

Theory and Calibration

A Location-Based Model of Organic Matter Fate within the Sand-Based Surface Layer of a Putting Green, Version 5.1

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Introduction

Managing soil organic matter (SOM) in golf course putting greens is a major agronomic challenge facing golf course superintendents. If organic matter levels become excessive, the putting surface will be soft, bumpy and prone to disease and scalping. Yet measures to control organic matter accumulation such as topdressing, hollow-tyne (HT) aeration, solid-tyne (ST) aeration, direct injection (DI) and deep verticutting (DV) are commonly disruptive and result in player dissatisfaction and reduced course revenues. This article describes a location-based simulation model of organic matter accumulation, decay, dilution and removal to track the fate of SOM in the sand-based surface layer of a putting green. This will provide superintendents a decision support tool to better manage organic matter within their putting greens.

Theory: Mass Balance Equations for a Soil Organic Matter Model

The following SOM mass balance equation takes into consideration the initial SOM quantity within the root zone, the monthly accumulation of SOM, the monthly decay of SOM, the monthly dilution of SOM by topdressing, solid-tyne aeration, or direct injection and the monthly removal of SOM by hollow-tyne aeration or deep verticutting. Thus, for each month over a 15-year period and for each of 5 depth intervals spanning 0 to 125 mm (0 to 5 in), the following equation is applied performing a mass balance of SOM:

$$SOM_e = SOM_i + SOM_a - SOM_m - n_d \cdot SOM_d - n_r \cdot SOM_r$$

Where SOM_e is the soil organic matter at month's end (g kg^{-1}), SOM_i is the month's beginning soil organic matter (g kg^{-1}), SOM_a is the monthly accumulation of soil organic matter (g kg^{-1}), SOM_m is the monthly decay of soil organic matter (g kg^{-1}), n_d is the number of SOM dilution applications, SOM_d is the SOM reduction effect via dilution (g kg^{-1}), n_r is the number of SOM removal applications, and SOM_r is the SOM reduction effect via removal (g kg^{-1}).

Monthly SOM Accumulation and Decay

The monthly accumulation of soil organic matter is a function of soil depth and mean monthly air temperature via the following equations:

$$SOM_a = AC_{mx} + \frac{(AC_0 - AC_{mx})}{1 + \left(\frac{z}{z_h}\right)^s}$$

Which is a form of the negative logistic equation of soil depth (Landsberg, 1977); where z is soil depth (mm), AC_0 is the monthly organic matter accumulation (g kg^{-1}) at the soil surface ($z = 0$), AC_{mx} is the monthly organic matter accumulation (g kg^{-1}) at the maximum soil depth ($z = 125$), z_h is the depth of $\frac{1}{2}$ maximum SOM accumulation (mm) and s is a shape factor. The term AC_0 is also a function of mean monthly air temperature for the location of interest via the Growth Potential Reference equation (GCSAA, 2010):

$$AC_0 = K_{AC} \cdot \exp\left\{-\frac{1}{2}\left[\frac{(T_l - T_o)}{sd}\right]^2\right\}$$

where K_{AC} is the SOM accumulation rate coefficient (g kg^{-1}), T_l is the mean monthly air temperature for the given location (F), T_o is the optimum turfgrass growth temperature (F) and sd is the standard deviation of the distribution. Values for T_o and sd are specified depending on whether cool season or warm season turfgrass is being grown at the location of interest. For cool season turfgrass $T_o = 68$ F and $sd = 10$; and for warm season turfgrass $T_o = 88$ F and $sd = 12$ (GCSAA, 2010).

