THE MANAGEMENT SUBMODEL OF THE WIND EROSION PREDICTION SYSTEM

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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 the simulation of the physical processes controlling wind erosion. WEPS is comprised of five databases and several submodels which reflect the physical processes of erosion, soil water movement, plant growth, residue decomposition, dynamic soil properties, and management practices.*

This article describes the WEPS management submodel component which simulates the effects of typical cropping management practices, such as tillage, planting, harvesting, irrigation, or residue burning, at an operational level. Such management practices can affect the surface conditions, which in turn affect wind erosion potential. A variety of land management operations is simulated by identifying the primary physical processes involved and representing each individual operation as a sequenced set of those processes. The process categories include: 1) surface modification (the creation or destruction of ridges and/or furrow dikes that form oriented surface roughness, change the surface random roughness, and destroy the soil crust); 2) mass manipulation within soil layers (the changes in the aggregate size distribution and soil porosity, the mixing of soil and residue among soil layers, and soil layer inversion); 3) biomass manipulation (burying and resurfacing of residue, clipping the standing residue, flattening the standing residue, killing the live crop biomass, and removing biomass); and 4) soil amendments (the application of residue/manure for cover, seeding or planting crops, and irrigation).

Keywords. *Tillage, Modeling, Models, Soil, Wind erosion, Crop rotation.*

The development of the Wind Erosion Prediction System (WEPS) was started by USDA-Agricultural Research Service (ARS) scientists around 1985. The WEPS project was initiated in response to customer requests, primarily from the Soil Conservation Service (SCS), for improved wind erosion technology. WEPS was intended to replace the predominately empirical Wind Erosion Equation (Woodruff and Siddoway, 1965) that was principally used by SCS at the time for estimates of field-scale soil loss caused by wind erosion. WEPS was to be the prediction tool for those who plan soil conservation systems, conduct environmental planning, or assess offsite impacts of wind erosion. SCS, now the Natural Resources Conservation Service (NRCS), implemented WEPS in 2010 (U.S. Gov., 2010) and uses it exclusively for cropland field wind erosion assessments, compliance checking, and for determining wind erosion estimates required for qualifying acceptance in some of their National Programs. WEPS incorporates improved technology for computing soil loss from agricultural fields by wind and provides new capabilities such as calculating the suspension loss, estimating the PM-10 emissions, and specifying the direction in which the soil leaves the field (Wagner, 2012). WEPS contains several submodels that reflect different sets of physical processes: a) erosion (the entrainment, transport, and deposition of airborne particles); b) hydrology (the water movement within the soil); c) plant growth (the development of the leaf, stem, and reproductive plant components); d) residue decomposition (the decay of plant materials); e) soil (the surface soil conditions changed by daily weather conditions); and f) management (the simulation of applied cultural practices). These submodels are supported by five databases: soil, operation, plant growth/decomposition, wind barriers, and climate, including wind data. Figure 1 shows the basic structure of WEPS 1.0, including the interface user inputs, the submodels in the science code, and the databases.

As a process-based planning tool, WEPS is expected to reflect the effects of various management practices that may affect a site's susceptibility to wind erosion. The diversity of these practices makes this task difficult, but WEPS must adequately simulate typical cultural practices to accurately assess their effects on the susceptibility to wind erosion. The management submodel is assigned the task of handling the cultural practices that affect the

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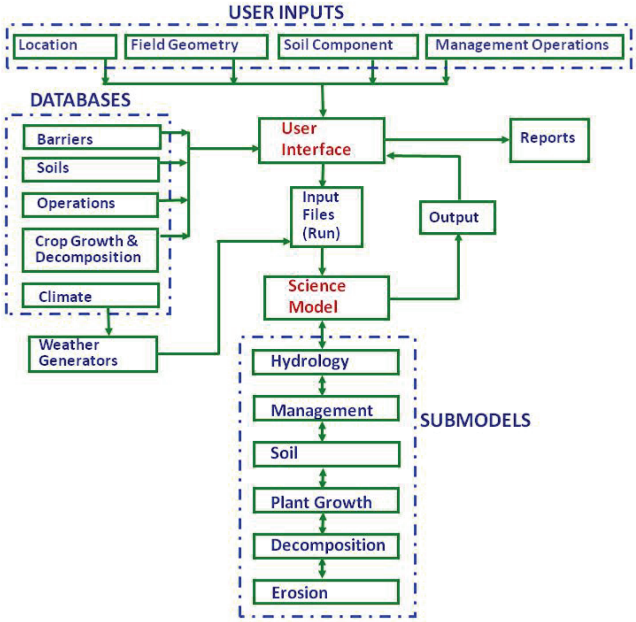

Figure 1. Schematic diagram of the WEPS 1.0 interface, science model submodels and databases.

soil/vegetation surface "state" within WEPS, including primary and secondary tillage, cultivation, planting/seeding, and harvesting operations as well as irrigation, burning, and grazing practices. Note that there are other previous publications regarding the Management submodel of WEPS. However, they either describe earlier versions of the submodel during the development of WEPS or provide incomplete descriptions of the submodel. This article is intended to be the definitive reference for the Management submodel in the current WEPS release (version 1.2.15) and address the deficiencies of the older publications. Specifically, those publications are Wagner and Fox (2001) and Wagner (2011). This submodel combines the efforts of prior researchers as described below.

Submodel Description

The Management submodel characterizes a variety of land management actions by identifying the primary physical processes involved in and representing each individual management operation as a sequenced set of those primary physical processes. Those processes include: 1) surface modification (the creation or destruction of ridges and/or dikes that form an oriented surface roughness, the changes in surface random roughness, and the destruction of the soil crust); 2) soil layer mass manipulation (the changes in the aggregate size distribution and soil porosity, the mixing of the soil and residue among soil layers, and soil layer inversion); 3) biomass manipulation (burying and resurfacing of residue, clipping standing residue, flattening standing residue, killing live crop biomass, and biomass removal); and 4) soil amendments (the addition or removal of manure and residue, planting/seeding, and irrigation).

In accord with the WEPS design philosophy, the Management submodel simulates these processes on a physical basis, if possible, and incorporates the concepts of conservation of mass. It employs functional relationships developed from field and laboratory data of other published research, if available, using a minimum of parameters with readily available and/or attainable values. Some process representations were simplified due to a lack of knowledge about those processes. However, because of its inherent design, the WEPS Management submodel can be expanded and improved as new knowledge is gained about how physical processes affect the soil, surface, and biomass due to human initiated (management) events.

