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# SOM dynamics and erosion in an agricultural test field of the Clear Creek, IA watershed

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## Abstract

To date, few studies have examined in detail the role of spatial variabilities of erosion on Soil Organic Matter (SOM). More specifically, the role of deposition is still poorly understood. The nature of the research is novel because it combines dynamic model simulations using the Water Erosion Prediction Project (WEPP) and CENTURY SOM dynamics model to evaluate soil and SOM loss in an agricultural test field of the Clear Creek, IA watershed. In addition, numerical simulations were coupled with limited field investigations calibrating and verifying WEPP and CENTURY. The main task of this study was to evaluate changes in SOM dynamics in a field using CENTURY and accounting for the interdependence of historical and current management practices, erosion (i.e., soil loss and deposition), and decomposition. Simulations were conducted under three different erosion scenarios determined using WEPP to demonstrate the importance of including deposition in studies of SOM dynamics: (1) assuming no erosion, (2) using an average erosion rate for the whole field, and (3) dividing the field into an erosional upland and depositional floodplain. The total SOM concentrations produced by the segmented field simulation agreed best with the measured field values. Simulated SOM concentrations values for the upland were 13% lower and values for the floodplain were 16% higher than measured field values. The results of this investigation compare well with the simulation results of other studies in terms of the effects of deposition on SOM distributions and that more detailed erosion values lead to better performance of the model. Deposition decreased SOM loss from the field by accounting for sequestration of carbon.

## 1 Introduction

The collection of organic by-products from the breakdown of plant and animal residues in the pedosphere, which is referred to as Soil Organic Matter (SOM), strongly influences several soil biogeochemical properties (e.g., aggregate stability and water-





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holding capacity) and processes, like infiltration/runoff (Lal, 2004). Thus, understanding the spatial distributions of SOM is integral to evaluate soil and water quality within the critical zone, which is comprised of components from the atmosphere, lithosphere, and biosphere interacting between the top of the canopy and the bottom of the aquifer (National Research Council, 2001; Chorover et al., 2007).

Spatial distributions of SOM are quantified most simply through the following budget:

$$\frac{\delta S}{\delta t} = I - e - d \tag{1}$$

where the concentration of SOM at a specific place and time ($S$) is the sum of inputs from plant and animal residues ($I$) balanced by changes due to erosion (e) and decomposition ($d$). Soil erosion encompasses the four stages of detachment, transport, redistribution, and deposition (Lal, 2005), while decomposition is the biological or chemical breakdown of complex organic material into simpler products that results in the release of $CO_2$ (Brady and Weil, 2008).

The constituents of Eq. (1) are controlled by interrelated driving forces within the critical zone (Fig. 1). The relative influences of the individual controls differ depending on different land uses, landscape positions, and scales, at which they are studied. Moreover, many aspects of these interactions are grossly understudied, which inhibits overall understanding of the processes occurring in the critical zone (Chorover et al., 2007).

In the atmosphere, climate, namely temperature and precipitation, dictates primary productivity affecting both the residue quantity and quality, which is expressed as the relative ease of the residue to decompose (Duiker and Lal, 1999). Climate also affects the microbial activity driving the decomposition of the residue (Cole et al., 1993). Finally, precipitation intensity and duration determines raindrop impact and runoff, respectively, which are the triggering mechanisms for soil detachment and transport.

Soil detachment results from the breakdown of soil aggregates, or complexes of inorganic minerals and SOM. Within aggregates, SOM is physically protected from decomposing microbes. Thus, soil texture (i.e., clay content and aggregate size) can regulate decomposition (Bricklemyer et al., 2007), as well as influence soil erodibility (Gilley et al., 1993).

The degree of soil erosion results not only from the interplay between hydrologic forcings (i.e., raindrop impact and runoff) and soil biogeochemical properties (e.g., aggregate stability), but also the influences of anthropogenically applied management practices (Dalzell et al., 2004; Papanicolaou and Abaci, 2008). In some instances, management practices amplify erosion rates, while other management practices dampen the impacts of the hydrologic forcings and soil characteristics on erosion. For example, it is widely accepted that conventional tillage in agricultural fields enhances erosion by disassociating soil aggregates, decreasing soil strength, and facilitating particle mobility under fluid forces (Williams, 1981). Reduced tillage practices have been shown to maintain aggregate structure, thereby limiting grain particle entrainment by flow (Paustian et al., 2000).

Now, a strong relationship exists between erosion and SOM loss (Starr et al., 2000; Papanicolaou et al., 2009), so it follows that SOM concentrations are also strongly influenced by the applied management practices. Previous studies have shown that the effects of agricultural management practices (i.e., tillage) on SOM can vary considerably depending on the practice intensity (Duiker and Myers, 2005; Lal, 2005; Kennedy and Schillinger, 2006). For example, long-term conventional tillage reduces net primary productivity, and ultimately the carbon input to the soil. However, tillage increases aeration and facilitates contact between residue and the decomposing microbes, thus stimulating microbial activity (Bot and Benites, 2005) and mineralization rates (Moorman et al., 2004). Conversely, short-term conservation tillage preserves aggregate stability thereby protecting SOM, as well as improving soil tilth (Lal, 2005).

In addition to these observations, tillage-induced erosion has been shown to remove substantial amounts of SOM, especially immediately following conversion to cultivated land (Starr et al., 2000; Manies et al., 2001). In fact, it has been estimated that approximately one-half of the topsoil (i.e., the highly organic O and A horizons) in Iowa was lost since settlement due to agriculture (Pimental et al., 1995).



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However, the exact relationship between SOM and erosion (i.e., soil loss and deposition) remains unclear. It can be deduced that on an undisturbed field or one with little topography, erosion would be minimal (Fig. 2a). Thus, SOM loss would primarily take place through decomposition. Conversely, in agricultural fields with moderate to severe slopes, erosion can play a more prominent role in SOM loss (Fig. 2b). Along the shoulder and back slope, soil loss would exceed deposition resulting in substantial SOM loss. On toe slopes and floodplains, deposition would dominate potentially leading to sequestration of carbon (Gregorich et al., 1998), with as much as 0.6–1.5 Gt C/yr sequestered through burial (Stallard, 1998; Smith et al., 2001; Renwick et al., 2004).