Monthly decay of soil organic matter, SOM_m , is considered as a first order rate process (Plante and Parton, 2007) given by the equation:

$$SOM_m = TF_m \cdot K_m \cdot SOM_i$$

where TF_m is the temperature factor [0.1 – 1] adjusting the decay to local temperature, K_m is the decay rate coefficient and SOM_i is the soil organic matter at the beginning of the month (g kg^{-1}). Further, the temperature factor, TF_m , is calculated to be a function of the mean monthly air temperature through the equation (Neitch et al., 2011):

$$TF_m = 0.9 \cdot \left[\frac{T_l}{T_l + \exp(18.5 - 0.2 \cdot T_l)} \right] + 0.1.$$

Sand-Based Mixes for SOM Management Operations

This tool offers the possibility to use two sand-based mixes for SOM management. Only mixes containing up to 2 components are allowed. That is, the user could choose to use unamended sand (a 1-component “mix”), or sand plus a common root zone amendment (a 2-component mix) The amendment may be either organic, such as sphagnum peat, or inorganic, such as Profile. The amendment percent by volume is variable.

The SOM content of the sand-based amendment is calculated by a mixing model (Taylor and Blake, 1984):

$$SOM_m = \frac{(SOM_a \cdot V_a \cdot \rho_a) + (SOM_s \cdot V_s \cdot \rho_s)}{[(V_a \cdot \rho_a) + (V_s \cdot \rho_s)]}$$

where SOM_m is the organic matter of the mix (g kg^{-1}), SOM_a is the organic matter of the amendment (g kg^{-1}), SOM_s is the organic matter of the sand (g kg^{-1}), V_a is the amendment volume (m^3), V_s is the sand volume (m^3), ρ_a is the amendment bulk density (kg m^{-3}), and ρ_s is the sand bulk density (kg m^{-3}).

Similarly, the inorganic amendment content of the mix is given by:

$$IA_m = \frac{(IA_a \cdot V_a \cdot \rho_a)}{[(V_a \cdot \rho_a) + (V_s \cdot \rho_s)]}$$

where IA_m is the inorganic amendment content of the mix (g kg^{-1}) and IA_a is the inorganic amendment content of the amendment (g kg^{-1}). It is presumed that the sand does not also contain an inorganic amendment.

The bulk density of the mix is given by the equation (adapted from USDA-NRCS):

$$\rho_m = \frac{1}{\left[\left(\frac{MF_a}{\rho_a} \right) + \left(\frac{(1 - MF_a)}{\rho_s} \right) \right]}$$

Where ρ_m is the bulk density of the mix (kg m^{-3}) and MF_a is the mass fraction of the amendment given by $MF_a = M_a / M_t$ with $M_t = M_a + M_s$. In addition, $M_a = V_a \cdot \rho_a$ and $M_s = V_s \cdot \rho_s$ where M_a is the mass of the amendment (kg) and M_s is the mass of the sand (kg). Finally, in this equation, if the “mix” is unamended sand, then ρ_a is set equal to 1 and $\rho_m = \rho_s$.

Equations for Topdressing Operations

For a specified month when topdressing is applied as an organic matter dilution operation, the efficacy of this operation is calculated by a mixing model (Taylor and Blake, 1984) where a volume of sand-based mix added to the existing surface layer dilutes the organic matter:

$$SOM_{d1} = \frac{(SOM_m \cdot V_m \cdot \rho_m) + (SOM_{e1} \cdot V_{e1} \cdot \rho_{e1})}{[(V_m \cdot \rho_m) + (V_{e1} \cdot \rho_{e1})]}$$

where SOM_{d1} is the soil organic matter of layer 1 following dilution by topdressing (g kg^{-1}), SOM_m is the organic matter of the mix (g kg^{-1}), SOM_{e1} is the existing soil organic matter, following the accumulation and decay calculation, (g kg^{-1}), V_m is the volume of added mix (m^3) V_{e1} is the existing volume of layer 1 (m^3), ρ_m is the bulk density of the added mix (kg m^{-3}) and ρ_{e1} is the existing bulk density of layer 1 (kg m^{-3}).