These processes are assumed to be independent of each other and are simulated sequentially. Each management operation is thus represented by an appropriate list of processes. The individual processes and their order of simulation describe each specific operation. The order of processes is specified to account for how an operation affects the "after-operation" state of the system. For example, for an operation that performs a soil tillage disturbance action and adds residue to the surface, one would obtain different "after-operation" results depending on whether the "add residue" process was specified before or after the "residue burial" process. Typical multi-tool and ganged multi-implement operations also can be described easily and fully by repeating the necessary processes for each tool (tillage) element that is a component 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 can thus be described independently based on its effects on the soil, surface, and residue states in order of occurrence during the operation.

Each specific physical process represented by an operation is uniquely defined for that operation by the appropriate process equation and the assigned coefficients' values for that equation. Thus, if an operation breaks a portion of the surface crust and mixes the soil contents to some degree throughout the tillage zone, the associated equations for destroying the surface crust (eq. 1) and mixing soil properties within the soil layers (eq. 10) would be applied. The corresponding values of the coefficients assigned to the operation define the extent to which those equations modify the soil/surface state of the system; e.g., ζ (the fraction of the crust removed based upon the surface area tilled) for equation 1 and μ (the mass mixing efficiency) for equation 10. The complete list of coefficient values for the pertinent process equations representing a specific operation represent a management "record" for that operation. A collection of such operation records are referred to as an operation database for WEPS. NRCS has developed a set of operation records for WEPS where the assigned coefficient values for those operations have been derived from research data, similar operations, and best estimates from knowledgeable NRCS staff. However, the scope of this manuscript is to document only the process equations and not the derivation of the coefficient values for individual operations.

The list of management operations performed for a given management plan (the crop rotation/tillage sequence or the cyclical list of cultural practices) is specified in a management file. On the dates when operations are to be performed, the Management submodel will execute the routines implementing the process equations required to simulate the effects of those operations, based upon the specified process equations and coefficient values included in the management file.

Assumptions and Limitations

Several assumptions and limitations have been imposed on the Management submodel for the current WEPS 1.0 release (version 1.2.15) for reasons ranging from limiting the scope of the submodel to the inadequate knowledge of specific processes that may have a significant impact on the soil and/or surface under specific conditions. Some of these assumptions and limitations are expected to be relaxed in future releases as more relevant research data becomes available and user needs dictate. The current assumptions and limitations that affect the Management submodel are:

1. The tillage depths are adjusted to the nearest soil layer boundary of the simulation. This ensures that the most recent tillage operation modifications on the soil state are adequately represented within the tilled soil layers; i.e., no averaging of soil properties occurs within a simulated soil layer due to a tillage depth that does not fall exactly on a soil layer boundary. Note that the number and thickness of the simulated soil layers used in WEPS are determined algorithmically by default and depend on the information about the usually coarser soil layer horizon that is typically provided as an input to the WEPS model. The soil layering routine follows the built-in rules that specify the general soil layering structure of the simulation; e.g., the default initial layer thicknesses, which increase by depth, the maximum and minimum allowable thicknesses for a layer, etc. WEPS command line options are available for a user to influence the construction of the WEPS-simulated soil layer structure.
2. In the Management submodel, the total water content of the soil within the current tillage zone is assumed to be unaffected by a tillage operation. The hydrology component of WEPS is expected to handle changes in the surface and soil layer water content. Thus, the usual rapid drying of the surface and soil within the tillage zone following the typical tillage operations is simulated in the hydrology module; however, the soil water content within the tillage zone can be redistributed due to the mixing of the soil among the tillage zone soil layers in the Management submodel.
3. The tillage depth alone is assumed to determine only which soil layers are directly affected by a tillage operation. The specific assigned processes for each operation determine the actual influence on the surface and within the soil tillage zone.
4. The effects of the tillage operations on the soil layers below the tillage depth are not currently considered; e.g., subsoil compaction below the tillage zone due to a tillage implement's mass.
5. No surface tillage "compaction" process is currently included in the WEPS Management submodel.
6. The tillage operations are currently assumed to not "increase" the soil aggregate sizes, e.g., the consolidation of aggregates, at this time. The consolidation of the soil aggregates in WEPS occurs only through the climatic effects of precipitation, wetting of the soil layers, and puddle formation on the surface prior to infiltration as simulated within the WEPS Soil submodel. Most of the tillage operations that generate large aggregates on the surface involve the breakdown of the consolidated soil, represented in WEPS as a distribution of "very large" aggregates that exist within the tillage zone prior to the tillage operation.
7. The effects of a management operation are assumed to be homogeneous. The effects of tractor tires will not be considered (except where they may knock down a significant proportion of the standing residue). Certain zone-related tillage operations, such as a row cultivator or strip tillage, are treated so that the result will be "spatially averaged" to determine the equivalent representative values that are assigned to the homogeneous region.
8. The dry stability and density of the aggregates in each layer are assumed to be unaffected by the tillage operations. This decision is based on analysis of the limited field data available. Future research may provide statistically significant effects that could then be modeled, but these properties can still change among the soil layers within the tillage zone due to the mixing of aggregates among these layers that is caused by tillage operations.

Physical Processes Modeled

In WEPS, spatial variability is handled through the use of subregions (Note that the first released version, WEPS 1.0, was limited to a single subregion.). Hence, in each subregion, the submodel considers the soil mass, surface, and biomass properties to be homogeneous in the horizontal direction but variable in the vertical direction (the soil layers). The soil surface is considered to include various combinations of random roughness, ridges, or ridges and dikes. Live vegetation (crops) and decomposing biomass (crop residue) may exist in the soil and on the surface in standing and/or flat orientations.

The physical processes (actions) that most often modify the current state of the soil, surface, and biomass properties in WEPS have been identified. The processes have been formulated into equations that represent the effect of those actions upon the pertinent soil, surface, and biomass properties. A typical management operation will often perform several of these identified actions, so the effect of a management operation on the soil, surface, and biomass state is simulated as a sequential series of "step-change" processes. The processes modeled by the Management submodel are listed in table 1 under the type of action they perform, and each process is described.

Table 1. Management processes.

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 and/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 completes the transfer of the killed crop biomass to the residue decomposition pools. This is a WEPS-specific function to address a deficiency in the current model design that does not allow this process to occur automatically within the model.
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 and/or into the soil.