Few studies have examined in detail the role of spatial variations of both soil loss and deposition on SOM (e.g., Polyakov and Lal, 2004), relative to studies focusing on climate and texture controls (e.g., Cole et al., 1993; Bricklemyer et al., 2007). Most of these efforts were limited by underestimating the importance of deposition on SOM dynamics (Gregorich et al., 1998), leading to potentially significant errors in SOM-estimation. For example, studies have linked models, which simulate SOM dynamics (e.g., CENTURY), with either lumped erosion models, such as the Universal Soil Loss Equation (USLE), or coarse field erosion estimates (e.g. Monreal et al., 1997; Harden et al., 1999; Manies et al., 2001; Pennock and Frick, 2001; Yadav and Malanson, 2008). However, recent studies have shown that deposition of eroded material, which is dependent on terrain, soil roughness, vegetative (or residue) cover, and runoff coefficients, can be a significant source of SOM (Mancilla, 2001; Pennock and Frick, 2001; Fox and Papanicolaou, 2007, 2008; Papanicolaou and Abaci, 2008). Hence deposition should not be ignored, especially if an impact assessment of different management practices on soil erosion and SOM dynamics is needed.

In light of this apparent need to account for deposition, the main objective of this study was to better understand the spatial distributions of SOM as controlled by soil loss and deposition resulting from historical and current management strategies on SOM dynamics. SOM dynamics were modeled using the CENTURY SOM dynamics model, which accounted for the interdependence of management practices, soil loss/deposition, and decomposition for an agricultural test field in the Clear Creek, IA watershed. Different scenarios of erosion, which included (1) no erosion, (2) an average erosion rate for the whole field, and (3) individual rates for the erosional upland and depositional floodplain, were determined using the Water Erosion Prediction Project (WEPP). These erosion rates were then implemented into CENTURY to determine C budgets for the test field. It was hypothesized that deposition would mute the overall C loss from the test field. Improving C budgets would provide better understanding of the global carbon cycle, as well as the biogeochemical processes occurring in the critical zone.

## 2 Materials and methods

### 2.1 CENTURY SOM dynamics model

The SOM dynamics of the test field were evaluated using the CENTURY Soil Organic Matter model, version 4, which is currently the most used and tested version of the model (Metherell et al., 1993). CENTURY simulates nutrient dynamics (carbon, nitrogen, phosphorus, and sulfur) through plant-soil interactions for different ecosystems including grasslands, agricultural lands, and forests. The model's primary use is as an analysis tool for controls on SOM and productivity. SOM changes strongly reflect the integration of ecosystem processes, environmental changes, and anthropogenic influences. More detailed descriptions of the model can be found in Metherell et al. (1993) and Theregowda (2007).

The CENTURY model is a synthesis of multiple sub-models (e.g., soil organic matter/decomposition sub-model, water budget sub-model, and grassland/crop sub-model) with a management/events scheduling function that computes the fluxes of C, N, P, and S through the various compartments in the model.

The SOM sub-model is an important component of CENTURY. The sub-model initially partitions crop residue and roots after harvest into either metabolic or structural




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carbon pools based on the lignin: nitrogen ratio of the residue (Metherell et al., 1993). Residue with higher lignin concentrations is partitioned to the structural pool, while residue with lower lignin concentrations is placed in the metabolic pool. As the residue decomposes and is incorporated into the soil, the model differentiates the carbon into three pools (active, slow, and passive) based on decomposition rates. The active pool consisting of microbes and their by-products (e.g., proteins, amino acids, sugars, and starches), as well as low density SOM (termed as the light fraction; Cambardella and Elliot, 1992) has short turnover times of 2 to 4 yr (Parton et al., 1988). This pool is strongly influenced by both climate and management practices (Bot and Benites, 2005). The slow pool is comprised of mostly cellulose, hemi-cellulose, and SOM that is physically protected within soil aggregates. These products are more resistant to decomposition and have turnover times of 20 to 50 yr (Parton et al., 1988). The passive pool contains lignin, which is chemically resistant to decomposition and has a long turnover time (800–1200 yr; Parton et al., 1988). All carbon flows linearly through the SOM sub-model, with rates proportional to the amounts of C in the different pools, until all carbon has been metabolized into $CO_2$. Flows of N, P, and S are related to the C flows through simple elemental ratios.

CENTURY simulates SOM dynamics of the different C pools using monthly time steps in the surface horizon of the soil column. Multiple soil layers can be implemented into CENTURY; however, SOM dynamics only occur in the surface horizon, identified as the active layer. The recommended depth of the active layer is 20 cm, but it should not exceed 30 cm in CENTURY simulations.

### 2.2 Model simulations

In this study, SOM dynamics were simulated in a test field of the Clear Creek, IA watershed for the entire period of cultivation for the field using CENTURY. SOM pools were allowed to reach steady state during an extended initialization period of 15 000 yr (the approximate length time since the last glaciation of this area) before the implementation of agricultural practices. It is important to have an extended initialization period to allow default nutrient concentrations to reach equilibrium before implementing a disturbance, like conversion to agriculture (Manies et al., 2000 and 2001).

For initialization, default parameters and concentrations of C of grassland vegetation (i.e., bluegrass) were used, essentially simulating native prairie. Annual light grazing and a periodic burn every 15 years were included during the period (Ehrenreich and Aikman, 1963). The output values of this initialization period were used as initial values for the subsequent cropped period.

Three different simulations of erosion for the cropped period were conducted in this study that were based on different degrees of erosion (i.e., soil loss and deposition) and were provided via previously calibrated/verified WEPP simulations (Papanicolaou and Abaci, 2008). The first simulation contained no erosion, while the second simulation used an average soil loss value for the whole test field. During the third simulation, the test field was segmented into upland and floodplain components. The upland experienced only soil loss during the cropped period, according to WEPP. On the floodplain, WEPP simulations suggested both soil loss and deposition occurred; however, the floodplain was a net depositional area.

### 2.3 CENTURY inputs

Input data for CENTURY are distributed into twelve data files. These files contain information regarding crops and trees, tillage, harvesting, grazing, irrigation, fertilization and additional organic matter additions, fires, fixed parameters regarding decomposition rates, and site specific parameters, which include climate and soil type. Each file contains a certain subset of variables. Most of the internal parameters in CENTURY were determined by calibrating the model to long-term soil decomposition experiments (1 to 5 yr) where different types of plant material were added to soils of different textures (Parton et al., 1987).

Many of the input parameters used for this study were default values provided by CENTURY. However, certain site-specific parameters required user-defined values. These values, which are detailed below, include information regarding the soil texture, climate, and applied management practices, as well as erosion (i.e., soil loss and deposition).

### 2.3.1 Study site

CENTURY simulations were conducted for a test field within the Clear Creek, IA watershed (HUC-10: 0708020904). The watershed comprises approximately 270 $km^2$ in east-central Iowa (Fig. 3) and drains to the Iowa River. Since settlement, nearly 80% of the watershed has been converted from a prairie and forested area to row-crop agriculture and pastures. Currently, the dominant rotation in the watershed is corn-soybean and the two crops are in roughly equal proportions throughout the watershed. Although agriculture is still prominent in the watershed, Clear Creek is experiencing a marked increase in population.

