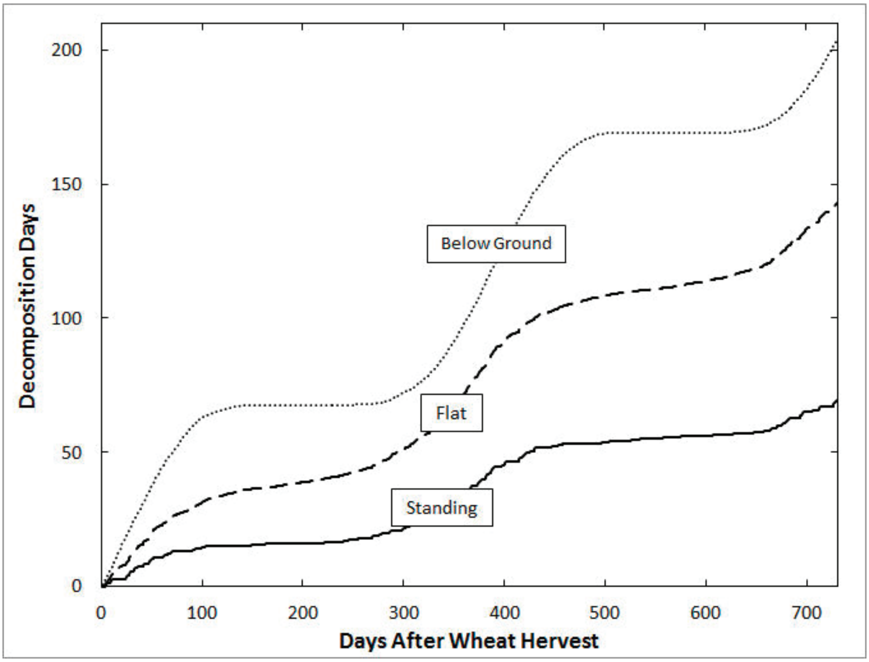


Fig. 4–8. Decomposition day accumulation for standing, flat and below-ground residue for the two-yr Colorado winter wheat–summer fallow rotation. Curves are medians of 50 simulations.

where $MF_{s,\,t\text{-}1}$ = moisture function for standing residue on the previous day, $MF_s = 1$ if the right-hand side of Eq. 3 exceeds 1. The moisture function is based on precipitation P (mm), with 4 mm of precipitation considered to saturate the standing residue. MF_s decreases by 60% each day following a wetting event (Schomberg et al., 1996). After more than 4 dry days in a row, $MF_s = 0$ (Fig. 4–6).

The temperature function is calculated as described by Steiner et al. (1999) for residue decomposition:

$$\mathrm{TF} = \frac{2(T-T_b)^2(T_0-T_b)^2-(T-T_b)^4}{(T_0-T_b)^4} \qquad [4]$$

where T = temperature (°C), T_o = optimum temperature for decomposition (32°C), and T_b = a base temperature (0°C) below which no decomposition occurs (see Fig. 4–7).

A comparison of the relative rate of decomposition between standing, flat and below ground residue at one location is presented in Fig. 4–8 and illustrates the importance of the simulation of moisture status on residue decomposition.

The erosion submodel is the primary of the six submodels that comprise WEPS (Hagen, 1991). The wind friction velocity at the soil surface, defined as the square root of surface shear stress divided by the fluid density, is the expression of the force of the wind driving soil movement. The Wind Erosion Prediction System simulates erosion processes if the surface threshold friction velocity is less than the actual friction velocity (computed from the hourly wind speed and current surface aerodynamic roughness for the specified wind direction). For a given field, there is no single surface threshold velocity but rather a range of velocities depending on the soil surface condition, including aggregation, roughness, crop status, and moisture. To delineate erosion rates among various potential surfaces, several individual erosion processes are identified in the erosion submodel (Fig. 4–9). These processes include i) direct entrainment (emission) of loose soil by wind or saltation impacts, ii) abrasion of soil from clods or crust by saltation impacts, and iii) breakage of saltation/creep-size aggregates to suspension-size (Mirzamostafa et al., 1998) and are simulated individually. Trapping of saltation/creep when transport capacity is exceeded on micro-relief and interception by plant stalks is also simulated.

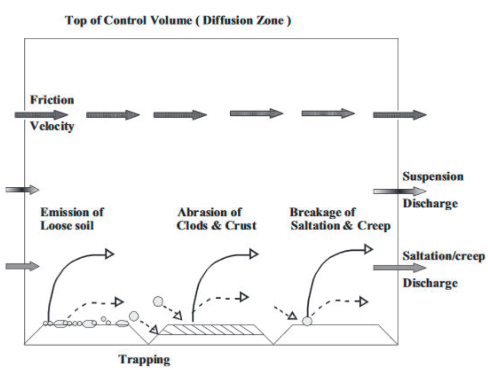


Fig. 4–9. Simulated erosion processes on a bare soil in an individual grid cell (from Hagen, 2008).