Similarly, the inorganic amendment content of layer 1 is given by:

$$IA_{d1} = \frac{(IA_m \cdot V_m \cdot \rho_m) + (IA_{e1} \cdot V_{e1} \cdot \rho_{e1})}{[(V_m \cdot \rho_m) + (V_{e1} \cdot \rho_{e1})]}$$

where IA_{d1} is the inorganic amendment content of layer 1 following dilution by topdressing (g kg^{-1}), IA_m is the inorganic content of the mix (g kg^{-1}) and IA_{e1} is the existing inorganic amendment content.

Further, the existing bulk density of layer 1 is given by the equation (adapted from USDA-NRCS):

$$\rho_{e1} = \frac{1}{\left[\left(\frac{0.001 \cdot SOM_{e1}}{\rho_{om}} \right) + \left(\frac{0.001 \cdot IA_{e1}}{\rho_{ia}} \right) + \left(\frac{(1 - 0.001) \cdot (SOM_{e1} + IA_{e1})}{\rho_s} \right) \right]}$$

where ρ_{om} is the bulk density of the organic fraction of the existing soil (kg m^{-3}), ρ_{ia} is the bulk density of the inorganic fraction of the existing soil (kg m^{-3}) and ρ_s is the bulk density of the sand fraction of the existing soil (kg m^{-3}). The same equation as above can be used to calculate the bulk density of layer 1 following dilution, ρ_{d1} , via replacement of SOM_{e1} with SOM_{d1} and IA_{e1} with IA_{d1} .

Additionally, a soil volume from layer 1 equal to the volume of mix added to the surface is combined with layer 2 through use of the mixing model. This continues layer by layer throughout the 5 depth intervals, preserving the layer dimensions in the mass balance calculation. Thus, for layer 2 the equation for soil organic matter is:

$$SOM_{d2} = \frac{(SOM_{d1} \cdot V_m \cdot \rho_{d1}) + (SOM_{e2} \cdot V_{e2} \cdot \rho_{e2})}{[(V_m \cdot \rho_{d1}) + (V_{e2} \cdot \rho_{e2})]}$$

where SOM_{d2} is the soil organic matter of layer 2 following dilution by topdressing to layer 1 (g kg^{-1}), SOM_{e2} is the existing soil organic matter of layer 2 (g kg^{-1}), V_{e2} is the existing volume of layer 2 (m^3) and ρ_{e2} is the existing bulk density of layer 2 (kg m^{-3}).

Similarly, the inorganic amendment content of layer 2 is given by:

$$IA_{d2} = \frac{(IA_{d1} \cdot V_m \cdot \rho_{d1}) + (IA_{e2} \cdot V_{e2} \cdot \rho_{e2})}{[(V_m \cdot \rho_{d1}) + (V_{e2} \cdot \rho_{e2})]}$$

where IA_{d2} is the inorganic amendment content of layer 2 following dilution by topdressing to layer 1 (g kg^{-1}) and IA_{e2} is the existing inorganic amendment content of layer 2 (g kg^{-1}),

And the existing bulk density of layer 2, ρ_{e2} , is calculated using the same equation as that for the existing bulk density of layer 1, ρ_{e1} , via replacement of SOM_{e1} with SOM_{e2} and IA_{e1} with IA_{e2} . Further, this same equation can be used to calculate the bulk density of layer 2 following dilution, ρ_{d2} , via replacement of SOM_{e2} with SOM_{d2} and IA_{e2} with IA_{d2} .

Equations for Solid-Tyne or Direct Injection Operations

For a specified month when solid-tyne aeration or direct injection is applied as an organic matter dilution operation, the equations for organic matter dilution are similar to those for topdressing. The exception here is that ST aeration and DI can occur in successive depth intervals from 1 to 5 depending on the depths of ST aeration, or DI. Using layer 2 as an example, where ST aeration or DI has occurred in both layers 1 and 2, the mixing equation becomes:

$$SOM_{d2} = \frac{(SOM_m \cdot V_m \cdot \rho_m) + (SOM_{e2} \cdot V_{e2} \cdot \rho_{e2})}{[(V_m \cdot \rho_m) + (V_{e2} \cdot \rho_{e2})]}$$

where SOM_{d2} is the soil organic matter of layer 2 following dilution by ST aeration or DI (g kg^{-1}) and here V_m is the volume of the mix added into layer 2 (m^3).