The test field is within a 26 $km^2$, predominantly rural, headwater catchment of the South Amana, IA area (Fig. 3). This catchment has two main sub-basins, both of which contain first order streams. Each stream length is approximately 6 river-km during the wet season. The outlet of the catchment is approximately 30 river-km above the Iowa River confluence.

The catchment is the focal point of the Clear Creek Experiment Watershed, which is an ideal natural laboratory for evaluating soil and water concerns due to an established infrastructure maintained by the University of Iowa to monitor several environmental parameters. In addition, an extensive geospatial, chemical, and eco-hydrological database exists, as well as a detailed history of land uses and management practices for the watershed (Papanicolaou and Abaci, 2008).

The test field (Fig. 4a) used in the computer simulations is a convex hillslope located in the southern part of the catchment. The elevation of the hillslope decreases 23.8 m along a slope length of 130 m yielding an average declination of 0.18. The predominant soil series on the ridge and shoulder of the hillslope (Fig. 4b) is Tama (Fine-Silty, Mixed, Superactive, Mesic Typic Argiudoll). Soils of the Tama series are mollisols, or prairie-derived soils. They are well-drained and are formed from loess. The Colo-




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overwash soil series (Fine-Silty, Mixed, Superactive, Mesic Cumulic Endoaquoll) is at the toe slope and floodplain. Soils of the Colo series are derived from alluvium and are poorly drained. Long cores (2 m) were collected using a truck mounted Giddings probe in the field to confirm soil series maps and identify important soil properties (Table 1; Papanicolaou et al., 2008). Samples were collected along transects at the ridge, shoulder, backslope, and floodplain of the test field and were analyzed for their organic carbon content to provide a verification dataset for this study.

#### 2.3.2 Climate

Decomposition is a prominent controlling factor of SOM dynamics and climatic conditions directly affect decomposition rates. Climatic variables are important inputs in CENTURY because decomposition is calculated as a single function of temperature and precipitation (Metherell et al., 1993). Optimum levels of soil temperature and moisture, which are influenced by air temperature and precipitation, exist that produce maximum decompositions rates. These rates will decrease as levels deviate from the optimum values.

Observed climate data (Table 2) were obtained from the Iowa Environmental Mesonet, IEM, which collects environmental data from cooperating members with observing networks. One such site was located less than 5 km from the test field.

These data were supplemented with estimates obtained via a stochastic weather generator, CLIGEN (Nicks, 1985). CLIGEN produces daily estimates of precipitation, temperature, dew point, wind, and solar radiation for a single geographic point, using monthly parameters (means, standard deviations, skewness, etc.) derived from the historic measurements.

CENTURY provides different options for climatic inputs. Monthly averages, which were varied based on variability and skewness statistics, were used during the initialization period. Average values were assumed to be sufficient to establish base-level conditions for the simulations. Historical monthly averages were used during the cropped period because these values would provide better accuracy for the model.

### 2.3.3 Test field management strategies

The test field was native prairie through 1930. Since then, three different land management strategies have been utilized at the test field. Specific details regarding each period were described in detail in Theregowda (2007) and are summarized herein (Table 3). The CENTURY and WEPP simulations were based on this established management history.

The first management period consisted of a 3-year Corn, Corn, Oat-Meadow (CCOM) rotation, which lasted from 1931 through 1975. Corn was planted in the first two years followed by a year of oats with a winter cover crop of alfalfa. Conventional tillage was implemented during this period that utilized a tandem disk, field cultivator, and moldboard plow. Organic fertilizers were used until 1950 when inorganic fertilizers were then implemented. In 1976, the oat-meadow year in the rotation was replaced with soybean leaving a Corn-Corn-Bean (CCB) rotation. Management practices were similar with the later part of the previous period, except the moldboard plow was not used. The current management period began in 1991 and involves a two-year corn-soybean rotation using reduced tillage practices and applications of anhydrous ammonia (STC-NTB).

### 2.3.4 Erosion

Along with decomposition, erosion significantly affects SOM within CENTURY; however, the model does not directly calculate erosion. It must be supplied by the user as a monthly input.

Soil loss during the initialization period was determined using the Universal Soil Loss Equation (USLE). The USLE was a first attempt at developing a unified, widely applicable erosion model. It provides long-term average annual gross erosion rates. The model develops individual indices for the dominant factors controlling erosion: rainfall erosivity ($R$), soil erodibility ($K$), slope length ($L$), slope steepness ($S$), vegetative cover/management practices ($C$), and conservation measures ($P$) (Wischmeier and

Smith, 1965). The parameters of the USLE are empirically based on a large historical dataset.

The USLE was chosen for the initialization period to simplify the monthly inputs. Soil loss rates were determined for both the erosional upland and depositional floodplain (Table 4). An individual soil loss rate was determined for the fire year, while another rate was used for the non-fire years.

Soil loss/deposition rates during the simulation period were provided by WEPP (Table 5). The advantage of this coupling of WEPP and CENTURY is that WEPP is a distributed model for surface runoff, soil properties, and management practices (Flanagan and Nearing, 1995). WEPP's strengths include being a physically-based model with a complete management practice database, which accounts for soil loss/deposition. Another advantage of using WEPP in this study was that baseline values of key model parameters such as erosional strength and the effective hydraulic conductivity were measured in-situ prior to applying them to WEPP (Papanicolaou and Abaci, 2008).

The WEPP platform is an agglomeration of five sub-components: climate, topography, soil, management and watershed structure (Renschler and Flanagan, 2002). A comprehensive review of the model formulation is available in Flanagan and Nearing (1995) with a recent evaluation found in Laflen et al. (2004).

WEPP calculates rainfall excess (or runoff) by the Green-Ampt Mein-Larson infiltration equation. The peak runoff rate is determined by kinematic wave overland flow routing, if the model is run for single storm events, or by simplified regression equations based on the kinematic wave model, if the model is run in a continuous mode (as was the case for this study).

