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Simulation of Tillage and Other Management Operations in WEPS[1]

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Abstract

The Wind Erosion Prediction System (WEPS) is a process-based, daily time-step, computer model that predicts soil erosion via simulation of the physical processes controlling wind erosion. To do so, WEPS must also adequately describe changes to the soil state and surface conditions on a daily basis. The WEPS Management submodel component attempts to simulate the major effects related to the most prevalent cultural practices used by producers and land managers that influence a site's susceptibility to wind erosion. The range of practices includes primary and secondary tilling, cultivating, planting/seeding, harvesting, and fertilizing operations, as well as irrigating, burning, and grazing. The Management submodel simulates the variety of land management operations by identifying the primary physical processes involved and representing each individual operation as a sequenced set of those processes. They include: 1) mass manipulation (changes in aggregate size distribution and soil porosity, mixing of soil and residue among soil layers, and soil layer inversion); 2) surface modification (creation or destruction of ridges and/or furrow dikes that form oriented surface roughness, changes in surface random roughness, and destruction of soil crust); 3) biomass manipulation (burying and resurfacing residue, clipping standing residue, flattening standing residue, killing live crop biomass, and removing biomass); and 4) soil amendment (fertilizing, planting, and irrigating).

Keywords: Soil erosion, Wind erosion, Air quality, Erosion models, WEPS.

Introduction

Development of the Wind Erosion Prediction System (WEPS) was initiated by USDA-Agricultural Research Service (ARS) scientists in response to customer requests for improved wind erosion technology. WEPS is intended to replace the predominately empirical Wind Erosion Equation (Woodruff and Siddoway, 1965) as a prediction tool for those who plan soil conservation systems, conduct environmental planning, or assess off-site impacts caused by wind erosion. WEPS incorporates improved technology for computing soil loss by wind from agricultural fields. It also provides new capabilities such as separate calculating and reporting of creep/saltation size particles, suspension loss, and PM-10 emission estimates from the field (Wagner, 1996).

As a process-based planning tool, WEPS is expected to reflect the effects of various management practices upon wind erosion. Therefore, the objective of the WEPS Management submodel is to simulate the temporal changes in the soil and on the surface caused by those management practices. For WEPS to accurately assess management effects upon a site's susceptibility to wind erosion, the Management submodel must adequately simulate the many diverse cultural practices employed by producers. Those practices include, but are not limited to, typical primary and secondary tilling, cultivating, planting/seeding, harvesting, and fertilizing operations, as well as irrigating, burning, and grazing events.

Submodel Description

The Management submodel simulates the variety of land management operations by identifying the primary physical processes involved and representing each individual operation as a sequenced set of those processes. They include: 1) mass manipulation (changes in aggregate size distribution and soil porosity, mixing of soil and residue among soil layers, and soil layer inversion); 2) surface modification (creation or destruction of ridges and/or furrow dikes that form oriented surface roughness, changes in surface random roughness, and destruction of soil crust); 3) biomass manipulation (burying and resurfacing residue, clipping standing residue, flattening

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standing residue, killing live crop vegetation, and removing biomass); and 4) soil amendments (fertilizing, planting, and irrigating).

In accord with the WEPS design philosophy, the Management submodel simulates these processes via a physical basis if possible, incorporates conservation of mass and energy concepts, and attempts to employ a minimum of parameters with readily available and/or attainable values. Each management operation is represented by a list of independent and sequential processes. Typical multi-tool and ganged multi-implement operations also can be described fully by repeating necessary processes in the description of such operations. For example, a disk-ripper may have a front gang of disk blades, a middle gang of chisel shanks, and a back row of disk blades. Each of these tillage tool components thus can be described independently based on its effects upon the soil, surface, and residue states in order of occurrence during the operation.

Modeling of Physical Processes

In WEPS, spatial variability is handled through the use of subregions. In each subregion, the submodel considers the soil mass, soil surface, and biomass properties to be homogeneous in a horizontal plane, yet variable in the vertical direction (soil layers). The soil surface is considered to include various combinations of random roughness, ridges, and furrow dikes. Live and dead biomass (growing vegetation and crop residue) may exist in the soil and on the surface in standing and/or flat orientations.