Similarly, the inorganic amendment content of layer 2 is given by:

$$IA_{d2} = \frac{(IA_m \cdot V_m \cdot \rho_m) + (IA_{e2} \cdot V_{e2} \cdot \rho_{e2})}{[(V_m \cdot \rho_m) + (V_{e2} \cdot \rho_{e2})]}$$

where IA_{d1} is the inorganic amendment content of layer 2 following dilution by ST aeration or DI (g kg^{-1}).

The total volume of mix added either by ST aeration or DI are calculated from the diameter of the opening created, the depth and the spacing of the respective applications. All other terms are as before with the recognition that the subscript d in this equation is for dilution following ST aeration or DI.

The solid-tyne aeration is accompanied by a topdressing application when applying mix to fill the holes. Consequently, the identical equations as used for a topdressing application alone will be applied when topdressing accompanies this operation. This topdressing, however, will most likely be to a deeper depth than for routine topdressing alone.

Equations for Hollow-Tyne or Deep Verticutting Operations

Soil organic matter removal by hollow-tyne aeration or deep verticutting involves extracting and disposing a volume of the existing soil and replacing this same volume with the mix. The extracted volume for HT aeration is dependent on the diameter, depth and spacing of the coring tool used. The extracted volume for DV is dependent on the width of the blade used, the depth of application (no deeper than 2.54 cm) and assuming spacing between blades of 2.54 cm. Thus, the successive depth intervals from 1 to 5 can be affected by SOM removal using HT aeration, but only layer 1 is affected by DV. Subsequently a mixing model is employed where the volume of mix added to fill the aeration hole or slits serves to dilute the organic matter in the existing affected layers. Because the volume of mix used in the refilling operation precisely equals the volume of soil removed, the layer dimensions are preserved and a single equation can be applied to each affected layer. Thus:

$$SOM_r = \frac{(SOM_m \cdot V_r \cdot \rho_m) + (SOM_e \cdot (V_e - V_r) \cdot \rho_e)}{[(V_r \cdot \rho_m) + ((V_e - V_r) \cdot \rho_e)]}$$

where SOM_r is the soil organic matter following a removal operation within an affected layer using either HT aeration or DV (g kg^{-1}) and V_r is the volume of soil removed and added mix (m^3).

Inorganic amendment content following existing soil removal and backfilling of the holes or slits is given by:

$$IA_r = \frac{(IA_m \cdot V_r \cdot \rho_m) + (IA_e \cdot (V_e - V_r) \cdot \rho_e)}{[(V_r \cdot \rho_m) + ((V_e - V_r) \cdot \rho_e)]}$$

where IA_r is the soil inorganic amendment content a removal operation within an affected layer using either HT aeration or DV (g kg^{-1}).

Both of the hollow-tyne aeration and deep verticutting operations are accompanied by a topdressing when applying mix to fill the holes or slits. Consequently the identical equations as used for a routine topdressing application will be applied when topdressing accompanies these respective operations. This topdressing, however, will most likely be to a deeper depth than for routine topdressing alone.

Model Inputs

There are 2 types of inputs into the model, the SOM accumulation and decay parameters and the management plan and operation details parameters. The SOM accumulation and decay parameters include local, mean monthly temperatures, and the equation parameters: AC_0 , AC_{mx} , z_h , s , T_o , sd , K_m , SOM_i . The management plan and operation details parameters include the number of SOM control operations performed in a given month and details such as topdressing depths; HT tube diameters, spacing and depth of coring; ST and DI hole diameters, spacing and depths; and DV blade widths and depth. Finally, the model calculations yield spatial mean SOM contents as if a large diameter core (such as a cup cutter) sample was withdrawn for testing. This large diameter sample would average across relict hollow-tyne, solid-tyne, direct injection and deep verticutting aeration holes.