Erosion is differentiated into rill and interrill components by WEPP. Interrill erosion is initiated by soil detachment from raindrop impact and the sediment is carried to rills by overland flow. Rill erosion is considered a function of sediment detachment, the existing sediment load in the runoff, and sediment transport capacity (Flanagan and Nearing, 1995). The driving sediment transport equation for rill erosion in WEPP includes the steady-state sediment continuity:

$$\frac{\delta G}{\delta x} = D_f + D_i \tag{2}$$

where $G$ is sediment load (kg/s/m), $D_f$ is rill erosion rate (kg/s/m$^2$), and $D_i$ is the interrill erosion rate (kg/s/m$^2$) or interrill source term. $D_f$ is detachment in rills caused when the applied hydraulic shear stress exceeds the critical shear stress of the soil and when the sediment load is less than the sediment carrying capacity. Rill detachment is quantified as:

$$D_f = K_r * (\tau_f - \tau_c) * 1 - \frac{G}{T_c} \tag{3}$$

where $K_r$ is a rill erodibility parameter (s/m), $\tau_f$ is bed shear stress exerted by the fluid (Pa), $\tau_c$ is the critical shear stress (Pa), and $T_c$ is sediment transport capacity (kg/s/m). Net deposition in the rill is computed when the sediment load, $G$, is greater than the sediment transport capacity, $T_c$. The equation for deposition follows:

$$D_f = \frac{\beta * V_f}{q} * (T_c - G) \tag{4}$$

where $V_f$ is the effective fall velocity for the sediment (m/s), $q$ is unit discharge in the rills (m$^2$/s), and $\beta$ is a raindrop-induced turbulence coefficient. $D_i$, or the soil delivered from interrills, is always positive and is considered proportional to the product of rainfall intensity and interrill runoff rate, with a constant of proportionality being the interrill erodibility parameter, $K_i$. See Flanagan and Nearing (1995) for full specification of the WEPP model equations.

#### 2.3.5 SOM loss

SOM loss due to erosion is determined in CENTURY using an enrichment ratio ($E$; Teixeira and Misra, 2005), which is expressed as the proportion of SOM in transported sediment, $S_e$, to that of SOM in uneroded soil, $S_{ur}$:

$$E = \frac{S_e}{S_{ur}} \tag{5}$$

An $E>1$ indicates that the eroded sediment is enriched in SOM relative to the uneroded soil, whereas an $E<1$ denotes the opposite. Enrichment ratios within the Clear Creek watershed range between 1.0 and 2.4 (Papanicolaou et al., 2009), which suggests the likelihood of high rates of SOM loss during runoff events.

The fraction of C lost from the active layer ($F_{\text{lost}}$) due to erosion is determined using the erosion rate ($P_{\text{sloss}}$) and enrichment ratio (Colorado State University, 1993).

$$F_{\text{lost}} = \frac{p_{\text{sloss}}}{(1000 * B_d * e_{\text{depth}})} * E \tag{6}$$

where $B_d$ is the soil bulk density and $e_{\text{depth}}$ is the depth of the active layer. The C-loss from the active layer ($S_{\text{loss}}$) is then determined as follows:

$$S_{\text{loss}} = \frac{S_{tc}}{F_{\text{lost}}} \tag{7}$$

where $S_{tc}$ is the total organic carbon in the active layer.

The depth of soil removed from the active layer is replaced by an equivalent depth from the soil horizon below the active layer. The carbon input (*input*) from this lower horizon to the active layer is based on the distribution of C in the lower horizon, which is simply a fraction of the available C in the active layer. The input is merely added to the active layer.

Version 4 of CENTURY does not account for deposition; moreover, deposition cannot simply be defined as negative soil loss. In order to circumvent this limitation, deposition was determined by redefining $F_{\text{lost}}$ as the fraction of soil (and C) sequestered and *input* as the amount of C added through deposition. Regardless if the C is lost by erosion or sequestered; it is still removed from the active layer. Redefining the terms in the





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erosion subroutine allowed for implementing the deposition rate as a positive value and the proper functioning of the above equations.

As with soil loss, the initialization of the C pools of the added soil was important (Metherell et al., 1993). It was assumed that the deposited material was enriched in the light fraction of SOM and depleted in C from the slow and passive pools. Actual values for the C pool distribution were determined during the calibration of the model.

### 2.4 Model calibration and verification

Calibration of CENTURY for the test field was conducted by adjusting specific sensitive parameters within physical ranges, which were determined either via implicit/explicit measurements or based on values reported in the literature (e.g., Santhi et al., 2001). A set of governing factors, which represent the physical forcings, pedologic characteristics, and management practices within the watershed, was selected to provide indirect accounting of the entire range of processes (Buol et al., 1997). Calibration of only the most sensitive parameters helped limit overparameterization.

Because of the limited number of governing factors determined during a sensitivity analysis, the model was manually calibrated by adjusting one parameter and keeping the remaining parameters constant. Calibration continued until the simulated $S_{tc}$ approached average values of cores collected in near proximity of the test field for the US Department of Agriculture – Natural Resources Conservation Service Soil Survey Laboratory. The chosen cores were described as pedons containing either the Tama or Colo soil series. Average particle size distributions and bulk densities for these cores (Table 1) were used in the calibration process with erosion rates and management practices from the test field. It was assumed that management practices and erosion rates were similar throughout the region.

Factors considered in the calibration of CENTURY included erosion rates of the initialization period, particle size, bulk density, enrichment ratios, decomposition rates, the flow rate of SOM to slow and passive pools, and the SOM distribution of either the lower horizon or deposited sediment (Table 6). Predetermined ranges of these influential factors were evaluated to determine the appropriate values for the model.

Verification of the model was conducted by implementing the particle size and bulk densities of the cores collected within the test field into the calibrated model. The success of the verification was based on the accuracy of the model to predict the $S_{tc}$ of the samples collected on the transects in the test field.

## 3 Results and discussion

The foci of this study were the changes in SOM dynamics resulting from shifts in different management practices and the effects of utilizing deposition rates in SOM evaluations. SOM results from CENTURY simulations that incorporated different scenarios of WEPP-determined soil loss/deposition rates for the test field are presented herein. The following levels of erosion were used in the study: (1) no erosion, (2) average soil loss rates for the whole test field, and (3) soil loss and deposition rates for the upland and floodplain, respectively, of the test field. SOM results will primarily consist of total SOM concentrations, $S_{tc}$, which incorporate structural/metabolic C, as well as the active, slow, and passive pools (Metherell et al., 1993).

### 3.1 USLE & WEPP erosion rates

Erosion rates for the CENTURY initialization period were determined using the USLE to simplify the monthly inputs for the lengthy period (Table 4). Erosion rates were minimal during most of this period due to the high vegetative cover of the prairie grasses. Higher erosion rates were experienced every 15th year of the initialization period due to the simulated burning of the test field.

During the CENTURY simulations of the cropland period for the test field, soil loss/deposition rates were determined using WEPP. WEPP provides physically based erosion values for different segments of the test field (i.e., upland and floodplain). In the upland, only soil loss occurred; however, in the floodplain both soil loss and deposition were observed.

During the CCOM and CCB periods, while conventional tillage practices were implemented (i.e., tillage depth=20 cm), erosion rates in the upland were extremely high (Table 5). The erosion was slightly higher during the CCB period relative to the CCOM period even with the elimination of moldboard plow use. The benefits gained from foregoing the use of the moldboard plow were balanced by the negative effects of the decreased residue quantities resulting from no longer planting the winter cover crop. Despite the high erosion, much of the eroded sediment was deposited on the floodplain because net deposition was observed on the floodplain of the field (Table 5).