Soil Surface Manipulation

The soil surface is described within WEPS by random and oriented (the presence of ridges and dikes) roughness values, the fraction of the surface that is non-erodible (covered with rocks), and the fraction that is non-crusted and crusted. The condition of the non-crusted surface is described by the aggregate size distribution, the average aggregate density, and the dry aggregate stability values in the surface layer. In addition, properties describing the condition of the crusted surface, e.g., the crust thickness, density, and dry stability, as well as the amount of loose, erodible material on the crusted fraction of the surface are also maintained. The soil surface can be directly modified by an operation through any of the following processes.

Crust Process

Many field operations modify the soil surface and destroy all or part of the existing crust. This destruction is described by the equation:

$$Cr_f = (1-\zeta)Cr_0 \tag{1}$$

where

Cr_f = fraction of the surface that is crusted after the operation,

Cr_0 = fraction of the surface that is crusted before the operation,

ζ = fraction of the surface that is tilled by the field operation ($0 \leq \zeta \leq 1$).

Field implements are assumed to destroy the crust within the surface area tilled. Many field implements break all of the surface crust across the entire width of the tool, and thus $\zeta = 1$. However, some operations do not till the entire surface or are designed or used in a way that only a portion of the surface is tilled ($\zeta < 1$), so some crust is left unbroken. Examples of some ζ operation parameter values as defined by NRCS are: a) a disk plow or tandem disk (1.0); b) a rotary bed cultivator where only the beds are tilled (0.85); c) a double disk opener no-till grain drill where only the portion around the opener slot is tilled (0.65); d) a strip till planter where only a strip is tilled where the seeds are placed in the ground (0.3); and e) a wide row spacing double disk opener planter where even less surface area is tilled (0.15).

There are also instances where non-tillage operations may destroy a portion of the surface, such as a roller used to flatten residue or wheel traffic from a sprayer, fertilizer spreader, or harvester. Equation 1 can be applied for those operations as well, however further research is necessary to determine their respective coefficients and determine if that type of breakage has the same effect as tillage on wind erosion.

Roughen Process

The random roughness of a surface within the Management submodel is represented in terms of the random roughness index of Allmaras et al. (1966). The process is defined by two parameters: a roughness flag and a roughness value. The flag determines whether the value will be used as the actual value (always use specified random roughness value) or considered to be the nominal value (allow WEPS to auto-adjust random roughness value). When the flag is set to represent the actual value, none of the adjustments for the soil type and the biomass quantity mentioned below are performed, and only the tillage fraction and intensity are applied. The adjustments for soil type and biomass quantity used in the Revised Universal Soil Loss Equation version 2 (RUSLE2) were adopted later to increase commonality between the models.

When the flag is set to specify the nominal roughness value, the method and equations from RUSLE2 (USDA, 2008) are applied. The nominal random roughness value, when assigned to an implement, RR_{impl}, in WEPS, is defined as the typical field value expected under a standard soil type (silt loam) that is composed of 15% clay and 65% silt and contains a very high soil biomass density (dry basis, greater than 44 kg ha^{-1} mm^{-1}) within the tillage zone (the depth of the soil disturbance), which includes both the buried residue and the roots. Therefore, the base RR_{impl} assigned to an operation tool is first adjusted for the soil type, RR_{s_adj}, which comes directly from the RUSLE2 model (USDA, 2008) and then by the quantity of the residue within the tillage zone, RR_{b_adj}, which also comes directly from RUSLE2 but is converted to metric units. Therefore, the roughness values are higher for soils that are high in clay content and lower for soils that are high in sand content, according to the following relationship:

$$RR_{s_{adj}} = \begin{cases} 0.16(siltf)^{0.25} + 1.47(clayf)^{0.27} & when\, RR_{s_{adj}} > 0.6 \\ 0.6 & \end{cases} \quad (2)$$

where

$RR_{s_{adj}}$ = RR adjustment factor for soil type

$clayf$ = fraction of clay in soil

$siltf$ = fraction of silt in the soil

The roughness values also increase with increasing quantities of buried biomass present at the time of the soil disturbance. Thus, the roughness values are also adjusted as a function of the biomass (buried residue and roots) within the depth of the soil disturbance using the following equation:

$$RR_{b_{adj}} = \begin{cases} \mathrm{RR_{impl}} \cdot \mathrm{RR_{s_{adj}}} & when \quad RR_{impl} \cdot RR_{s_{adj}} < RR_{bio\_min} \\ RR_{bio\_min} + \left(RR_{impl} \cdot RR_{s_{adj}} - RR_{bio\_min} \right) & \\ \quad \left(0.8(1 - exp\left(-339.92 \cdot B_m \right)\right) + 0.2) & \end{cases} \quad (3)$$

where

$RR_{b_{adj}}$ = RR adj. for buried biomass (mm),

$RR_{s_{adj}}$ = RR adj. factor for soil type,

RR_{impl} = assigned nominal RR value for tillage operation (mm),

RR_{bio_min} = 6.096 = Minimum reference RR value below which no biomass adjustment is made (mm),

B_m = buried biomass density (dry basis) within the soil tillage layer (kg m^{-2} mm^{-1}),

RR_{bio_min} = reflects the roughness value assumed for water erosion from unit plots,

0.2 = reflects the portion of the roughness value that is not affected by the soil biomass (USDA, 2008).

Most tillage tools cannot reduce the surface roughness to the value usually associated with the operation under all field surface roughness conditions. To account for this, a tillage intensity factor, λ, is assigned to each tillage operation (Alberts, et al., 1995). If the pre-tillage random roughness, RR_o, is greater than the roughness associated with an implement, RR_{impl} (after adjustment for the soil type and the quantity of residue in the tillage zone), the degree of change in the surface roughness is dependent on the value of the tillage intensity assigned to the operation tool. If the tillage operation does not modify the entire surface, the post-tillage random roughness is weighted accordingly.

$$RR_f = \begin{cases} \zeta RR_{b_{adj}} + (1-\zeta)RR_0 & RR_{b_{adj}} \geq RR_0 \\ \zeta\left[\lambda RR_{b_{adj}} + (1-\lambda)RR_0 \right] + (1-\zeta)RR_0 & RR_{b_{adj}} < RR_0 \end{cases} \quad (4)$$

where

RR_f = final tilled surface random roughness (mm),

RR_0 = pre-tillage surface random roughness (mm),

$RR_{b_{adj}}$ = implement-assigned roughness after adjustment for the soil type and biomass (mm),

λ = tillage intensity factor ($0 \leq \lambda \leq 1$),

ζ = fraction of the surface tilled by the operation ($0 \leq \zeta \leq 1$).