Model Calibration Results

A model calibration study was conducted in order to estimate values of the accumulation and decay parameters. Model calibration of the SOM model involved the use of field measurements and the adjustment of accumulation and decay parameters to gain a best fit of the simulation results to the measured data. Often in model calibration, the measurements are referred to as observations and the simulation outputs are referred to as the predictions; where the differences between the two are the residuals. Thus this process is to minimize the residuals and provides values of input parameters, resulting in a model that is true-to-nature. In this case I employed literature values of putting green SOM observations from experiments at specific locations and using a variety of SOM control operations. Literature values amenable for calibration for cool season turfgrass included: Carrow (2003); Glasgow et al. (2005); Landreth et al. (2008); Carley et al. (2011); Ervin and Nichols (2011).

The following are two example calibration results. In the first case, experimental data were taken from Ervin and Nichols (2011) comparing seasonal topdressing only or seasonal topdressing plus twice yearly hollow-tyne aeration. Sampling dates were 11, 23, and 35 months after inception of the study. The results (**Fig. 1**), after adjusting the accumulation and decay parameters, suggest that the predicted 0 – 5 cm mean SOM values closely matched those

observed. The sole exception was for the coring treatment at 23 months where predicted values somewhat exceeded those observed.

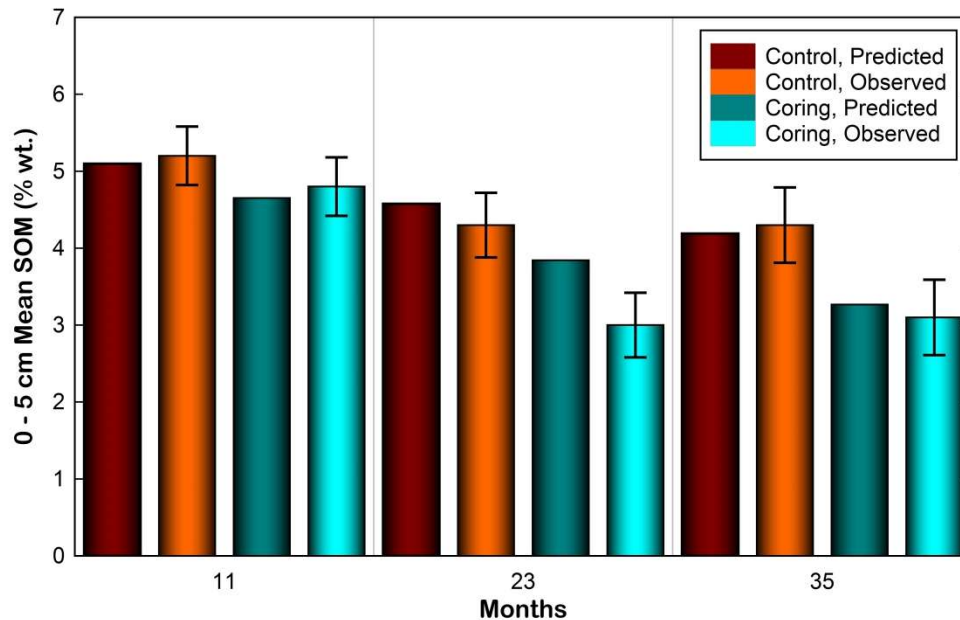


Fig. 1. Calibration results of observed and predicted 0 – 5 cm depth mean soil organic matter contents where the observed values were from Ervin and Nichols (2011). Sand was applied to both treatments for each coring event (March and September) was 12 ft³/1000 ft². Seasonal topdressing applied 0.15 ft³ to both treatments for each topdressing event. The total yearly sand applied for both treatments was 24.6 ft³/1000 ft². Hollow-tyne aeration employed a 0.5-inch (1.27-cm) diameter tine to 2-inch (50-mm) depth with 1.3 x 1.5-inch (3.4 x 3.8-cm) spacing. The Initial organic matter content was 5.8 %.