The conservation tillage practices implemented at the test field in 1991 (i.e., tillage depth=7.6 cm), resulted in a dramatic decrease in erosion rates of the upland (Table 5). Moreover, deposition on the floodplain also decreased. In fact, during the STC-NTB period there was slight erosion on the floodplain (Table 5).

### 3.2 CENTURY initialization period

The initialization period for the CENTURY simulations established steady state concentrations of SOM for the test field, which served as a baseline, from which to evaluate the effects of introduced agricultural practices. Steady state conditions were reached when organic matter accumulation from native grass residue equaled organic matter loss due to erosion and decomposition (Bot and Benites, 2005).

During the initialization period of the CENTURY simulations in this study, equilibrium conditions were obtained relatively quickly (Fig. 5). Equilibrium concentrations of total SOM for the upland and floodplain components of the test field were 12 600±87 $g/m^2$ and 18 300±88 $g/m^2$, respectively. SOM loss due to erosion was minimal during this period with an accumulated SOM loss from the test field during the final 1000 years of only 10.2 $g/m^2/yr$. Decomposition was the primary mechanism of SOM loss from the test field in this period, which averaged 415±42 $g/m^2/yr$ of $CO_2$ lost through decomposition during equilibrium conditions.

Comparisons of SOM concentrations between the floodplain and the upland showed that floodplain SOM concentrations approached higher values. Higher SOM values on the floodplain resulted from lower erosion rates and excess moisture conditions existing on the floodplain, which can produce anaerobic conditions, due to poorly drained soils and lower slopes. Excess water can cause stagnation and low aeration, which inhibit decomposition of organic matter (Wells et al., 1997).

Concentration trends during the initialization period of this study were similar to CENTURY-simulated SOM values for a test field in Western Iowa by Manies et al. (2001). SOM values at the end of the initialization period for this study were higher than those in Manies et al. (2001); however, differences may be explained by more intense grazing and a shorter interval between fires in Manies et al. (2001) leading to higher erosion rates than this study. The higher erosion rates would remove more SOM from the simulated test site in the Manies et al. (2001) field leaving lower SOM concentrations.

### 3.3 CENTURY cropland period

Simulations of the cropland period were conducted under three different erosion scenarios to demonstrate the importance of including deposition in studies of SOM dynamics. Initially, the test field SOM dynamics were simulated without erosion to establish the role of decomposition. The test field SOM dynamics were then simulated using average soil loss values for the whole test field. Overall, the field has experienced a net loss of soil during the cropped period. The final simulation segmented the field into two components, an erosional upland and depositional floodplain. The upland component was spatially three times larger than the floodplain component, so all SOM values for this simulation were weighted proportionately.

The final $S_{tc}$ values for each simulation were used for verification of the model calibration (Table 7). Both the no erosion and whole field simulations produced higher $S_{tc}$ values than measured in the field. The total SOM concentrations produced by the segmented simulation agreed well with the measured field values (Table 7). Simulated $S_{tc}$ values for the upland were 13% lower and values for the floodplain were 16%

higher than measured field values. Thus, more detailed erosion values led to better performance of the model.

Despite the differences in accuracy when compared to field measurements, trends of SOM for all three simulations were similar showing an initial increase in $S_{tc}$ immediately following the conversion to agriculture due to incorporation of the prairie grass residue into the soil. A marked decrease was then observed in all three cases. This decrease was more gradual for the no erosion and whole test field simulations than for the segmented field simulation (Fig. 6). Total SOM concentrations decreased 22%, 36%, and 64% from the original concentration for the no erosion, whole field, and segmented field simulations, respectively. Previous studies have also shown large decreases in SOM after the introduction of tillage (e.g., Manies et al., 2001; Conant et al., 2007). Despite the large decreases in $S_{tc}$ for the segmented field simulation, a slight increase in total SOM concentrations was observed during the during the most recent management period, STC-NTB (Fig. 6), which was not seen in the other two simulations.

The primary mechanism for SOM loss during the cropland period was tillage-induced erosion and not decomposition as observed during the initialization period. Extensive tillage can break down soil aggregates reducing soil strength, which can increase erosion (Lal, 2005). In CENTURY, SOM loss and erosion are directly related (Parton et al., 1987; Metherell et al., 1993), and since the soil loss/deposition rates for the test field substantially increased due to tillage (over 2 orders of magnitude during the CCOM and CCB periods), the SOM loss was also considerably high. The majority of the SOM loss occurred during the first management period, which was attributed to the high soil loss and large store of available C from the incorporated prairie residue. Prairie residue provided additional input of SOM, most probably in the slow (cellulosic) pool. Erosional losses of SOM for the test field decreased after this high point through the remainder of the simulation period.

Budgeting of the erosional losses of SOM during the whole field suggested that 8510 g/m$^2$ of $S_{tc}$ were removed from the field during the cropped period, which is less than 13 300 g/m$^2$ of $S_{tc}$ from the upland component of the segmented field simulation.

This is when comparing the soil loss rates for these simulations. The lower soil loss rate of the whole field simulation also produced higher $S_{tc}$ values.

However, deposition muted the SOM loss due to erosion in the segmented simulation. The eroded soil and SOM in the uplands were retrained on the floodplain before leaving the field. Thus, on larger scales, less sediment was lost from the system. The floodplain component sequestered 6710 g/m$^2$ of $S_{tc}$ yielding a net loss of only 6561 g/m$^2$ of $S_{tc}$ from the test field during the segmented simulation, which is 22% difference compared to the whole field simulation.

Moreover, existing sediment on the floodplain was buried, which inhibits its decomposition by limiting aeration and possibly inducing anaerobic conditions. Both these effects have implications regarding global carbon budgets (Polyakov and Lal, 2004).

Even though deposition would inhibit decomposition of buried sediments, increased decomposition in the active layer would result from deposition of the finer, highly organic material from the upland. The deposited material would more easily decomposed because it consists of the light fraction (LF). The LF organic-matter was defined originally by Greenland and Ford (1964) to be material having a density of <2.0 g/cm$^3$ and composed of partially decomposed plant residue having a C/N ratio of <25 (Cambardella and Elliot, 1992). Moreover, mineralization would be eclipsed by higher water holding capacities, which exist on the floodplain leading to higher $CO_2$ emissions (Manies et al., 2001). These findings agree with studies by Fox and Papanicolaou (2007 and 2008), which examined the movement of SOM in watersheds using stable Carbon and Nitrogen isotopes. Ignoring deposition in simulations of SOM dynamics during this period would underestimate decomposition rates and $CO_2$ emissions from the soil.