Soil Surface Manipulation

A soil surface is described within WEPS by random and oriented roughness, fraction of surface that is crusted, and the amount of loose, erodible material on the crusted fraction of the surface. Random roughness of a surface within the Management submodel is represented in terms of the random roughness index of Allmaras et al (1966). The nominal random roughness value, RR_o, in WEPS is defined as the typical field value expected under a standard soil type (silt loam) and "high" residue quantities within the tillage zone for the operation. Therefore, the base RR_o assigned to an operation tool first is adjusted for soil type and quantity of residue within the tillage zone. Because most tillage tools cannot reduce the surface roughness to the value usually associated with the operation under all field surface roughness conditions, the following approach is used to represent that effect. A tillage intensity factor is assigned to each tillage operation as is done in the Water Erosion Prediction Project (WEPP) (Lane and Nearing, 1989). If the pre-tillage random roughness is greater than the RR_o associated with an implement (after adjustment for soil type and tillage zone residue quantity), the degree of surface roughness change is dependent upon the tillage intensity value assigned to the operation tool. If the tillage operation does not modify the entire surface, the post-tillage random roughness is weighted accordingly.

Oriented roughness is defined within the submodel as uniform rows of ridges and furrows running in parallel lines. Thus, oriented roughness can be specified via ridge top width, ridge height, ridge spacing, and row direction (ridge slopes of 4:1 are assumed to exist). If dikes exist in the furrows, they are assumed to be equally spaced with the same slope and top width as the ridges. Therefore, only furrow dike height and spacing are required to define dikes within the model. Default values for ridge and dike parameters are provided for each tillage operation but are modifiable by the user. Parameter flags are used to define how an operation may be affected by pre existing oriented roughness, e.g., completely remove the ridges and/or furrow dikes, partially destroy them, rebuild them using the existing ridge spacing, or replace them based upon new ridge/dike specifications.

Management operations, such as tillage, that modify the soil surface can destroy crust that is present. The amount of surface crust destroyed by a management operation is specified by a decrusting parameter. Most management operations that affect the surface configuration will destroy all of the crust area; however, some operations do not modify (till) the entire surface area. Thus, the de-crusting factor is applied only to the fraction of surface being tilled. Also, because the "loose, erodible material" is defined only where a developed crust exists, its value is set to zero when the crust fraction is zero.

Soil Mass Manipulation

Soil mass manipulation processes modify a series of stacked, parallel, homogeneous layers with a specified thickness. Conservation of mass is a fundamental principle used in developing the processes that affect soil layer properties (e.g. layer thickness, bulk density, water content, aggregate size distribution, dry aggregate stability, aggregate density, and particle size distribution).

The aggregate size distribution (ASD) at the soil surface provides information necessary to determine the quantity of erodible-size aggregates available for direct emission and saltation, as well as the degree of shelter provided to erodible-size aggregates by larger aggregates. Aggregate size distribution below the surface is also of interest, because emergency tillage operations used to control wind erosion fail if sufficient non-erodible aggregates are not available to bring to the surface. Aggregate size distributions are represented within WEPS as a four-parameter modified lognormal distribution (Wagner and Ding, 1994). Tillage-induced aggregate breakage is simulated within the Management submodel of WEPS using a Markov chain-based, two-parameter, stochastic model (Wagner and Ding, 1993).

The mixing process represents the uniting or blending of soil layer properties within soil layers only. The mixing process employed in the Management submodel uses a single mixing parameter. The values range from zero for no mixing to one for complete mixing. All layers within the tillage zone are weighted equally in the layer mixing process. It is a mass-based mixing process, which is similar to the volume-based mixing process used in the Erosion Productivity/Impact Calculator (EPIC) and WEPP models (Sharpley and Williams, 1990; Lane and Nearing 1989). All soil layer variables defined as concentrations of the soil mass in the layer (e.g., intrinsic soil properties such as the fractions of sand, silt, clay, and organic matter; cation exchange capacity; and nutrient levels) can be mixed directly.

