Soil management, crop rotations, and biomass removal effects on soil organic matter content

by

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CHAPTER 1. GENERAL INTRODUCTION

Scope of the Study

Current energy price increases and oil market problems have induced interest in alternative sources of energy that could be a substitute for crude oil, among these, biomass derived materials. Biomass includes wood, crops, and residues from agricultural and forest products than can be converted into a number of different liquid fuels or biofuels. Biomass is a relatively cheap, renewable source of energy that can be grown almost anywhere.

However, there are environmental hazards associated with growing and harvesting biomass for biofuel production. Environmental hazards include soil degradation due to depletion of soil organic matter, which is a serious concern. If the soil organic matter decreases, a number of consequences can be expected such as loss of productivity, loss of soil water retention capabilities, and an increased risk of erosion. It is essential for decision makers to have knowledge about the impacts that bioenergy systems may have on the environment. With better knowledge there is an increased chance that natural resources will be preserved and food or biomass production will be sustained. For that reason the goal of this research was to evaluate the relative effects of biomass production and removal on soil organic matter changes within various agricultural management systems.

General Overview

This doctorate research is divided into three components. The first component analyzes a 40-year long Hungarian field dataset developed from soil organic matter measurement as influenced by various agricultural management systems. The combination of varying management practices entails different rates of manure and fertilizer applications and crop rotations with concurrent aboveground biomass incorporation vs. removal. This dataset was evaluated with the objective of determining the impact of a broad range of soil management practices on soil organic matter content when crop biomass is removed vs. incorporated.

In the second component this core dataset then was used to evaluate performance of two soil organic carbon models: SCI (Soil Conditioning Index) and EPIC (Environmental Policy Impact Calculator). Both SCI and EPIC have a component that enables the models to predict soil organic matter changes in different regions with various agricultural management practices. For that reason the second component of my research focuses on comparing the ability of these models to estimate soil organic matter changes due to different management practices by comparing the experimental data to simulations from each model. In the third component EPIC was used to evaluate the effect of various management practices on soil organic matter content changes in central Iowa. Iowa was chosen for the simulation since it is a major crop producing state with great biomass resource base.

Dissertation Organization

This dissertation contains six separate chapters. The first chapter introduces the scope of this dissertation, entails a short introduction of each research component, describes the organization of this dissertation, and emphasizes the relevance of this research. The second chapter is the literature review on soil organic matter, which is the core research topic of this dissertation. The third chapter addresses the first component of the research study and it is titled, "Crop Rotation, Nutrient Management, and Biomass Removal Effects on Soil Organic Matter Content". The fourth chapter addresses the second component of the research and it is titled, "Estimating Soil Management Impacts on Soil Organic Matter Content Utilizing EPIC and SCI". The fifth chapter addresses the third component of this dissertation and it is titled, "Biomass Removal Effects on Soil Organic Matter Predicted by EPIC in Central Iowa". Finally, chapter six recaptures the major findings and draws general conclusions of this dissertation research. Chapters three, four, five, and six are written in manuscript format and will be submitted to peer-reviewed journals for publication.

Importance of this Dissertation

This research addresses biomass removal effects on soil organic matter as biomass removal interacts with variety of management practices including different crop rotation, nutrient management and tillage practices. Therefore the results of this dissertation could help to identify whether or not agricultural management systems can support intensive residue removal and still maintain soil organic matter content and could help to identify management practices that would support this. In addition, the results of this dissertation can help further evaluate modeling tools that could be used in decision making processes associated with agricultural biomass production for the biofuel industry.

CHAPTER 2. LITERATURE REVIEW

The Role of Crop Residues

In the 1970`s and early 80`s self-sufficient energy production prompted research interest in using farm crop residues for energy production (Larson, 1979), an interest that has been recently renewed and expanded. The U.S. government "Vision for Bioenergy and Bio-based Products in the United States" set a goal that 5 percent of power, 20 percent of transportation fuels, and 25 percent of chemicals will be produced from biomass by the year 2030 (Perlack et al., 2005). Biofuels are transportation fuels produced from biomass and are recognized as feasible alternatives to offset emission of carbon dioxide (CO_2) from fossil-fuel combustion (Giampietro et al., 1997). Besides energy crops, plant residues after grain harvest including unharvested leafy stalks, and straws are viewed as the most readily available feedstock for bio-based industries.