The erosion submodel partitions estimated losses into total (<

2.0 mm diameter), saltation and creep (2.0 to 0.1 mm), suspension (0.1 mm), and emission of particulates with aerodynamic diameter less than 10 μm (PM_{10}) into the atmosphere. Based on conservation of mass in a control volume (Fig. 4–9), a one-dimensional, quasi-steady state equation for the physical processes involved in saltation creep is:

$$\frac{dq_{sc}}{dX} = G_{en} + G_{an} - Gss_{bk} - G_{tp} \quad [5]$$

where q_{sc} = horizontal saltation+creep discharge (kg m^{-1} s^{-1}), X = downwind distance from nonerodible boundary (*m*), G_{en} = vertical flux from emission of loose aggregates (kg m^{-2} s^{-1}), G_{an} = vertical flux from abrasion of surface clods and crust (kg m^{-2} s^{-1}), Gss_{bk} = vertical flux of suspension aggregates from breakage of saltation+creep aggregates (kg m^{-2} s^{-1}), and G_{tp} = vertical flux from trapping of saltation+creep aggregates (kg m^{-2} s^{-1}).

In WEPS, surface trapping and plant interception (i.e., deposition) are simulated as:

$$G_{tp} = C_t \left(1 - \frac{q_{cp}}{q_{en}}\right) q_{sc} + C_i q_{sc}, \; q_{en} \geq q_{cp} \quad [6]$$

where C_t = coefficient of surface trapping (m^{-1}), C_i = coefficient of plant interception (m^{-1}), q_{en} = transport capacity of the wind (kg m^{-1} s^{-1}), and q_{cp} = transport capacity of the surface (kg m^{-1} s^{-1}).

For generating the suspension component when friction velocity is above threshold, the control volume extends to the top of the dust cloud and a one-dimensional, quasi-steady state equation for the physical processes is:

$$\frac{dq_{ss}}{dX} = \left(Gss_{en} + Gss_{an} + Gss_{bk}\right)\left(1 - Css_i\right), U_* > U_{*t} \quad [7]$$

where q_{ss} = horizontal suspension component discharge (kg m^{-1} s^{-1}), Gss_{en} = vertical emission flux of loose, suspension-size aggregates (kg m^{-2} s^{-1}), Gss_{an} = vertical flux of suspension-size aggregates created by abrasion of clods and crust (kg m^{-2} s^{-1}), Gss_{bk} = vertical flux of suspension-size aggregates created by breakage of saltation/creep-size aggregates (kg m^{-2} s^{-1}), Css_i = fraction of suspension-size aggregate flux intercepted by standing biomass, U_* = friction velocity at soil surface below standing biomass when present (m s^{-1}), and U_{*t} = dynamic threshold friction velocity (m s^{-1}).

When friction velocity is below threshold, the equation for deposition of suspension is:

$$\frac{dq_{ss}}{dX} = -Gss_{dp}, U_* < U_{*t} \quad [8]$$

where Gss_{dp} = vertical flux (deposition) of suspension-size aggregates above a non-eroding surface (kg m^{-2} s^{-1}).

Finally, the simulation equation for the PM_{10} component of the suspended soil was developed by Hagen et al. (1996). Three different sources of PM_{10} were also identified to contribute different fractions of PM_{10} from the suspension generated from each source. This results in the parameterized equation:

$$\frac{dq10}{dX} = SF10_{en} Gss_{en} + SF10_{an} Gss_{an} + SF10_{bk} Gss_{bk} \quad [9]$$

where $SF10_{en}$ = soil fraction of PM_{10} in suspension-size surface soil, $SF10_{an}$ = soil fraction of PM_{10} in suspension-size aggregates created during abrasion of clods and crust, and $SF10_{bk}$ = soil fraction of PM_{10} in suspension-size aggregates broken from saltation and creep-size aggregates.

Currently WEPS simulates a field as an area referred to as a simulation region that considers soil and management to be homogeneous across the field. However, by partitioning the simulation region into a series of small, uniform areas by gridding, and periodically updating the surface conditions, the erosion process encompasses both the spatial and temporal variations in field erodibility during a wind erosion event. The erosion processes begin with calculation of surface threshold friction velocities and end with periodic updates in surface conditions caused by the soil loss and deposition that occur during erosion. The erosion submodel of WEPS provides estimates of onsite and offsite impacts of erosion and also predicts the size components of the moving soil for improved conservation planning and evaluations of associated environmental impacts.

Experiments were also conducted during WEPS development to validate that the erosion routines were producing accurate and precise erosion estimates (Fryrear et al., 1991; Feng and Sharratt 2007, 2009; Hagen, 2004a). The Wind Erosion Prediction System simulation of soil erosion by wind has undergone extensive independent field and wind tunnel testing and validation. Good agreements (i.e., coefficients of determination ranging from 0.87 to 0.98) were found in a number of studies between measured and WEPS-simulated erosion (Buschiazzo and Zobeck, 2008; Funk et al., 2004; Liu et al., 2014). Soil loss measurements from 46 storm events in six states were compared to predictions from the WEPS erosion submodel by Hagen (2004a) who found measured and simulated erosion values were in "reasonable agreement" (R^2 = 0.73). Feng and Sharratt (2009) tested the WEPS erosion submodel and concluded that the model underestimated soil loss by overestimating the threshold friction velocity, but it should be noted that they studied only small intensity storms. Other researchers have also found WEPS to underestimate the occurrence of small storms (Feng and Sharratt, 2007; Funk et al., 2004). Hagen (2004a) found a similar response for small storms which he attributed to spatial variability of the test sites having small inclusions of higher erodibility than the average surface. The effects of field spatial variability on erodibility parameters and subsequent wind erosion prediction were also cited by van Donk and Skidmore (2003) for WEPS validations in eastern Colorado and Visser et al. (2005) in Burkina Faso. Agricultural fields often have multiple areas where one or more field characteristics vary spatially within the field, such as under strip cropping or a field with more than one soil type. These differences across a field can affect wind erosion (Okin, 2005) and are not accounted for in the current WEPS. Gillette (1999) observed that dust storms, particularly in vegetated terrains, often display distinct plumes emanating from relatively small areas which, despite their size, account for the majority of airborne dust. This phenomenon was cited by Okin and Gillette (2004) as a major source of error in general model estimates of dust emissions.