The loosening process is defined as the addition of air into the soil layer. This is represented as a change in the soil layer bulk density as defined in the EPIC model (Sharpley and Williams, 1990). The soil's reference "settled" bulk density is estimated using organic matter and particle size distribution (Rawls, 1983). All changes in soil layer bulk density require a corresponding change in soil layer thickness, which is accomplished by applying the conservation of mass principle.

The inversion process is defined as the reversal of the vertical order of soil layer properties within the working depth of the tillage tool. This is represented in WEPS by simply transferring soil properties from the lower layers to the upper layers and vice versa. Because layer thickness can vary by depth, property values are averaged when the transposed layers don't match the original layers, thus maintaining the conservation of properties by mass.

Biomass Manipulation

The biomass manipulation processes describe the effects that management operations have on the growing crop and the various biomass pools maintained in the WEPS model. The biomass manipulation processes handled by the Management submodel are flattening, burying, resurfacing, cutting, thinning, killing, removing, and planting/seeding.

Flattening is defined as the transfer of standing residue to flat residue (Wagner and Nelson, 1995). This process is simulated simply by specifying the fraction of standing residue that is flattened by the operation. Typically, standing residue that actually gets buried into the soil is handled by applying the flattening process prior to the burying process. This is different from thinning, which transfers live biomass to flat residue and decreases the plant population proportionally.

The burying process is defined as the transfer of aboveground flat biomass into the soil. This process occurs with many tillage operations. It is simulated in WEPS by specifying the fraction of aboveground residue that is buried. The quantity buried is adjusted based upon both speed and depth selected for the operation relative to a nominal speed and tillage tool depth set for the operation. The biomass is distributed throughout the soil tillage zone based upon the basic type of tillage tool used by the operation.

Resurfacing is defined as the transfer of buried biomass within the tillage zone back to the surface. Specifying the fraction of belowground residue brought to the surface allows simulation of the process.

The cutting process simply changes the height of standing biomass to a prescribed value. The biomass above the cutting height is either removed or added to the surface biomass pool, depending upon a "cut flag" value. Cut height can be specified as either an absolute or relative value referenced from the ground surface or down from the current height of the biomass.

The killing process stops the growth of biomass. The process may be initiated by tillage operations, the application of herbicides, or burning. The "kill flag" value can be set to specify that only annual plants are killed or both annuals and perennials.

The removing process extracts biomass from the site. This process is usually the result of harvest, grazing, or burning operations. The amount, type, and location on the plant (e.g., belowground, aboveground, yield) of the biomass are specified for removal by these operations.

The planting/seeding process triggers the plant growth routines in WEPS to begin simulation of the growth of a crop. Plant height, silhouette area, leaf area, and row direction define the geometry affecting wind movement at the soil surface.

Soil Amendments

Addition of specific materials to the soil and/or surface are also addressed in the Management submodel. Currently, fertilizers, dust suppressants (not yet implemented), irrigation water, and biomass can be applied to the surface or incorporated into the soil. The quantity of amendments applied is user-specified for those operations.

Summary

The WEPS Management submodel attempts to simulate the major processes related to the most prevalent cultural practices used by producers and land managers that influence a site□s susceptibility to wind erosion. The range of practices includes primary and secondary tilling, cultivating, planting/seeding, harvesting, and fertilizing operations, as well as irrigating, burning, and grazing. The processes are simulated via a physical basis if possible, incorporating conservation of mass and energy concepts. Because use of a minimum number of parameters with readily available and/or attainable values was a goal of the submodel design, simplifications were made in representing some processes. Simulation of other processes was constrained simply by a lack of knowledge. However, because of its design, the WEPS Management submodel can be expanded and improved as new knowledge is gained relating to the physical processes affecting the soil surface and mass, and biomass.

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