ESTIMATING SOIL PRODUCTIVITY AND ENERGY EFFICIENCY USING WEBSOIL SURVEY, SOIL PRODUCTIVITY INDEX CALCULATOR, AND BIOFUEL ENERGY SYSTEMS SIMULATOR.

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ABSTRACT

Soils have varying production capacities for a specific plant or sequence of plants under defined management strategies. The production capacity or "productivity" can be quantified as a mathematical function of a soils ability to sufficiently sustain plant growth and development. The result of this function is a productivity index value that can be used to estimate crop yield and develop management strategies. This paper demonstrates a simulation of how erosion and loss of soil organic carbon can impact productivity, profitability, and energy efficiency for a typical corn production field in South Dakota. Energy and productivity values are calculated in an MS Excel workbook using data sourced from an online soil survey and a biofuel systems model. These data used with spatial soils data to demonstrate the spatial variation of these parameters within a field.

Keywords: Precision farming, productivity index, erosion, soil carbon

INTRODUCTION

The production capacity of a soil depends on rooting depth, topsoil thickness, available water capacity, plant nutrient storage, surface runoff, soil tilth, and soil organic carbon (McCormack et al., 1982). The soil productivity index is calculated as a function of these parameters that can be translated into biomass and energy yield and production estimates for individual soils or aggregated for field scale estimates. Several models have been developed for calculating soil PI values. The model presented in this chapter was developed by Pierce et al. (1983) which assesses the effects of erosion on soil productivity.

Water, wind, and gravity assisted by tillage are erosive forces that move soil from upper to lower landscape positions. Tillage, loosens and exposes soil to erosive forces in addition to direct translocation of soil resulting in tillage erosion (Lindstrom et al., 1990 and Govers et al., 1999). In eroded landscapes, managers may attempt to maintain or improve productivity by increasing material inputs which increases energy inputs. Increasing material inputs may fail or only partially recover productivity as damage to many soil properties (soil orgainic carbon, available water holding capacity, root zone depth, and soil structure) are not easily reclaimed or repaired. Together, increased inputs and decreased production capacity reduce energy efficiencies of crop production systems in eroded landscapes.

MATERIALS AND METHODS

This simulation uses a 39 hectare (Ha) (96 acre) field located in Lake County South Dakota. Soil mapping units and the area they occupy shown in Table 1. Soil mapping units and data required to estimate the productivity indices were obtain from the USDA Web Soil Survey (Soil Survey Staff, 2009). Soils data sourced from WSS is entered into an MS Excel® (Microsoft® Corporation, 2007) workbook; "Soil Productivity Index Calculator" (SPIC) (Schumacher and Reitsma, 2010) that uses methods developed by Pierce et al. (1983) for assessing long-term impact of erosion on soil productivity.

Table 1. Soil Mapping Units Occuring in Study Field

Map Unit Name	Area (Ha)
Badus Silty Clay Loam	0.16
Baltic Silty Clay Loam	0.16
Clarno-Ethan loams	0.45
Egan-Beadle complex (B)	3.20
Egan-Beadle complex (C)	14.08
Egan-Wentworth silty clay loam	10.32
Viborg silty clay loam	4.33
Whitewood silty clay loam	3.84
Worthing silty clay loam	2.35

Based on Pierce et al. (1983) the mathematics of the PI model is expressed as:

$$PI = \sum_{i=1}^{r} \left(A_i \times C_i \times D_i \times WF \right)$$

where, PI is the Productivity index, r is the number of soil horizons, A is the sufficiency of available water capacity (AWC), C is sufficiency of bulk density, D is the sufficiency of pH, and WF is the weighting factor. Parameters required for the SPIC are provided in Table 2.

Soil productivity index values were calculated for each soil at time zero (T_0) and at time one (T_1). Yield (bu•acre^{-1}) and crop value (US \$ •bu^{-1}) estimates are user defined entered on the "Summary" worksheet of the SPIC. The yield value is the yield at T_0 and may be based on proven field average yield, county average yield, or other yield data. Yield at T_0 is assumed to be 160 bu•acre^{-1}. Crop value may be based on contract, average annual, or current offering prices. In this exercise, corn value is based on a selling price of $3.50 US•bu^{-1} ($154/Mg).