One question that arose from the trend of the floodplain SOM concentrations was why SOM concentrations declined, if deposition was occurring. This should result in a net addition of SOM. However, the decline resulted from a model limitation, which was mentioned above. It is important to note that CENTURY focuses on only the active surface layer, whose depth is set by the user through the parameter, EDEPTH. As deposited sediments added depth to the active layer, the corresponding amount





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was removed from the bottom of the active layer to maintain the assigned depth, i.e., buried SOM was removed from the active layer. The deposited material, which was comprised of the light fraction, was different from the SOM material removed (more stable forms of SOM). These more stable forms were not replaced from above and the overall SOM concentrations declined.

## 4 Conclusions

The preservation of soil quality is of extreme relevance in the US Corn Belt where local economies are driven by agricultural production. Soil quality is difficult to measure directly because it is a function of several factors, like SOM. SOM content, which influences other soil biogeochemical properties, provides a reliable surrogate measure of soil quality.

SOM concentrations were strongly influenced by the applied management practices to the test field, which controlled the erosion and deposition occurring at the site. To date, few studies have examined in detail the role of spatial and temporal variations of erosion/ deposition on SOM, i.e., the role of deposition is still poorly understood. The main goal of this study was to evaluate the effects of historical and current management strategies on SOM dynamics (an indicator of soil quality) for an agricultural test field in the Clear Creek, IA watershed by accounting for the interdependence of management practices, soil loss/deposition, and decomposition. The nature of the research is novel because it combines dynamic model simulations using WEPP and CENTURY to evaluate soil and SOM loss from the field.

In this study, deposition was shown to mute the SOM loss due to erosion. The high losses of soil and SOM in the uplands were entrained on the floodplain before leaving the field. These effects have implications regarding global carbon budgets (Polyakov and Lal, 2004). Thus, it is important to accurately account for the roles of both erosion and deposition occurring in a field to provide reliable estimates of SOM loss.

The present research was performed using CENTURY simulations that were limited to monthly predictions of SOM loss. This inherent limitation of the CENTURY model did not hinder understanding of the SOM dynamics resulting from different management practices. Changes in management practices occurred in periods longer than the monthly time step. Hence the model captured the effects of changing management practices on SOM dynamics. However, future studies that intend to capture daily changes in SOM due to different anthropogenic activities should consider the use daily event models like DAYCENT (Del Grosso et al., 2006).

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**Table 1.** Soil core data from test field.

| Soil series | Source | Sand (%) | Silt (%) | Clay (%) | Bulk density ($g/cm^3$) | Organic matter (%) | Wilting point | Field capacity |
|---|---|---|---|---|---|---|---|---|
| Tama | SSL cores | 1.5 | 67.5 | 31 | 1.20 | 1.80 | 0.123 | 0.35 |
| | Test field cores | 2.8 | 67.5 | 29.7 | 1.45 | 2.03 | 0.123 | 0.35 |
| Colo | SSL cores | 4 | 64 | 32 | 1.30 | 2.37 | 0.150 | 0.38 |
| | Test field cores | 2.3 | 82.3 | 15.5 | 1.53 | 1.96 | 0.155 | 0.38 |



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**Table 2.** Monthly average climate conditions for test field.

| Month | Precipitation (cm) | Min. Temperature (°C) | Max. Temperature (°C) |
|---|---|---|---|
| Jan | 2.55 | −8 | 2 |
| Feb | 2.21 | −10 | −1 |
| Mar | 5.25 | −3 | 8 |
| Apr | 8.25 | 4 | 17 |
| May | 10.4 | 10 | 23 |
| Jun | 11.9 | 15 | 28 |
| Jul | 11.6 | 18 | 30 |
| Aug | 10.3 | 16 | 29 |
| Sep | 9.47 | 11 | 25 |
| Oct | 6.22 | 5 | 19 |
| Nov | 6.10 | −2 | 9 |
| Dec | 3.39 | −8 | 1 |



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**Table 3.** Management practices in test field.

| Management scenario | Date | Operation | Description |
|---|---|---|---|
| Initialization | 04/01/0001 | Plant | Bluegrass |
| | 11/01/0001 | Harvest | Light grazing |
| | 11/01/0015 | Fire | Medium heat |
| CCOM | 04/15/0001 | Secondary tillage | Tandem disk, 8 cm |
| | 05/01/0001 | Tillage | Tandem disk, 8 cm |
| | 05/10/0001 | Plant | Corn |
| | 05/30/0001 | Tillage | Field cultivator, 8 cm |
| | 06/15/0001 | Tillage | Field cultivator, 8 cm |
| | 10/15/0001 | Harvest | 90% Crop |
| | 11/01/0001 | Tillage | Chisel plow w/coulters and twisted pts |
| | 04/15/0002 | Tillage | Tandem disk, 8 cm |
| | 05/01/0002 | Tillage | Tandem disk, 8 cm |
| | 05/10/0002 | Plant | Corn |
| | 05/30/0002 | Tillage | Field cultivator, 8 cm |
| | 06/15/0002 | Tillage | Field cultivator, 8 cm |
| | 10/15/0002 | Harvest | 90% Crop |
| | 04/01/0003 | Tillage | Tandem disk, 8 cm |
| | 04/07/0003 | Tillage | Tandem disk, 8 cm |
| | 04/10/0003 | Plant | Oats |
| | 07/01/0003 | Harvest | Oats |
| | 07/02/0003 | Plant | Alfalfa |
| | 09/01/0003 | Cut | Alfalfa |
| | 11/01/0003 | Tillage | Moldboard plow, 20 cm |
| CCB | 04/15/0046 | Tillage | Tandem disk, 8 cm |
| | 05/01/0046 | Tillage | Tandem disk, 8 cm |
| | 05/10/0046 | Plant | Corn |
| | 05/30/0046 | Tillage | Field cultivator, 8 cm |
| | 06/15/0046 | Tillage | Field cultivator, 8 cm |
| | 10/15/0046 | Harvest | 90% Crop |
| | 11/01/0046 | Tillage | Chisel plow w/coulters and twisted pts |
| | 04/15/0047 | Tillage | Tandem disk, 8 cm |
| | 05/01/0047 | Tillage | Tandem disk, 8 cm |
| | 05/10/0047 | Plant | Corn |
| | 05/30/0047 | Tillage | Field cultivator, 8 cm |
| | 06/15/0047 | Tillage | Field cultivator, 8 cm |
| | 10/15/0047 | Harvest | 90% Crop |
| | 11/01/0047 | Tillage | Chisel plow w/coulters and twisted pts |
| | 04/15/0048 | Tillage | Tandem disk, 8 cm |
| | 05/01/0048 | Tillage | Tandem disk, 8 cm |
| | 05/15/0048 | Plant | Soybeans |
| | 10/15/0048 | Harvest | 30% Crop |
| NTB-STC | 04/01/0061 | Tillage | Field cultivator, 20 cm |
| | 04/15/0061 | Tillage | Field cultivator, 8 cm |
| | 05/01/0061 | Plant | Corn |
| | 10/01/0061 | Harvest | 50% Crop |
| | 05/01/0062 | Plant | Soybeans |
| | 09/25/0062 | Harvest | 30% Crop |
| | 11/01/0062 | Tillage | Anhydrous applicator w/closing disks |