Example Use of WEPS for Conservation Planning

The strongest utility of WEPS is its ability to apply multiple "what-if" management scenarios to the land for developing and evaluating alternatives for wind erosion control. Typically a land manager cannot change the location or soil, leaving field geometry and management as the only viable options for erosion control. Through the detailed WEPS output summarized in Table 4–2, the user can observe the surface conditions responsible for excessive soil loss as well as the practices and conditions that are contributing to wind erosion for periods of two weeks or less throughout the rotation. The calculated WEPS results also include the amount of soil loss for each direction which aids in the placement of barriers, strip cropping, or other directional erosion control methods. The effects of alternative conservation practices on field conditions can thus be evaluated to reduce soil loss for various periods of the rotation. By simulating potential alternatives to the field geometry (e.g., field size, barriers, strip cropping) and management operations (e.g., tillage direction, reduced tillage, timing of operations), WEPS allows the user to rapidly compare the effects of various practices on the amount and direction of soil loss.

The Wind Erosion Prediction System has been developed into two configurations (e.g., public and NRCS) to better fit the needs of each community of users. For example, the public configuration allows for greater manipulation of parameters of interest to the user such as a researcher. The NRCS configuration on the other hand, does not allow the user to alter as many parameters to provide consistency in simulations across the agency. The NRCS configuration of WEPS (version 1.3.9) was used for the simulation scenarios presented here. Under this configuration, WEPS simulations are run for 50 yr per crop rotation year (e.g., a 2-yr crop rotation would run 50 yr for each year of the crop rotation for a total of 100 simulation years). Results reported here are the averages of all 50 simulation years for each year of a crop

Table 4–2. Output parameters provided by WEPS on a two week basis for a simulated crop rotation.

Parameter †	Parameter Class	Sub-Parameter	Units
Period Dates			
Operation			
Crop			
Wind Erosion		Average Total Gross Soil Loss	kg m^{-2}
	Net Soil Loss From Field	Average Total	kg m^{-2}
		Average Creep + Saltation	kg m^{-2}
		Average Suspension	kg m^{-2}
		Average PM_{10}	kg m^{-2}
Mass Passing Indicated Field Boundary	Creep + Saltation	Mass Leaving Each Field Boundary	kg m^{-1}
	Suspension		kg m^{-1}
	PM_{10}		kg m^{-1}
Within Field Wind Erosion Activity	Saltating Emission Region	Soil Loss	kg m^{-2}
		Field Area	ha and fraction
	Deposition Region	Soil Deposition	kg m^{-2}
		Field Area	ha and fraction
	High Flux Region	Field Area	ha and fraction
	Sheltered Region	Field Area	ha and fraction
Weather Information		Average Total Period Precipitation	mm
		Average Wind Energy > 8 m/s	KJ m^{-2} day^{-1}
		Snow Depth > 20 mm	fraction
Average Biomass Surface Conditions on Date	Crop Vegetation (Live)	Canopy Cover	fraction
		Effective Standing Silhouette	m^2 m^{-2}
		Leaf and Stem Mass	kg m^{-2}
		Root Mass	kg m^{-2}
		Crop Height	m
		Number of Crop Stems	number m^{-2}
	Crop Residue (Dead)	Surface Cover	fraction
		Effective Standing Silhouette	m^2 m^{-2}
		Flat Mass	kg m^{-2}
		Standing Mass	kg m^{-2}
		Buried Mass	kg m^{-2}
		Buried Root Mass	kg m^{-2}
		Weighted Residue Height	m
		Number of Residue Stems	number m^{-2}
	Vegetation and Residue Biomass (Live plus Dead)	Surface Cover	fraction
		Effective Standing Silhouette	m^2 m^{-2}
		Flat Mass	kg m^{-2}
		Effective Standing Mass	kg m^{-2}
		All Buried Mass	kg m^{-2}
Average Soil Surface Conditions on Date	Oriented Roughness	Ridge Orientation (from North)	degrees
		Ridge Height	mm
		Ridge Spacing	mm
	Random Roughness	Standard Deviation	mm
	Aggregation	Aggregates < 0.84 mm	fraction
		Dry Aggregate Stability	ln(J m^{-2})
	Crust	Crust Cover	fraction

† These are the output parameters generated in the NRCS configuration of WEPS. Other configurations allow viewing additional output for research purposes.

rotation. The latest public release of WEPS, including the WEPS User Manual is available for download at: https://www.ars.usda.gov/research/software/.