Most NRCS defined operations use the "Allow WEPS to auto-adjust random roughness value." Therefore, they will apply both the soil and biomass adjustment factors and use the λ and ζ values assigned to the implement along with the RR_{impl} value. Typical values for λ, ζ and RR_{impl} are: rotary tiller (1.0, 1.0, 10.2 mm); moldboard plow (1.0, 1.0, 48.2 mm); rodweeder (0.25, 1.0, 7.6 mm); and ridge till planter (0.5, 0.65, 10.2 mm). Thus, the rotary tiller and moldboard plow will achieve the nominal roughness, after adjustments for soil and buried biomass, under all initial surface roughness conditions, while the rodweeder and ridge till planter will not achieve the nominal roughness value, after adjustments for soil and buried biomass, if the original surface roughness is greater than the nominal roughness value.

Ridge/Dike Process

Oriented roughness is defined by uniform rows of ridges and furrows running in parallel lines, with the height being the distance from the bottom of the furrow to the top of the crest (Chepil and Milne, 1941) and the spacing being commonly described as the distance between successive furrows or ridges. While Chepil and Woodruff (1954) asserted, "The degree of surface roughness depends on … size, shape, and lateral frequency of clods, ripples, and ridges," no researcher has performed more to quantify the degree of surface roughness provided by ridges than describe the height and spacing. To facilitate the utilization of future research and to acknowledge the use of beds (ridges with flat tops) in vegetable production in regions susceptible to wind erosion, the oriented roughness is described by the top width, height, and spacing of the ridge and the row direction within WEPS. If dikes exist in the furrows, they are assumed to be uniformly spaced with the same slope and top width as the ridges. Therefore, only the furrow dike height and spacing are required to define dikes within WEPS.

A "ridge modification" flag determines how an operation can influence the oriented roughness. Based on the flag value: a) a tillage tool can change the current surface configuration into the desired configuration with respect to the oriented roughness, regardless of the previous surface oriented roughness state (Ridges/dikes set to specified values); b) the operation will modify the current oriented roughness based upon the depth of tillage specified (Ridges/dikes set, based on tillage depth); or c) the operation will not disturb the current oriented roughness, regardless of its value, as with row cultivation tools (Pre-existing ridges/dikes left unchanged). In cases where the tillage tool can only partially modify the current oriented roughness, past modelers (Sharpley and Williams, 1990) estimated the effect based on the depth of the current tillage operation and the previous ridge forming operation. This parameterization violates the no lag state modeling approach used in this submodel, and therefore a linear estimation using only the ridge height and the tillage depth of the current operation and pre-tillage ridge height was developed.

$$\hat{R}_h = R_{impl} \qquad D_{act} \geq R_h / 2 \tag{5}$$

$$\hat{R}_h = R_{impl} \qquad D_{act} < R_h / 2 \text{ and } R_{impl} \geq 2\left(R_h / 2 - D_{act}\right)$$

$$\hat{R}_h = 2\left(R_h / 2 - D_{act}\right) \qquad D_{act} < R_h / 2 \text{ and } R_{impl} < 2\left(R_h / 2 - D_{act}\right)$$

where

$\hat{R}_h$ = post tillage ridge height (mm),
R_h = pretillage ridge height (mm),
R_{impl} = ridge height set by the implement (mm),
D_{act} = actual tillage depth (mm).

Most NRCS defined ridging operations use the "Ridges/dikes set to specified values" flag since it expects that the ridge height specified is desired by the operator and the tillage depth will be adjusted to achieve it. The operations that are not intended to modify ridges, either do not include this process, or have the flag set to "Pre-existing ridges/dikes left unchanged" such as planters that seed on an existing ridge bed. The operations that have the flag set to "Ridges/dikes set, based on tillage depth" are light tillage operations, like a harrow cultivator, that are not capable of tilling deep enough to remove tall ridges if used on such a surface condition.

Soil Mass Manipulation

Soil mass manipulation processes modify a series of stacked, parallel, homogeneous layers with a specified thickness. The conservation of mass principle was used to develop the following submodel processes that affect the soil layer properties (e.g., the layer thickness, bulk density, water content, aggregate size distribution, dry aggregate stability, aggregate density, and particle size distribution).

Crush Process

The aggregate size distribution at the soil surface provides the information necessary to determine the quantity of aggregates that are erodible in size and are available for direct emission and saltation, as well as the degree of shelter provided to these aggregates by larger aggregates. The aggregate size distribution below the surface is also of interest because emergency tillage operations used to control wind erosion fail if insufficient non-erodible aggregates are available to bring to the surface.

The aggregate size distributions are represented within WEPS as a four-parameter modified log-normal distribution (Wagner and Ding, 1994). The tillage-induced aggregate breakage is simulated within the Management submodel of WEPS with a Markov chain-based, two-parameter, stochastic model (Wagner and Ding, 1993).

Currently, a simple two-parameter functional representation (eq. 7) is used to represent the aggregate breakage process for a given operation tool and applied in equation 6. The tillage-induced aggregate breakage was also found to be dependent upon the soil type and water content at the time of tillage (Wagner et al., 1992; Wagner and Ding, 1993, Wagner et al., 1994). However, no water content and soil type functional relationships are employed in WEPS 1.0 because the tillage operations are simulated only on fixed dates regardless of soil water content and limited soil/tillage data were available to fully develop soil type relationships from the data. The aggregate breakage model can be summarized as follows in the context of the soil aggregate crushing process, as expressed by Wagner and Ding (1993):

A soil aggregate is assumed to consist of many particles, with each having an extremely small volume and a unit mass. The soil particles can travel only downward from a larger aggregate size class to smaller aggregate size classes after each tillage pass (crushing of an aggregate). If a size class is called a "state," then the transition of soil particles from one state to another can be treated as a completely random event. A probability matrix, P[i,j], can be constructed for all possible transitions occurring in the soil when it's aggregate size distribution (0 to i-1) (mass fractions across different size classes) shifts or transfers from w[i] to $\hat{w}[k]_{(0\,to\,i-1)}$ *size, after one crushing stage (tillage pass). P[i,j], often called a transition matrix, maintains the properties of a Markov chain and does not change with the number of tillage passes performed but depends on the type of tillage and the specific soil conditions.*

Mathematically, the Markov chain-based crushing model is of the form:

$$\hat{w}[i]_{1\times n} = w[i]_{(1\times n)} P[i,j]_{(n\times n)} \tag{6}$$

where

$\hat{w}[i]$ = post-tillage array of the aggregate size class fractions,
w[i] = pre-tillage array of the aggregate size class fractions,

$P[i,j]$ = transition matrix,
i,j = indices for the soil aggregate size classes,
n = maximum number of the aggregate size classes.