**Table 4.** USLE parametres and erosion for test field initialization period.

| Area | *R* | *K* | *LS* | *C* | *P* | Delivery ratio | Erosion rate (kg/m$^2$/yr) |
|---|---|---|---|---|---|---|---|
| Tama – fire | 175 | 0.30 | 6.12 | 0.1 | 1 | 0.500 | 3.60 |
| Tama – no fire | 175 | 0.3 | 6.12 | 0.000076 | 0.1 | n/a | 0.0005 |
| Colo – fire | 175 | 0.3 | 2.00 | 0.000076 | 0.1 | 0.667 | 1.57 |
| Colo – no fire | 175 | 0.3 | 2.00 | 0.1 | 1 | 0.667 | 0.0001 |

**Table 5.** WEPP erosion rates.

| Period | Years | Tama | | Colo | |
|---|---|---|---|---|---|
| | | Erosion rate (kg/m$^2$/yr) | Total depth of soil loss (cm) | Erosion rate (kg/m$^2$/yr) | Total depth of soil loss (cm) |
| CCOM | 45 | 11.8 | 48 | −14.9 | −57 |
| CCB | 15 | 12.3 | 17 | −16.3 | −21 |
| STC-NTB | 17 | 1.75 | 2.8 | 1.25 | 1.8 |

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**Table 6.** Calibration values for CENTURY simulations.

| Variable | Tama | Colo |
|---|---|---|
| Decomposition rate | | |
| Structural pool – surface | 1.95 | 1.95 |
| Structural pool – soil | 2.45 | 2.45 |
| Metabolic pool – surface | 7.4 | 7.4 |
| Metabolic pool – soil | 9.25 | 9.25 |
| Active pool – surface | 3 | 3 |
| Active pool – soil | 3.65 | 3.65 |
| Slow pool | 0.00225 | 0.00225 |
| Passive pool | 0.1 | 0.1 |
| EDEPTH | 0.3 | 0.3 |
| ENRICH | 1.1 | 1.1 |
| LHFZ(active) | 0.2 | 1.3 |
| LHFZ(slow) | 0.9 | 0.9 |
| LHFZ(passive) | 0.9 | 0.9 |
| PS1S3-transfer to slow | 0.01 | 0.01 |
| PS2S3-transfer to passive | 0.01 | 0.01 |



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**Table 7.** Century verification values.

| Simulation | Measured SOM ($g/m^2$) | Simulated SOM ($g/m^2$) | Percent error |
|---|---|---|---|
| No erosion | 5850 | 9920 | −0.70 |
| Whole field | 5850 | 8130 | −0.39 |
| Segmented field – Tama | 5900 | 5160 | 0.13 |
| Segmented field – Colo | 6000 | 6990 | −0.16 |

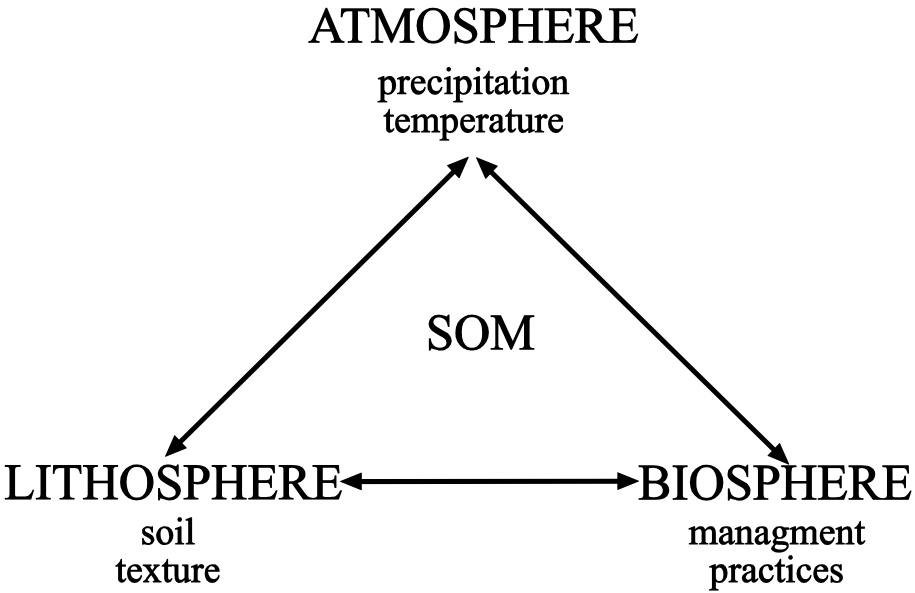


**Fig. 1.** Interactions between driving forces within the critical zone affect SOM.





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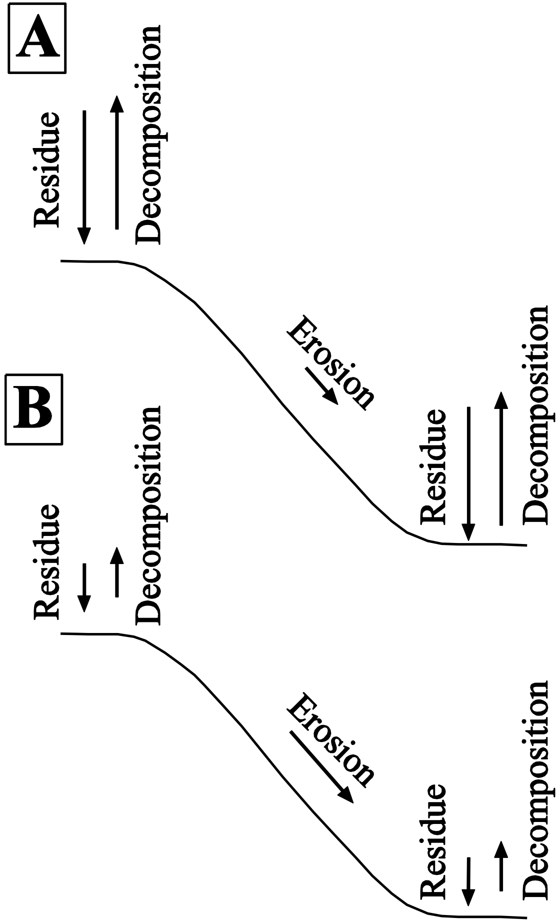


**Fig. 2.** Theoretical distributions of SOM within a field under the influences erosion. **(A)** Minimal soil loss and **(B)** high soil loss.