Scenario 1: Beginning Conditions

We begin with a simple simulation of a winter wheat–summer fallow crop rotation in the U.S. Great Plains for a farm located in southwest Kansas, near the town of Ulysses in Grant County (37.5622 N lat., 101.3080 W long.). A winter wheat–summer fallow rotation produces only one wheat crop every two years with a 14-mo fallow period between harvest of one crop of winter wheat and the planting of another to permit accumulation of moisture in the soil and reduce the risk of crop failure. Soil parameter data used were derived from the NRCS SSURGO database (USDA-NRCS, 1995), accessed from the NRCS National Soil Information System (NASIS) server (USDA-NRCS, 2011). The soil data used were obtained via download routines within WEPS via the NRCS Soil Data Mart. Weather files used were those generated by the WEPS weather generator models for the location. More information on WEPS weather model development, databases, and validation, can be obtained in Skidmore and Tatarko (1990) and van Donk et al. (2005). We used a cropping management file obtained from template files developed by NRCS for the Grant County location to provide the field operations applied (e.g., tillage, seedbed preparation, planting, harvesting, etc.). The National Resource Conservation Service template files are organized by Crop Management Zones (CMZ's) which are geographical regions within the United States that NRCS has defined as having common enough management practices and planting or harvesting dates to be grouped together. The management template for Grant County, Kansas was in CMZ 05. See the WEPS User Manual for information on accessing template management files. Under the NRCS configuration used, the

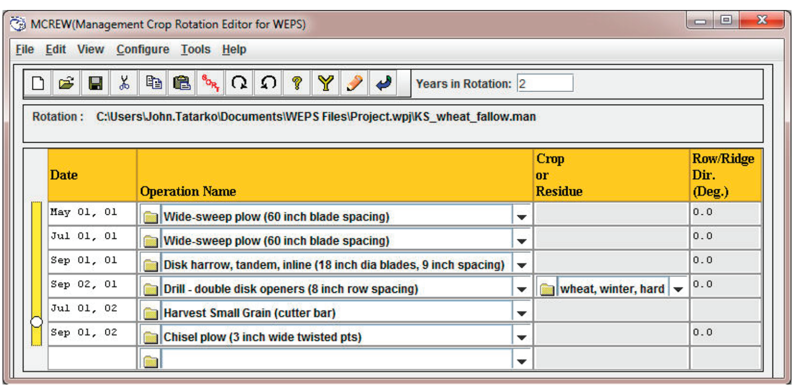


Fig. 4–10. Management practices for the beginning baseline scenario obtained from the NRCS template files.

default simulation is run for 50 yr per rotation year (i.e., 100 yr for the 2-yr rotation scenario). The inputs specified for the initial scenario were:

- Soil (to obtain soil parameters important to wind erosion simulation in WEPS): Bigbow fine sandy loam, 0 to 1% slopes, and the *T*-value is 1.12 kg m^{-2} yr^{-1} (i.e., 5 tons $acre^{-1}$ yr^{-1}).
- Location (to obtain the weather files): Grant County, Kansas. The nearest CLIGEN weather station for Grant County in WEPS is Ulysses. The WEPS Windgen parameters were interpolated between the three bounding Windgen stations using the centroid of the county.
- Field geometry (to define the area or field of simulation): 805 × 805 m or 64.8 ha (i.e., a quarter section); no wind barriers (i.e., no windbreaks); field orientation is 0° from North.
- Management (to provide the farmer applied crop management operations): Winter wheat-summer fallow rotation (i.e., crop sequence) for southwest Kansas with conventional tillage (see Fig. 4–10). Row or Ridge direction is 0° from North.

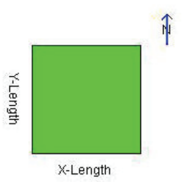
Run Summary

Natural Resources Conservation Service

Beginning_Scenario

Run Date:	Friday, May 15, 2015, 01:12 PM
Client Name:	No-conservation
Farm No:	--- **Tract No:** --- **Field No:**---
Run Location:	C:\Users\John.Tatarko\Documents\WEPS_Runs
Management:	KS_wheat_fallow.man
Soil:	Bigbow_5211_67_FSL.ifc

Location Site Information



X-Length:	804.7 m	**Mode:**	CYCLE
Y-Length:	804.7 m	**# Cycles:**	50
Area:	64.8 ha	**Site:**	UNITED STATES KANSAS GRANT
Elevation:	929.0 m	**Location:**	37.5622° N, 101.30797° W
Orientation:	0.0 °	**Cligen:**	ULYSSES
		Windgen:	LIBERAL MUNI (AWOS)

Erosion

Period	Crop/Residue	Gross Loss kg/m²	Net Soil Loss From Field (kg/m²) Total	Creep/Salt.	Suspen.	PM10
Rot. year: 1		15.9	15.9	6.1	9.8	0.25
Rot. year: 2	wheat, winter, hard	0.4	0.4	0.2	0.2	0.01
Ave. Annual		8.2	8.1	3.1	5.0	0.13

Crop Interval Erosion

Date Range	Days	Crop	Gross Loss kg/m²	Net Soil Loss From Field (kg/m²) Total	Creep/Salt.	Suspen.	PM10
Jul 02, 02 - Jul 01, 02	366	wheat, winter, hard	16.3	16.3	6.3	10.0	0.26