The effectiveness of the model relies on how accurately the transition matrix, $P[i,j]$, can be estimated. The transition matrix, consisting of $p_{i,j}$ elements was represented by a binomial distribution using the p_i relationship in equation 7. The specifics on how this was done are provided in detail by Wagner and Ding (1993). The most suitable two-parameter functional representation for p_i was found by Wagner and Ding (1993) to be:

$$p_i = \frac{1.0}{1.0 + \exp\left(-\alpha + \beta \frac{gmd_i}{gmd_{max}}\right)} \quad (7)$$

Where (For a rotary sieve of n sieves, the x_0 and x_{n+1} are arbitrary minimum and maximum aggregate sizes assumed to exist in the data. The values used during model development analysis were 0.01 mm and 152.4 mm, respectively. These values also correspond to the x_0 and x_{n+1} values from a four-parameter "modified" lognormal function describing an aggregate size distribution.):

i = 1,2,3,…,n,n+1 (n=number of sieve cuts),
gmd_i = geometric mean diameter of the aggregates in size class i (x_{i-1} to x_i) (mm),
gmd_{max} = geometric mean diameter of the aggregates in the largest size class (x_n to x_{n+1}) (mm),
α = aggregate size distribution breakage factor,
β = breakage intensity factor.

Parameter α reflects the breakage of all soil aggregates regardless of size. As α decreases, the percentage of soil aggregates that are breaking increases. Parameter β reflects the unevenness of breakage among aggregates in different size classes. Large β values indicate that crushing mainly affects the large soil aggregates. Currently NRCS has chosen to only select and apply the limited α and β parameter values obtained by Wagner and Ding (1993) for other implements based upon their similarity to the tested implements. Some operation α and β crushing parameters are provided here from Wagner and Ding (1993) for reference: a) chisel plow (2.4, -2.0); b) disk harrow (4.3, 2.0); c) field cultivator (3.0, 1.8); and d) rotary tiller (1.5, 0.56). NRCS has assigned crushing parameter values for other operations based upon their similarity to the tillage operations evaluated by Wagner and Ding (1993).

Loosen Process

The loosening process is defined as the addition of air in the soil layer. This is represented as a change in the soil layer bulk density in the Management submodel by equation 8 and is taken directly from the EPIC model (Sharpley and Williams, 1990). The reference "settled" bulk density, ρ_s, is determined using an interpolation of the published data, based on the soil texture and organic matter content, by Rawls (1983). Applying the conservation of mass principle requires a corresponding change to the soil layer thickness as shown in equation 9.

$$\hat{\rho}_l = \rho_l - \left(\rho_l - \frac{2}{3}\rho_{sl}\right)\mu \quad (8)$$

where

$\hat{\rho}_l$ = post-tillage bulk density for layer l (Mg m^{-3}),
ρ_l = pre-tillage bulk density for layer l (Mg m^{-3}),
ρ_{sl} = settled bulk density for layer l (Mg m^{-3}),
μ = loosening intensity coefficient ($0 \le \mu \le 1.0$).

$$\hat{Z}_l = Z_l \frac{\rho_l}{\hat{\rho}_l} \quad (9)$$

where

$\hat{Z}_l$ = post-tillage layer thickness for layer l (mm),
Z_l = pre-tillage layer thickness for layer l (mm).

Some typical NRCS defined operations have the following μ loosening parameter values: rotary tiller (0.7), moldboard plow (0.8), straight point chisel (0.85), and rodweeder (0.5).

Mix Process

The mixing process represents the uniting or blending of the soil layer properties among the layers that are within the depth of influence (tillage depth) and excludes surface constituents such as the crop residue and other non-soil elements. The mixing process uses a single mixing parameter, with values ranging from zero, for no mixing, to 1.0, for complete mixing, as described in the APEX, EPIC, and WEPP model documentation (Williams, et al., 2008; Sharpley and Williams, 1990; Alberts, et al., 1995). Expressed on a mass basis, the equation becomes:

$$\hat{X}_l = (1-\mu)X_l + \mu\left(\frac{\sum_{k=1}^{m}(\rho_k Z_k X_k)}{\sum_{k=1}^{m}(\rho_k Z_k)}\right) \quad (10)$$

where

$\hat{X}_l$ = final mass concentration in layer l,
X_l, X_k = initial mass concentrations in layers l and k,
μ = mass mixing efficiency coefficient ($0 \le \mu \le 1.0$),
$\rho_k Z_k$ = unit surface area mass of soil in layer k [M L^{-2}],
l, k = soil layer indices,
m = maximum number of soil layers.

Some typical NRCS defined operations have the following mass mixing efficiency coefficient values (μ): rotary tiller (0.9), moldboard plow (0.7), straight point chisel (0.37) and rodweeder (0.05).

Invert Process

The inversion process is the reversal of the vertical order of the soil layer properties within the working depth of the tillage tool. Thus, inversion is simply the reordering of the soil layer properties in the model where new values are assigned to each layer. Because the soil layer thicknesses are not re-ordered during this process, the soil layer properties are re-partitioned (averaged) into each layer.

BIOMASS MANIPULATION

The biomass manipulation processes describe the effects that the management operations have on the growing crop and the various biomass pools of a) residue age, b) location (standing, flat, buried), and c) plant component (stems, leaves, and reproductive components) maintained in the WEPS model. The biomass manipulation processes handled by the Management submodel are flatten, bury, re-surface, change standing biomass fall rate, cut/remove, thin population, kill/defoliate, and remove. The biomass manipulation processes are applied only to the fraction of the surface that is disturbed by the management operation, e.g., a tillage tool.