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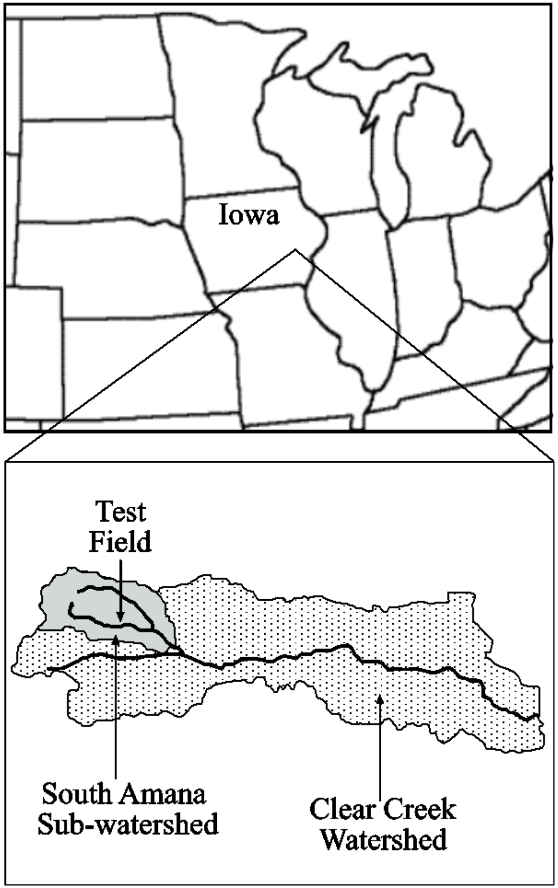


**Fig. 3.** Study site: identification of the test field in the Clear Creek, IA watershed.

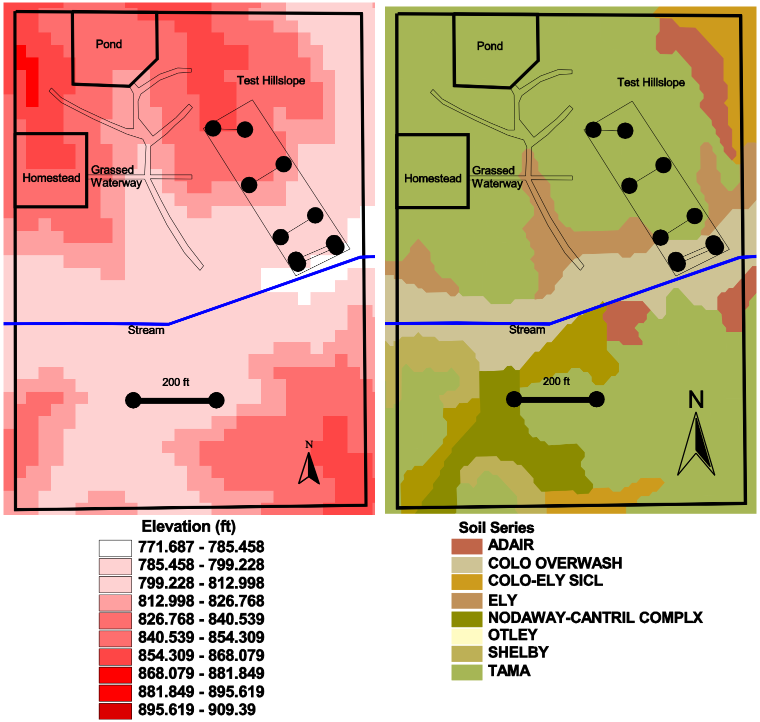


**Fig. 4. (A)** Digital Elevation Map of the test field. **(B)** IPSAID soils map for the test field. The test field is denoted by a box. Transects where field samples were collected are denoted by the black line with circles.



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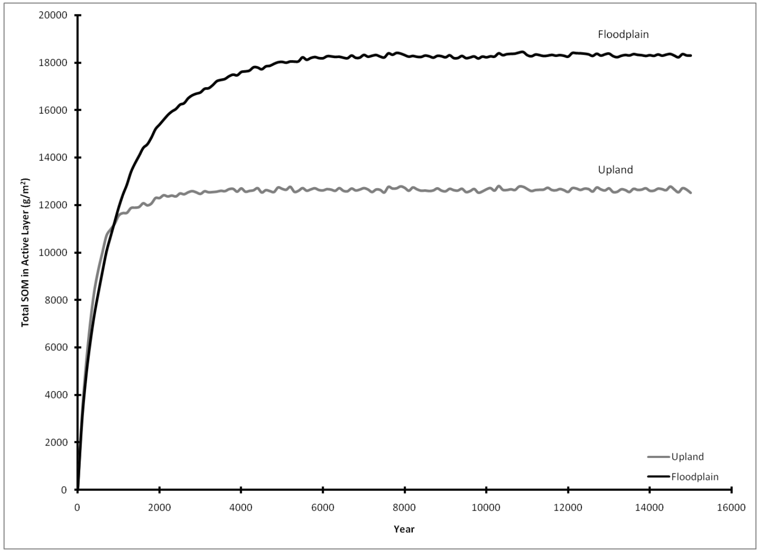


**Fig. 5.** Total SOM in the active layer ($S_{tc}$) during the initialization period.




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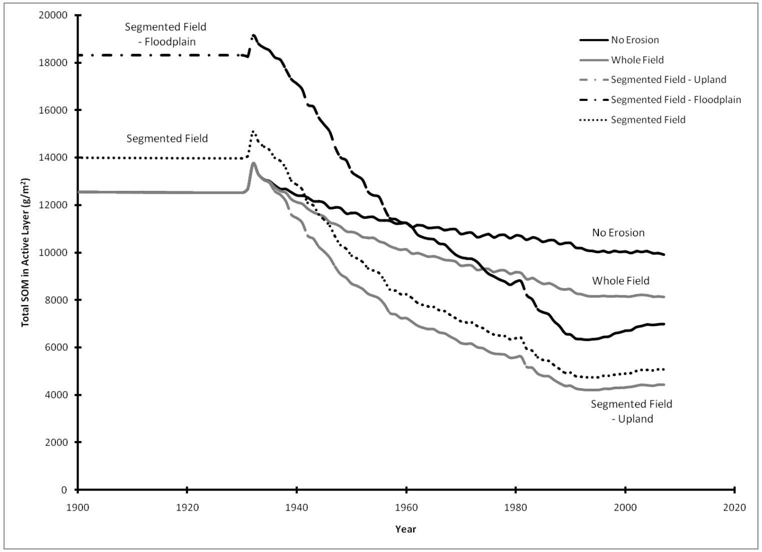


**Fig. 6.** Total SOM in the active layer ($S_{tc}$) during the simulation period under different erosion scenarios: mo erosion, whole field, segmented field.