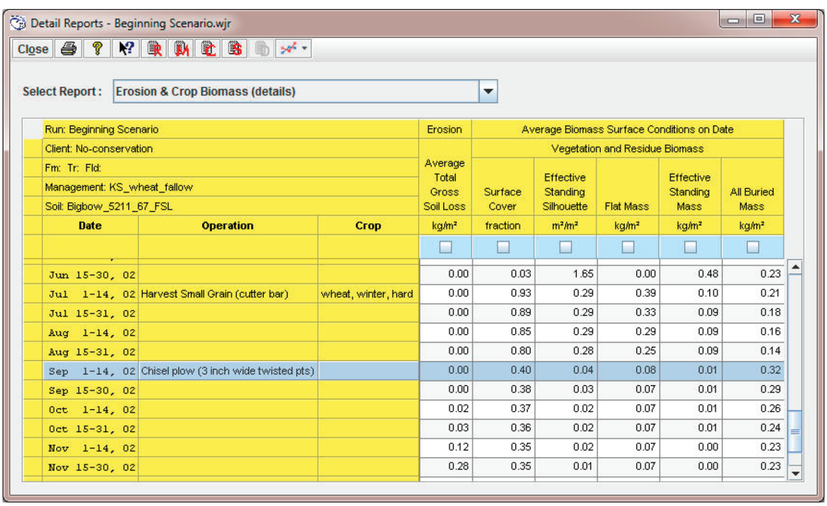
Harvests

Date	Crop	Residue kg/m²	Harvest Yield	Yield % Moisture
Jul 01, 02	wheat, winter, hard	1	0.3 kg/m²	10.9

Fig. 4–11. First page of Run Summary Report for the beginning baseline scenario.

Figure 4–10 shows the Management Crop Rotation Editor for WEPS (MCREW) screen where the crop management operations can be entered or altered by the user. The operations are entered as a date-ordered list. The folder symbol to the left of the “Operation Name” or “Crop or Residue” item opens a window to view and edit parameters for that operation or crop. The NRCS configuration only displays a limited set of parameters and only allows editing of some of those. The down arrow to the right of an operation name or crop provides a list of management operations or crops to choose from.

A summary of the results from the initial scenario is shown in Fig. 4–11. This Run Summary Report presents a synopsis of the simulation inputs as well as erosion losses and crop yields. Under the portion labeled Erosion, one can view the soil loss by rotation year as well as the average annual for the entire simulation (e.g., 100-yr simulation). In addition this section lists the total gross loss as well as net loss by size fraction. Gross loss is the total amount of soil removed from the field soil surface. Net soil loss represents the gross loss minus any deposition (typically due to downwind barriers) and is always less than or equal to gross loss. When deposition occurs, net loss will be less than gross loss and when there is no deposition within the field, gross and net loss will be equal. This beginning or baseline scenario resulted in an annual average total gross and net soil loss of 7.0 kg m^{-2} yr^{-1} with 13.4 and 0.6 kg m^{-2} yr^{-1} for the fallow (Rot. Year: 1) and wheat (Rot. year: 2) years of the rotation respectively (Fig. 4–11). The calculated soil loss is well above the stated NRCS tolerable amount for soil loss (*T*-value) of 1.12 kg m^{-2} yr^{-1} for this soil and thus conservation measures are warranted.



Date	Operation	Crop	Erosion: Average Total Gross Soil Loss (kg/m²)	Surface Cover (fraction)	Effective Standing Silhouette (m²/m²)	Flat Mass (kg/m²)	Effective Standing Mass (kg/m²)	All Buried Mass (kg/m²)
Jun 15-30, 02			0.00	0.03	1.65	0.00	0.48	0.23
Jul 1-14, 02	Harvest Small Grain (cutter bar)	wheat, winter, hard	0.00	0.93	0.29	0.39	0.10	0.21
Jul 15-31, 02			0.00	0.89	0.29	0.33	0.09	0.18
Aug 1-14, 02			0.00	0.85	0.29	0.29	0.09	0.16
Aug 15-31, 02			0.00	0.80	0.28	0.25	0.09	0.14
Sep 1-14, 02	Chisel plow (3 inch wide twisted pts)		0.00	0.40	0.04	0.08	0.01	0.32
Sep 15-30, 02			0.00	0.38	0.03	0.07	0.01	0.29
Oct 1-14, 02			0.02	0.37	0.02	0.07	0.01	0.26
Oct 15-31, 02			0.03	0.36	0.02	0.07	0.01	0.24
Nov 1-14, 02			0.12	0.35	0.02	0.07	0.00	0.23
Nov 15-30, 02			0.28	0.35	0.01	0.07	0.00	0.23

Fig. 4–12. A portion of the Detail Report, with the “Erosion & Crop Biomass (details)” display option selected, for the beginning scenario showing the reduction in surface cover and effective standing silhouette following the chisel plow operation.

Erosion							
		Gross Loss	Net Soil Loss From Field (kg/m²)				
Period	Crop/Residue	kg/m²	Total	Creep/Salt.	Suspen.	PM10
Rot. year: 1		3.3	3.3	1.3	2.0	0.05
Rot. year: 2	wheat, winter, hard	0.0	0.0	0.0	0.0	0.00
Ave. Annual		1.7	1.7	0.6	1.0	0.03

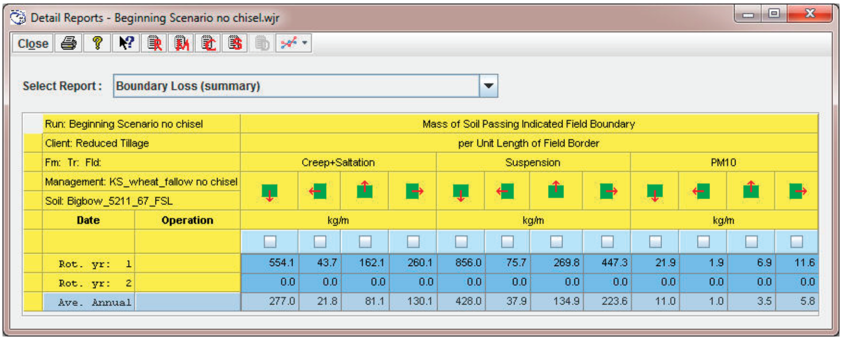
Fig. 4–13. Portion of the Run Summary showing erosion for scenario with chisel plow removed.