In the second case, the experimental observations are from Glasgow et al. (2005) where mean SOM was measured within 4 depth increments (3 shown here to prevent overlap of the deeper 2 measurements) for 7 putting greens built in successive years. All putting greens were built using the same sand-based construction method and received the same SOM control operations. The results (**Fig. 2**) show both a time and depth dependence with a general agreement between the observed and predicted values.

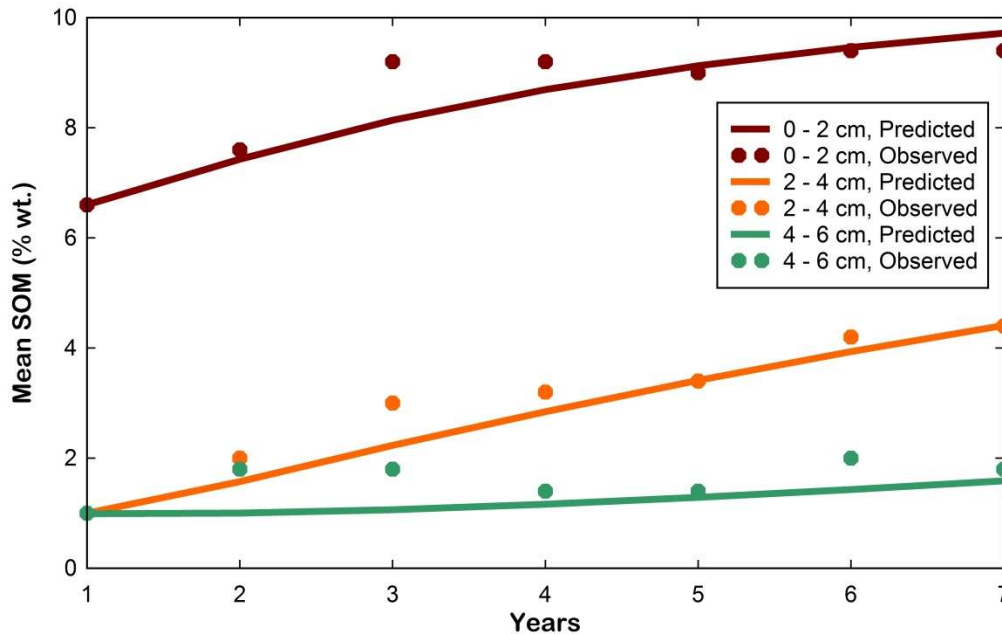


Fig. 2. Calibration results of observed (dots) and predicted (lines) mean soil organic matter contents over 7 years for depth intervals of 0 – 2 cm (0 – 0.8 in), 2 – 4 cm (0.8 – 1.6 in) and 4 – 6 cm (1.6 – 2.4 in). The observed data was from Glasgow et al. (2005). The initial (following year 1) organic matter contents were 6.5% for the 0 – 2 cm increment, 0.9% for the 2 – 4 cm increment and 1.0% for the 4 – 6 cm increment.

Mean SOM accumulation and decay parameter values from model calibration of the 5 experimental studies were then used to generate baseline values of these various parameters (**Table 1**). These cool-season-turfgrass baseline values are intended as inputs for use of the model in simulating how different SOM control operations affect greens soil organic matter contents. These baseline values are also intended as reasonable starting points for further model calibration studies.

Table 1. Baseline values of SOM accumulation and decay parameters for cool season turfgrass from the model calibration results.

Name	Symbol	Value	Units
Monthly Max. SOM Accumulation at $z = 0$	AC_0	3.5	$g\ kg^{-1}$
Monthly Max. SOM Accumulation at $z = 125$	AC_{mx}	0.03	$g\ kg^{-1}$
Depth of 1/2 Max. Accumulation	z_h	20	mm
Curve Shape Factor	s	10	-

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