The processes of flattening, burying, re-surfacing, and changing the standing biomass fall rate contain coefficients that depend on the "toughness/size" of the residue biomass being manipulated. The five toughness/size residue classes are a) fragile residue, b) moderately tough residue, c) non-fragile/large residue, d) woody residue, and e) small stones/gravel. Currently, there is no means within WEPS to "convert" a residue pool from one toughness/size class to another due to decomposition, etc. These five toughness/size residue classes and the accompanying flattening, burial, and re-surfacing coefficient values assigned to these processes for the individual operations match those used in RUSLE2 to achieve additional commonality between the ARS erosion models.

Flatten Process

Flattening is defined as the transfer of standing residue to flat residue (Wagner and Nelson, 1995). This is a process that occurs for many operations. Even non-tillage operations often have wheel traffic that flattens a portion of the standing vegetation. This process is simulated simply by specifying the fraction of standing residue and/or crop biomass that is flattened by the operation. Typically, standing residue that becomes buried into the soil is handled by applying the flattening process prior to the burying process. This is different from the thinning process, which provides methods to directly specify a reduction in the plant population, and the standing material is either removed or left flat in the field. WEPS maintains separate plant component pools (leaves, stems, storage) that are represented for each plant location pool (standing, flat, buried), so each plant component from standing plants and residue that are flattened must be transferred to their corresponding flat component pools. Thus, the "flat" pools are increased, the "standing" pools are decreased, and the plant population and standing residue stem counts are decreased proportionally. Applying conservation of mass as shown by Wagner and Nelson (1995) yields:

$$FL_f = FL_0 + ST_0 \gamma \zeta$$

$$ST_f = ST_0 (1 - \gamma \zeta) \qquad (11)$$

where

FL_f = flat mass after the operation (stem, leaf, and store pools),

FL_0 = flat mass before the operation (stem, leaf, and store pools),

ST_f = standing mass after the operation (stem, leaf, and store pools),

ST_0 = standing mass before the operation (stem, leaf, and store pools),

γ = flattening coefficient ($0 \leq \gamma \leq 1$),

ζ = fraction of surface that is tilled ($0 \leq \zeta \leq 1$).

Some typical NRCS defined operations have the following flattening coefficient (γ) values: rotary tiller (1.0), moldboard plow (1.0), straight point chisel (0.6), and rodweeder (0.4).

Bury Process

The burying process is defined as the transfer of above-ground, flat biomass into the soil (Wagner and Nelson, 1995). This process occurs with many tillage operations and is simulated in WEPS by specifying the fraction of above ground residue (on a mass basis) that is buried. The Wagner and Nelson (1995) basic mass burial concepts are applied in equation 12. The actual burial of the surface residue, accounting for effects of both the speed and depth for all plant component pools (stem, leaf, storage), is computed from:

$$RES_{bf} = RES_{b_0} + RES_{s_0} (B_{coef} D_{adj} S_{adj}) \zeta$$

$$RES_{sf} = RES_{s_0} - RES_{s_0} (B_{coef} D_{adj} S_{adj}) \zeta \qquad (12)$$

where

RES_{bf} = buried biomass after the operation (stem, leaf, and store pools) (kg m^{-2}),

RES_{b_0} = buried biomass before the operation (stem, leaf, and store pools) (kg m^{-2}),

RES_{sf} = flat surface biomass after the operation (stem, leaf, and store pools) (kg m^{-2}),

RES_{s_0} = flat surface biomass before the operation (stem, leaf, and store pools) (kg m^{-2}),

B_{coef} = burial coefficient for a specified "toughness/size" residue class,

S_{adj} = speed adjustment factor for the burial coefficient,

D_{adj} = depth adjustment factor for the burial coefficient,

ζ = fraction of surface tilled ($0 \leq \zeta \leq 1$).

The burial coefficient is adjusted based on both the travel speed and depth selected for the operation relative to a nominal speed and tillage tool depth set for the operation. These speed and depth adjustments to the burial coefficient, as well as the available methods of redistribution of buried residue by depth, were conceived by the RUSLE2 developers (USDA, 2008) as enhancements when they were incorporating the Wagner and Nelson (1995) mass flattening, burial and resurfacing processes into RUSLE2 as part of a joint effort to improve commonality between the two ARS models. Derivation of these particular equations (eqs. 13, 14, 15, and 16) are available in the RUSLE2 science document (USDA, 2008).

Biomass is distributed throughout the soil tillage zone based on the type of tillage tool used by the operation. Six types of burial by depth distribution processes are defined in WEPS and designated by a Burial Distribution Flag: 0) uniform burial, 1) mixing plus inversion burial, 2) mixing burial, 3) inversion burial, 4) lifting, fracturing burial, and 5) compression burial. The nominal speed and depth assigned to an operation are the "reference conditions" and are assumed to be the manufacturer's recommended or normal operating depth for the implement, machine, or tool that performs the burial process. The effect of the operation depth or soil disturbance depth on the burial efficiency is computed using:

$$D_{adj} = \frac{[1-(1-\frac{D_{act}}{D_{max}})^{2.7}]}{[1-(1-\frac{D_{ref}}{D_{max}})^{2.7}]}$$

$$\text{for} \quad D_{act} = \max[\,min\left(D_{spec}, D_{max}\right), D_{min}] \tag{13}$$

where
D_{adj} = depth adjustment factor for burial coefficient,
D_{spec} = specified tillage (soil disturbance) depth (mm),
D_{act} = actual soil disturbance depth (mm),
D_{ref} = nominal (reference) soil disturbance depth (mm),
D_{max} = maximum soil disturbance depth (mm),
D_{min} = minimum soil disturbance depth (mm).

Similarly, the effect of the speed on the surface residue burial is computed using:

$$S_{adj} = \frac{[0.6+0.4(S_{act}\,/\,S_{max})^{0.5}]}{[0.6+0.4(S_{ref}\,/\,S_{max})^{0.5}]} \tag{14}$$

$$\text{for } S_{act} = \max[\,min\left(S_{spec}, S_{max}\right), S_{min}]$$

where
S_{adj} = speed adjustment factor for the burial coefficient,
S_{spec} = specified operation speed (m s^{-1}),
S_{act} = actual operation speed (m s^{-1}),
S_{ref} = nominal (reference) operation speed (m s^{-1}),
S_{max} = maximum operation speed (m s^{-1}),
S_{min} = minimum operation speed (m s^{-1}).

The distribution of the buried residue into the tillage zone layers is defined by a cumulative mass distribution function for each type of residue burial. For most types, a function of the following form is used:

$$RES_{massfrac} = \left(\frac{D}{D_{act}}\right)^{b} \tag{15}$$

where
$RES_{massfrac}$ = fraction of the residue mass buried from the soil surface to depth D,
b = burial distribution exponent depending on the implement burial type,
D = depth in soil from the surface (mm),
D_{act} = actual tillage depth (mm).