Scenario 2: Reduced Tillage

Clicking the Detailed Report button at the top of the Summary Report reveals the detailed results listed in Table 4–2. That Detailed Report for the beginning scenario (a portion is displayed in Fig. 4–12) shows that erosion begins to drastically increase shortly after the chisel plow operation during the period of 1 to 4 Sept. 02 (blue highlighted row). A chisel plow operation was scheduled for 1 Sept. 02 (see Fig. 4–10) to control potential weeds. The increase in wind erosion is likely due to the chisel plow causing a 50% reduction in biomass surface cover from 80 to 40% and a 24% reduction in effective standing silhouette biomass (see Fig. 4–12, "Surface Cover" and "Effective Standing Silhouette" columns).

Reducing tillage but maintaining weed control can be obtained by substituting a herbicide spray operation for the chisel plow operation on 1 Sept. 02 (Fig. 4–10). This results in more standing residue (0.01 with chisel vs. 0.08 kg m^{-2} without) and flat residue (0.08 with chisel vs. 0.24 kg m^{-2} without) remaining on the surface (data table not shown) and reduced soil loss. When the chisel plow operation is removed resulting in less standing stem flattening and less residue burial, the amount of total soil loss is reduced to 1.7 kg m^{-2} yr^{-1} with 3.3 and 0.0 kg m^{-2} yr^{-1} for the fallow and wheat portions of the rotation respectively (Fig. 4–13). Although the loss is reduced significantly, the average gross loss from erosion is still above the *T*-value limit (≤ 1.12 kg m^{-2} yr^{-1}) during Rotation Year 1 (fallow) and thus further erosion control is needed. Note that removing the chisel operation also caused interactive effects on other parameters (data table not shown), including lower erodible aggregates (43% with chisel vs. 39% without), lower random roughness (16.7 mm with chisel vs. 2.4 mm without).

The new Detailed Reports with the chisel plow removed also reveals that a majority (~70%) of the creep plus saltation loss is across the north and south field boundaries. This is shown in the Detailed Reports in the row labeled Ave. Annual (Fig. 4–14) and is likely due to a predominant north-south wind direction in the area. This also coincides with the tillage direction of 0° from north, which allows little ridge (oriented) roughness protection for the field. Reorienting tillage direction to 90° from north (perpendicular to the north-south direction) further



Run: Beginning Scenario no chisel		Mass of Soil Passing Indicated Field Boundary											
Client: Reduced Tillage		per Unit Length of Field Border											
Fm: Tr: Fld:		Creep+Saltation				Suspension				PM10			
Management: KS_wheat_fallow no chisel Soil: Bigbow_5211_67_FSL		↓	←	↑	→	↓	←	↑	→	↓	←	↑	→
Date	**Operation**	kg/m				kg/m				kg/m			
Rot. yr: 1		554.1	43.7	162.1	260.1	856.0	75.7	269.8	447.3	21.9	1.9	6.9	11.6
Rot. yr: 2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ave. Annual		277.0	21.8	81.1	130.1	428.0	37.9	134.9	223.6	11.0	1.0	3.5	5.8

Fig. 4–14. A portion of the Detailed Report, with the "Boundary Loss (summary)" display option selected showing soil loss from north and south boundary.

reduces total soil loss to 1.6 kg m^{-2} yr^{-1} with the fallow year soil loss at 3.1 kg m^{-2} yr^{-1}, but these losses are still above *T*-value limits (data not shown).

Scenario 3: Add Barriers

A common wind erosion control method in the area and around the world is to use wind breaks as barriers to slow the wind. Barriers will be added to the scenario to see their effects on soil loss. By looking at the directional loss in the Detailed Report (Fig. 4–14), we see that most of the loss is coming off the south and east borders. This indicates that most of the erosive winds at this location are out of the north and west. Therefore the most effective location for barriers might be along the north and west field boundaries. For both boundaries, we selected "Tree 3r decd est leafon" from the barrier selection list on the main WEPS interface screen. The barrier type represents a three row mature deciduous tree windbreak with leaves on the trees that are well established. For example, a typical windbreak tree species in the U.S. Great Plains might be the Osage Orange (*Maclura pomifera* Raf. C.K. Schneid.). The simulated barriers have a width of 15.7 m, a height of 10.7 m, and a porosity fraction of 0.4 that, according to Skidmore and Hagen (1977) provides the greatest overall wind speed reduction.

The resulting simulation further reduces the gross soil loss to only 2.1 kg m^{-2} yr^{-1} for the fallow year and 1.1 kg m^{-2} yr^{-1} for the average annual gross soil loss (Fig. 4–15). Notice the net soil loss is less than gross soil loss, indicating that some soil is deposited

Erosion

		Gross Loss	Net Soil Loss From Field (kg/m²)			
Period	**Crop/Residue**	kg/m²	**Total**	**Creep/Salt.**	**Suspen.**	**PM10**
Rot. year: 1		2.1	1.9	0.8	1.1	0.03
Rot. year: 2	wheat, winter, hard	0.0	0.0	0.0	0.0	0.00
Ave. Annual		1.1	1.0	0.4	0.6	0.02

Fig. 4–15. Portion of the Run Summary showing erosion for scenario with chisel plow removed and barriers added on the north and west field boundaries.

just upwind of the barriers as research shows that winds decrease both up- and downwind of a barrier (Skidmore and Hagen, 1977). Soil loss in this case is reduced with barriers only slightly compared to a field with no barriers. Research has shown that barriers are effective in sheltering soil from wind erosion for a distance equal to 10 to 15 times the height of the barrier (Yusaiyin and Tanaka, 2009). In this scenario, a 10.7 m high barrier would therefore protect for only 107 to 160 m downwind leaving a distance of 645 to 698 m unprotected by the barrier. This unprotected distance is still sufficient to cause significant soil loss. Note that tree plantings will have limited effectiveness until they grow large enough to provide the designed protection and so their use is considered a long-term strategy for which the cost and benefits need to be considered.