Table 2 Parameters required for the SPIC.

Parameter	Worksheet Variable	Unit
[1]Map unit name	Map Unit Name	-----
[1]Number of horizons	Number of Horizons	-----
[1]Map unit symbol	MU Symbol	-----
[1]Horizon depth (bottom)	Depth (in)	Inches
[1]Available water	PAWHC	Inches/Inch
[1]Bulk density	BD	g/cm^3
[1]Soil pH	Ph	-----
[1]Hydrolic conductivity	Ksat	Micrometer per second
[1]Percent clay	Clay%	Percent (%)
[1]Percent passing #200	Passing 200	Percent (%)
[2]Maximum ideal yield	MAX Ideal YD	Bushel per Acre (Bu/A)
[3]Crop	Crop	-----
[3]Value of crop	Value (bu)	US dollars/bushel ($/Bu)
[1]Area of soil map unit	Area (Sq. ft)	Square feet (ft^2)

[1] Values obtained from Web Soil Survey.
[2] User defined value based on county average or proven yields.
[3] User defined values.

Using a geographic information system (GIS), spatial data retrieved from WSS is joined to results summarized in the SPIC, demonstrating the spatial variation of long-term erosion impacts on biomass and energy production. For the purpose of this simulation, an assessment was developed using the following simplifications:

- Soil conditions at T_0 (time 0) represent optimal productivity of each soil map unit;
- The first defined soil layer is completely removed by erosion at T_1 for soils likely to erode.
- Only soil map units with B or C slopes were assumed to erode.
- A dryland production and moldboard plow tillage system was used between T_0 and T_1;
- Material inputs were not applied at a variable rate and do not change between T_0 and T_1;
- Material inputs are optimal for plant growth at T_0 and T_1;
- Initial (T_0) proven corn yield for the field was 160 $bushel{\bullet}acre^{-1}$.

These simplifications assume a worst case scenario for erosion but provide conservative crop and energy productivity impact estimates. All units used in the SPIC discussed in this paper are consistent with those used in the WSS or otherwise noted. Currency, units are United States dollars (**$US**).

The Biofuels Energy Systems Simulator (BESS ver. 2008.3.1, Liska et al, 2009) calculates the energy efficiency, greenhouse gas emission, and natural resource requirements of a corn to ethanol biofuel production system. This paper will focus on the crop production component of the model assuming material inputs and management remains constant between T_0 and T_1.

Modified representative management (input) parameters of the US Midwest provided in the BESS model are used to build T_0 and T_1 scenarios for each soil map unit. BESS uses these scenarios to calculate a biofuel production life cycle analysis for each individual soil map unit. Results for T_0 and T_1 can be compared using BESS or the SPIC.

Results from the BESS and SPIC were joined to spatial soils data using a geographic information system (GIS), spatially depicting the impact of erosion on productivity and energy efficiency. These data can be used to target areas in the field where conservation efforts may have the greatest impact. Detailed methods are provided in Reitsma et al. (2010).

RESULTS AND DISCUSSION

Results from the BESS and SPIC simulation models provide an estimate of how erosion and consequential loss of organic carbon affects productivity, profitability, and energy efficiency in a continuous corn system where the corn is used for ethanol production. Table 3 summarizes simulation results on a field scale for the selected field. As erosion occurs and organic carbon is lost from the profile; productivity, profitability, and energy yield and efficiency declines.

Loss of top soil is predicted to lead to an over-all field production loss of nearly 1,500 bushel annually; equating to annual partial profit loss of over $5,000 (Table 3). The BESS predicts that energy use rate increase of 42 $MJ*Mg^{-1}$ as yield declines (Table 4). Over-all field average yield declined by 9 $Bu*Acre^{-1}$ equating to a loss of 23 Gal. $EtOH*Acre^{-1}$ annually. On an annual basis, simulation results suggest that erosion would increase crop production energy use by 42 $MJ*Mg^{-1}$ and with an over-all field loss of 176,208 MJ equating to a loss of ≈ 2,200 gallons of ethanol (80 MJ/gal EtOH) (Liska et al., 2009).