For a uniform mixing burial distribution implement type, the exponent b equals 1.0; for mixing plus inversion and lifting, fracturing types, b equals 0.5; and for mixing and compression types, b equals 0.3. For the inversion burial distribution implement type, the following equation is used:

$$\begin{aligned} &RES_{massfrac} = \\ &\quad 0.28\left\{exp\left[1.83\left(\frac{D}{D_{act}}\right)\right]-1\right\} \\ &\quad for\ \ 0 \le \frac{D}{D_{act}} \le 0.6 \\ &RES_{massfrac} = \\ &\quad 1-0.441\left\{\left[1-\left(\frac{D}{D_{act}}\right)\right]/\,0.4\right\}^{1.4} \\ &\quad for\ \ 0.6 < \frac{D}{D_{act}} \le 1.0 \end{aligned} \tag{16}$$

Some typical NRCS defined operations have the following burial parameter values: rotary tiller (0.9 "using mixing burial distribution"), moldboard plow (0.99 using "inversion" burial distribution), straight point chisel (0.76 using "mixing plus inversion and lifting, fracturing" burial distribution) and rodweeder (0.05 using "uniform mixing" burial distribution).

Re-Surface Process

Resurfacing is defined as the transfer of the buried biomass within the tillage zone back to the surface (Wagner and Nelson, 1995). This process occurs with ground-engaging tillage operations and is most prevalent with chisel-style tools. It is not uncommon for one to end up with more residue on the surface after using one of these type of implements if the original surface had little residue on the surface but contained a large amount of residue below the surface within the tillage zone. Specifying the fraction of below-ground residue within the tillage zone brought to the surface allows for the simulation of the process as outlined by Wagner and Nelson, 1995. The fraction is uniformly applied to all soil layers in the tillage zone.

$$\begin{aligned} RES_{bf} &= RES_{b_0} - RES_{s_0}(L_{coef})\zeta \\ RES_{sf} &= RES_{s_0} + RES_{b_0}(L_{coef})\zeta \end{aligned} \tag{17}$$

where
RES_{bf} = buried biomass after the operation (stem, leaf, and storage pools),
RES_{b_0} = buried biomass before the operation (stem, leaf, and storage pools),
RES_{sf} = flat surface biomass after the operation (stem, leaf, and storage pools),
RES_{s_0} = flat surface biomass before the operation (stem, leaf, and storage pools),
L_{coef} = lift (resurface) coefficient for a specified "toughness/size" residue class,
ζ = fraction of surface tilled ($0 \le \zeta \le 1$).

Some typical NRCS defined operations have the following resurfacing parameter values for a "toughness/size" residue class of "moderately tough residue" like wheat straw: rotary tiller (0.08), moldboard plow (0.02), straight point chisel (0.06) and rodweeder (0.0).

Change Standing Biomass Fall Rate Process

Most tillage operations that leave some residue standing will still affect the "fall threshold" and "fall rate" of the standing material due to the destruction of roots that anchor the standing residue in place (Steiner et al, 1994). By providing a process to specify adjustments to the standing residue "fall threshold" and "fall rate" assigned to a residue pool, an acceleration of the decline in the standing residue can be simulated. Various "fall rate" adjustments are assigned to an operation based on the residue "toughness/size" class. A "residue pool selection" flag is used to specify which residue age pools are to have their fall rate modified.

This process was added to WEPS when NRCS observed that the model showed standing residue existing much longer than common field observations indicated. These were management rotations that involve undercutting (wide sweep, rodweeder for example) with little flattening but significant disturbance of the soil. Trying to compensate for this by increasing the amount of residue flattened by these operations would result in too little standing residue after the operation. The adjustment factor provides for a way to have a realistic standing residue amount immediately after the operation and a realistic absence of standing residue within a reasonable time interval following the operation.

$$TH_f = TH_0 (TH_{adj}) \zeta$$

$$FR_f = FR_0 (FR_{adj}) \zeta \tag{18}$$

where

TH_f = threshold fall rate after the adjustment (decomposition days),

TH_0 = threshold fall rate assigned to the residue pool (decomposition days),

FR_f = fall rate after the adjustment (fract. of stems day^{-1}),

FR_0 = fall rate after the adjustment assigned to residue pool (fract. of stems day^{-1}),

TH_{adj} = threshold fall rate adjustment factor assigned to the operation,

FR_{adj} = fall rate adjustment factor assigned to the operation (assigned by "toughness/size" residue class),

ζ = fraction of surface tilled ($0 \le \zeta \le 1$).

All numbers in the database were determined from WEPS model run testing with NRCS. NRCS inserted values and ran the model to compare with their field experience with those rotations. This is an example of a process that could benefit from additional field experiments to determine actual measured standing residue fall rates after tillage. An example of NRCS defined operations are the "sweep plow" implements employing this process. They have the following fall rate adjustment factors (FR_{adj}) (3.0, 2.5, 2.0, 1.5, and 1.0) and threshold fall rate adjustment factors (TH_{adj}) (0.5, 0.6, 0.7, 0.8, and 1.0) assigned for the crop pool for each of the five "toughness/size" residue classes, The values are shown in most fragile to least fragile order. So a "fragile" crop residue, like soybeans, would be assigned a value of 3.0 for the fall rate adjustment and 0.5 for the threshold fall rate if using one of these" sweep plow" implements.

Cut/Remove Processes

The cutting process simply changes the height of the 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. The cut height can be specified as either an absolute or a relative value (fraction of total height) referenced from the ground surface or down from the current height of the biomass, depending on the specific "cut" process applied.

Thin Population Processes

Thinning is the process of reducing the plant and/or residue stem count. The manual pruning of plants is a common practice applied to vegetables crops. All "thinned" plant components are transferred to their corresponding flat pool components or removed as specified by the pool removal fraction coefficients. The degree of thinning can be specified by a specific desired plant stem population or as a fraction of the current plant stem population.

$$THINF_{remain} = \left(1.0 - THINF_{remove}\right)$$

or

$$THINF_{remain} = \min(1.0, \frac{STEMPOP_{desired}}{STEMPOR_{current}}) \tag{19}$$

where

$THINF_{remain}$ = fraction of the original population to remain,

$THINF_{remove}$ = fraction of the original population to remove,

$STEMPOP_{desired}$ = desired population (no. stems m^{-2}),

$STEMPOR_{current}$ = current population (no. stems m^{-2}).