Scenario 4: Strip cropping

Reducing the N–S field length by implementing a strip cropping management may provide further reductions by decreasing the field length in the predominant north-south wind direction. The field was therefore divided into 101 m wide strips (i.e., 10 passes with an implement of effective width of 10.1 m), oriented with long sides aligned east-west with row direction in the same east-west direction. Strip cropping assumes each phase of the rotation (i.e., wheat phase and fallow phase) is present in alternating strips for each year of the simulation. To do this, we need to only simulate one strip of the field with the reduced tillage wheat fallow management rotation as it covers both years of the rotation and results are reported on a per area basis. We also reset the tillage to 90°, to align with the long field direction. The resulting WEPS simulation shows that soil loss for the strip cropped field without wind barriers is reduced to an average 0.5 kg m^{-2} yr^{-1} and 1.0 kg m^{-2} yr^{-1} for the fallow year (Fig. 4–16), which is below the *T*-value loss limit. Additional reductions could possibly be obtained by further examining the detailed report and simulating other management scenarios.

In an actual strip cropping situation, the plan is usually to have a fallow field with adjacent strips growing a crop during the year which would act as a barrier and further reduce soil loss. This situation cannot be simulated for strip cropping with this version of WEPS and would best be simulated with a version of WEPS capable of simulating subregions within a field (presently being developed).

Erosion

		Gross Loss	Net Soil Loss From Field (kg/m²)			
Period	Crop/Residue	kg/m²	Total	Creep/Salt.	Suspen.	PM10
Rot. year: 1		1.0	1.0	0.7	0.3	0.01
Rot. year: 2	wheat, winter, hard	0.0	0.0	0.0	0.0	0.00
Ave. Annual		0.5	0.5	0.3	0.1	0.00

Fig. 4–16. Portion of the Run Summary showing erosion for scenario under strip cropping (barriers not included).

Run Name	Run Location	Management Name	Soil Name	Field Size (ha)	Annual Soil Loss Gross (kg/m^2)	Net Total (kg/m^2)	Net Creep/Salt (kg/m^2)	Net Suspension (kg/m^2)	Net PM10 (kg/m^2)
Beginning_Scenario	WEPS Cons	KS_wheat_fallow	Bigbow_5211_67_FSL	64.754	8.155	8.148	3.126	5.023	0.129
Beginning_Scenario no chisel	WEPS Cons	KS_wheat_fallow no chisel	Bigbow_5211_67_FSL	64.754	1.659	1.658	0.634	1.024	0.026
Beginning_Scenario no chisel 90 deg	WEPS Cons	KS_wheat_fallow no chisel 90 deg	Bigbow_5211_67_FSL	64.754	1.573	1.572	0.602	0.971	0.025
Beginning_Scenario no chisel 90 deg Strip	WEPS Cons	KS_wheat_fallow no chisel 90 deg	Bigbow_5211_67_FSL	8.127	0.476	0.476	0.328	0.148	0.003

Fig. 4–17. The WEPS Multiple Run Manager tool for comparing alternative management scenarios. Annual Soil Loss values displayed represent the annual loss averaged over the simulation years.

WEPS Multiple Run Manager tool

When many alternative scenarios are developed and examined as we have done here, the WEPS Multiple Run Manager (WMRM) utility provides a quick method to compare scenarios. This tool is available under the View Output menu button and allows the user to easily select any multiple of the scenarios desired for comparison of soil loss (Fig. 4–17). In this figure, the scenarios are listed under the "Run Name" column where Beginning Scenario is the initial baseline management. In addition, by clicking on the value in each column, WEPS will display additional details for that item. Annual Soil Loss values displayed represent the annual loss averaged over the simulation years. This comparison tool is further described in the WEPS User Manual.

Discussion

The scenarios presented are but a few examples of systematically exploring management alternatives using WEPS. The average total net losses as well as the net loss for each year of the rotation for the scenarios explored in this paper are shown in Fig. 4–18. Each successive scenario reduces net soil loss. Note how reducing tillage in the second scenario lowers soil loss to zero during the wheat year while fallow losses are about 25% of the baseline scenario. This demonstrates the value of keeping residue on the soil surface to control erosion losses. The user could try additional scenarios to not only continue to lower soil loss but also improve environmental benefits or reduce farming costs. Additional scenarios might include converting to a no-till system, including a cover crop, or perhaps adding another high-residue crop into the rotation.

Successful planning for wind erosion control on a specific field may require accounting for a number of varied considerations. Complete control with zero soil loss is rarely achieved in cultivated agriculture, especially under non-irrigated conditions. When exploring alternative conservation planning scenarios on cultivated agricultural fields with WEPS, the primary goal is to reduce wind erosion soil loss to an acceptable or sustainable level. Erosion loss depends on a number of factors such as soil type (i.e., erodibility), crop type (i.e., vegetative protection), or field location (i.e., climate and erosivity of the winds).