Mapping results of this simulation provides an indication of spatial variability and expanse across the landscape. The map in Figure 1 depicts spatial variability and expanse of the change in ethanol yield across the study field. Areas that are most impacted by erosion show the greatest decline in ethanol yield making them priority areas for considering investment in conservation practices, precisely placing and designing practices to realize the greatest return.

Table 3. Field Production & Profitability Summary

Crop	*Corn*
Crop Value ($ US/Bu)	*$3.50*
Total Area (Acres)	*96*
Field Average Yield (Bu/Acre)	*160*
Average PI, T_0	*0.79*
Average PI, T_1	*0.75*
Average Yield, T_0 (Bu/Acre)	*160*
Average Yield, T_1 (Bu/Acre)	*151*
Average Yield Difference, T_1 - T_0 (Bu/Acre)	*-9*
Average Partial Profit Change, T_1 - T_0 ($US/Acre)	*-$29.90*
Total Production, T_0 (Bu)	*17,376*
Total Production, T_1 (Bu)	*15,909*
Total Production Change, T_1 - T_0 (Bu)	*-1,467*
Net Annual Partial Profit Change, T_1 - T_0 ($ US)	*-$5,135.75*

Table 4. Field Energy Summary.

Ethanol Conversion Rate, Heating Value (MJ/Gal. EtOH)	*80*
Average Energy Use Rate, T_0 (MJ/Mg Grain)	*1,034*
Average Energy Use Rate, T_1 (MJ/Mg Grain)	*1,076*
Change in Energy Use Rate, T_1 - T_0 (MJ/Mg Grain)	*42*
Average Energy Yield, T_0 (MJ/Ha)	*44,503*
Average Energy Yield, T_1 (MJ/Ha)	*41,939*
Average Energy Yield Difference, T_1 – T_0 (MJ/Ha)	*-2,564*
Average Energy Yield, T_0 (MJ/A)	*18,010*
Average Energy Yield, T_1 (MJ/A)	*16,972*
Average Energy Yield Difference, T_1 – T_0 (MJ/A)	*-1,037*
Net Energy Production, T_0 (MJ)	*1,981,779*
Net Energy Production, T_1 (MJ)	*1,805,572*
Change in Net Energy Production, T_1 – T_0 (MJ)	*-176,208*
Average Energy Efficiency Output:Input, T_0 (MJ/MJ)	*1.80*
Average Energy Efficiency Output:Input, T_1 (MJ/MJ)	*1.79*
Average Change in Energy Efficiency, T_1 - T_0 (KJ/KJ)	*-8.89*
Net Ethanol Production, T_0 (Gal. EtOH)	*24,772*
Net Ethanol Production, T_1 (Gal. EtOH)	*22,570*
Change in Net Ethanol Production, T_1 - T_0 (Gal. EtOH)	*-2,203*
Change in Ethanol Yield, T_1 - T_0 (Gal. EtOH/Acre)	*-23*

CONCLUSIONS

This simple scenario selects one 97 acre (240 ha) field with complex slopes as an example to demonstrate how erosion can impact production and energy aspects of a cropping system. The analysis assumes worst case erosion scenario as SPIC calculates a PI value at T_1 based on removing the top layer of soil; assumed to be the first soil layer. Results from the energy analysis are conservative estimates as material inputs (fertilizer, manure, etc.) are kept constant between T_0 and T_1. However, these results demonstrate that the use of corn for biofuel production adds another facet to the importance of sustainable crop production.

Mapping results of this simulation provides an indication of spatial variability and expanse across the landscape. The map in figure 1 depicts spatial variability and expanse of the change in ethanol yield across the study field. Areas that are most impacted by erosion show the greatest decline in ethanol yield making them priority areas for considering investment in conservation practices, precisely placing and designing practices to realize the greatest return.

This chapter focuses on erosion but is only one facet of sustainable agricultural production. Tillage system, and soil organic carbon, residue, water, and pest management are among other considerations for designing a sustainable cropping system. As the biofuels industry evolves and demand for biofuels increases, energy efficiency of crop production is likely to become more important.

Figure 1. Map rendering of soil map unit symbolized to depict spatial variation of change in ethanol yield (US gallons·acre^{-1}) due to erosion.

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