Kill/Defoliate Process

The kill/defoliate process stops the growth of the biomass and transfers the "crop" biomass (roots, flat, or standing) to the corresponding categories in the "residue" biomass pools. 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 or both annuals and perennials be killed. The kill/defoliate process also can be used for defoliating a growing crop, e.g., the dropping of all standing crop leaf mass into the flat component of the crop pool (the flat component of the crop pool is a temporary storage pool for retaining the plant biomass from a growing crop until it is transferred to the flat residue pool for decomposition to begin). If the crop has sufficient reserve energy, it will regrow, otherwise it will die when defoliated. This is determined by a parameter in the crop growth record. If no crop is actively growing, this process does nothing.

The current "kill flag" values and their definitions are:

$$KILL_{flag} = 0 = \text{ No crop killed} \tag{20}$$

$$KILL_{flag} = 1 = \text{Annual crop killed, perennial crop not killed}$$

$$KILL_{flag} = 2 = \text{All crop types killed}$$

$$KILL_{flag} = 3 = \text{Crop defoliation triggered}$$

Removel Process

The remove process extracts biomass, either live crops and/or residue, from the site. This process is usually the result of harvest, grazing, or burning operations. The biomass amount, type, and position of the plant/residue are specified for removal by this process. The actual biomass pool variables available for fractional mass removal are the reproductive components (grain/fruit), leaves, stems, storage roots, and fibrous roots. Three remove-process flags specify the "position" of the biomass being removed (standing, flat, and buried locations), the pools selected for the biomass removal (crop, temporary crop, and residue decomposition pools) and the age of the material to be manipulated (crop, youngest residue, second youngest residue … oldest residue). These flag value definitions are:

$$SelectPosition_{flag} = 1 = \text{Standing and root components} \quad (21)$$

$$SelectPosition_{flag} = 2 = \text{Flat component}$$

$$SelectPosition_{flag} = 3 = \text{Standing, root and flat components}$$

$$SelectPosition_{flag} = 4 = \text{Buried component}$$

$$SelectPosition_{flag} = 5 = \text{Standing, root, and buried compinents}$$

$$SelectPosition_{flag} = 6 = \text{Flat and buried components}$$

$$SelectPosition_{flag} = 7 = \text{Standing, root, flat, and buried components}$$

$$SelectPool_{flag} = 1 = \text{Crop pool components}$$

$$SelectPool_{flag} = 2 = \text{Temporary pool components}$$

$$SelectPool_{flag} = 3 = \text{Crop and temporary pool components}$$

$$SelectPool_{flag} = 4 = \text{Residue pool components}$$

$$SelectPool_{flag} = 5 = \text{Crop and residue pool components}$$

$$SelectPool_{flag} = 6 = \text{Temporary and residue pool components}$$

$$SelectPool_{flag} = 7 = \text{Crop, temporary and residue pool components}$$

$$SelectAge_{flag} = 0 = \text{All ages}$$

$$SelectAge_{flag} = 2 = \text{Youngest residue age}$$

End Biomass Manipulation Process

This process completes the transfer of the remaining biomass from a harvested or killed crop into the appropriate residue decomposition pool. The harvesting processes and the kill process will typically terminate the active growth of a growing crop; the crop biomass is then moved into the "temporary crop" pool where additional biomass manipulation processes can still act on the crop material before it officially becomes crop residue within the WEPS model. It is normally specified as the last process in the harvesting and tillage operations that terminates the growth of a growing crop. This process is currently required for operations that "kill" growing crops in WEPS as decomposition can only occur in "residue" pools and not "crop" pools at this time in the model.

SOIL AMENDMENTS

The soil amendment processes add material, e.g., water, seeds, plants, residue, etc., to the surface and/or within soil layers.

Plant Process

This process triggers the plant growth routines in WEPS to begin the simulation of the growth of a crop. The parameters (row spacing, plant population, and number of tillers per plant) and flags (type of planting and seed placement location) are specified, along with a complete crop growth and residue decomposition record for this process. The flag values are:

$$PlantingType_{flag} = 0 = \text{Broadcast seeding} \quad (22)$$

$$PlantingType_{flag} = 1 = \text{Use implement ridge row spacing}$$

$$PlantingType_{flag} = 2 = \text{Use specified row spacing}$$

$$SeedPlacement_{flag} = 0 = \text{Seed row placed in the furrow bottom}$$

$$SeedPlacement_{flag} = 2 = \text{Seed row placed on the ridge top}$$

Irrigate Process

This process allows for the initiation and termination of scheduled irrigation events based on a management-allowed depletion level. Based on the parameter values, the model can simulate a wide range of irrigation scenarios, including sprinkler, furrow, flood, and drip irrigation and their associated scheduling and application rate constraints. An irrigation type is specified by its maximum and minimum daily application depth, either the rate or the duration of application, the minimum number of days between applications, and the location of application as a distance above (+) or below (-) the soil surface. A single irrigation event can also be specified.

Add Biomass Process

This process provides the means to add additional crop residue biomass (or other material simulated as a crop residue) to the surface and/or into the soil. Typical non-crop residue materials such as manure, wood chips, and plastic covers can be simulated by setting the appropriate parameter values for standing residue stem count, height and mass, flat residue mass and residue toughness class, buried residue mass and burial depth, and buried root residue mass and burial depth .

CONCLUSIONS

The WEPS Management submodel attempts to combine published work from previous researchers to simulate the major processes related to the most prevalent cultural practices used by producers and land managers that influence the susceptibility of a site to wind erosion. The range of practices includes primary and secondary tillage, cultivation, planting/seeding, harvesting, and fertilization operations, as well as irrigation, burning, and grazing. The processes are simulated from a physical basis, if possible, and incorporate the conservation of mass concepts. Because a goal of the submodel design was to use a minimum number of parameters with readily available and/or attainable values, the representations of some processes are simplified. The simulation of other processes was constrained simply by a lack of knowledge about those processes. The WEPS Management submodel can be expanded and improved as new knowledge is gained relating to the physical processes affecting the soil surface, soil mass, and biomass. Additionally, because WEPS represents a management operation as a sequence of physical processes, it not only allows for flexibility in how to describe specific existing operations but also allows for new implements and operations to be created and used easily within WEPS.

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