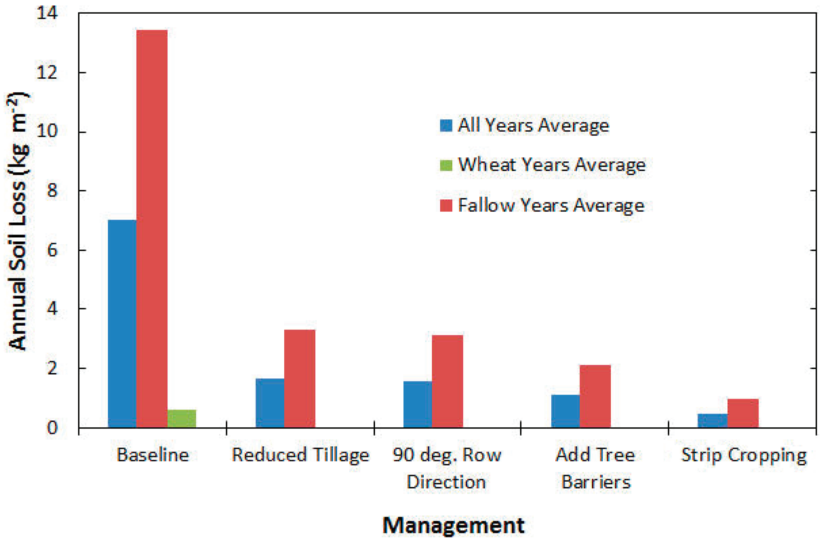


Fig. 4–18. Comparisons of simulated soil loss for the WEPS scenarios presented.

Another scenario to consider might be off-site effects such as the field of interest being near a roadway. The goal here may be to reduce soil from entering the right-of-way where it would be deposited in the ditch, on the road itself, or cause a danger of reduced visibility for traffic. Similarly, if a waterway, pond, or lake is in the affected downwind area, the goal of wind erosion controls may include preventing soil from entering the water and reducing water quality and reservoir capacity or channel flow cross-sectional area. Where a population center might be downwind, the goal may be to reduce suspension size particulates that affect air quality and visibility.

The duration of control effectiveness should also be considered. For example, dust suppressants are sometimes used to protect crops with lower tolerance to sandblast injury. However research has shown such controls to have a limited period of effectiveness similar to simply spraying water on the soil (Armbrust, 1999). Likewise planting a tree windbreak will have limited effectiveness when first planted but increase until the trees are fully grown. It is important to observe when the controls are most effective relative to the periods when erosion is occurring, such as vegetative barriers having varying leaf-on or leaf-off condition with the change of seasons.

Although the primary purpose of WEPS is to determine and reduce soil loss to some acceptable level, the economics of the controls applied may also be a factor in deciding which are eventually used. For the scenarios presented, the level of erosion control increased with each practice applied. While reducing tillage may reduce costs from fuel and labor, establishing a wind break will have increased associated costs. It is up to the individual land manager to evaluate the potential costs and benefits relative to the level of control from each practice. The NRCS has produced a number of conservation practice standards which describe many wind as well as water erosion control practices in detail to aid managers in conservation planning (USDA-NRCS, 2017). The details include such things as the purpose of the practice, criteria, conditions where they apply, specifications, operation and maintenance, and considerations for their effectiveness.

Conclusions

The Wind Erosion Prediction System is a physically-based daily simulation model that simulates weather, field surface conditions, and wind erosion, exploiting interactions between management operations, soil water dynamics, plant growth, residue decomposition, and soil aggregation and stability. The model was developed primarily to assist land managers in controlling wind erosion and establishing acceptable field-level conservation plans. The Wind Erosion Prediction System is widely used by NRCS for government program purposes of estimating wind erosion losses and developing control strategies. The model has also been used throughout the world for wind erosion research and applications to land management.

By systematically varying the field management input parameters for a specific field of interest, users (i.e., land managers) can compare various alternatives to control soil loss by wind. Because interpreting WEPS output is an integral part of using the model as a tool for developing conservation plans, options are provided for viewing detailed soil loss by periods and direction with period output also available for weather parameters such as wind energy as well as surface conditions such as soil erodibility and biomass amounts. Such information is useful in determining which period resulted in severe erosion and the specific conditions contributing to the loss.

Ongoing WEPS development incorporates advancing research to improve simulation of the soil surface erodibility as well as the erosion processes. Future model development needed to improve the application of WEPS for conservation planning includes expanding its capability to simulate multiple sub-regions that include multiple soils and management practices within a single simulation area. This will allow more realistic simulation of fields with multiple soil types or managements applied, such as strip cropping, to better simulate the interaction between different surfaces to estimate wind erosion. Within field variability is a significant factor in many agricultural and most range scenarios. The Wind Erosion Prediction System currently assumes a flat topographical field surface. Creation of routines that account for the effects of changing landscape elevations would be a great improvement for the application of the model on such terrains. Development of rapid assessment technologies for quantification of the surface state is also needed for both model development and user risk assessments. Through continued research, improvement, and applications, WEPS represents a significant body of work by USDA ARS and NRCS and supports an overall ARS goal of increasing agricultural productivity while reducing the environmental impacts of agriculture. As such, WEPS has potential to contribute to a sustainable food and fiber supply for U.S. and world populations.

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