Crop residue use for energy production can affect soil quality. From a soil management perspective unharvested crop residues are used for managing soil organic carbon (SOC). From the natural conservation perspective, plant residues are used to manage soil and water conservation. They are especially important in row crop agriculture where leafy stalks are the producer's primary tool for soil protection from erosive forces. Research showed that above ground biomass removal greatly affects both soil SOC dynamics and soil erosion (Larson et al., 1972; Holt, 1979; Lindstrom, 1986; Wilhelm et al., 2004).

Soil Organic Matter

Soil is a limited resource, on which natural ecosystems and agriculture depend (Black 1973; Larson and Pierce, 1994; Reicosky et al., 1995; Bruce et al., 1999). Soil organic matter (SOM) is an indicator for soil quality. At any time the amount of SOM present at a site reflects the net balance between organic matter (OM) additions and losses in the soil. Two biotic processes determine the additions and losses of organic matter: (1) quantity of crop residue, plant roots, and other organic material returned or added to the soil and their (2) rate of decomposition (Barber 1979; Batjes and Sombroek, 1997; Bruce et al., 1999*;* Lal et al., 1999; Farage et al., 2003). The rate of OM accumulation varies among soils, reflecting the influence of environmental factors on pedogenic processes: SOM content = *f* (climate, organisms, parent material, topography, time) (Jenny, 1941). All these factors are interdependent in the dynamic process of SOM accumulation or loss.

Climate Effects on Soil Organic Matter

Dry or cold climates support low vegetation production with low OM inputs, which leads to low SOM levels. On the contrary, warm and moist climates support high vegetation production thus high OM inputs. Correspondingly, soils under warm and moist climate have high SOM inputs (Post, 2002). Temperature and soil water content increases however enhance microbial activity and decomposition rates (Potter et al., 1998; Rice 2002). For instance, the Canadian Great Plains lost 50 percent of its SOM content (SOMC) during 6 decades of cultivation while the northeastern Brazil soils lost 40 percent of SOMC in only 6 years of cultivation (Tiessen et al., 1994).

Soil Organic Carbon Pools

Soil organic matter is a dynamic entity but it does not accumulate indefinitely in the soil and an equilibrium level is reached over time. However even when stocks are at equilibrium, SOM is still in a continual state of flux. As a decomposition process, OM cycle into and through different OM pools and replace materials that are lost, transferred to other pools, or mineralized (Six and Jastrow, 2002). Typically, there are three different pools distinguished: the (1) active pool, which consists of microbial biomass and labile organic compounds, and makes up less than 5 percent of the total SOC; the (2) slow pool, which accumulates plant nutrients for mineralization, makes up 20 to 40 percent of the total SOC; and the (3) recalcitrant pool, which contains organic materials that are difficult to degrade and makes up 60 to 70 percent of the total SOC. The level of OM in the soil is directly related to these SOC pools (Rice, 2002).

Soil Organic Matter Levels

Levels of SOM can be expressed in terms of SOC concentration (g kg^{-1}) or mass per unit area (g m^{-2}). SOMC can be indirectly estimated through multiplication of the organic carbon (C) concentration by the ratio of OM to organic C commonly found in soils: SOC x 1.724 = SOM. The concentration of SOM is the highest near the soil surface, where plant above ground biomass is added, and then declines with depth (Ajwa et al., 1998). The rate of SOM turnover also changes with depth. Compared to that in the deeper profile, surface soil usually has higher proportions of "young" OM from recent inputs of plant litter. Carbon comprises a relatively minor component of most soils, in terms of mass. A majority of soils contain from 1 to 3 percent C by mass in the surface horizons (Post, 2002).

Soil Carbon Sequestration

The ultimate source of soil C is atmospheric CO_2 that is captured by plants in photosynthesis. Soil C sequestration occurs when there is a net removal of atmospheric CO_2 resulting from greater C soil inputs than C outputs. Since there is an opportunity for managed ecosystems to act as C sinks and sequester atmospheric C, concerns about global warming and greenhouse gas emissions have directed researchers to evaluate the effects of different tillage practices on C sequestration (Benoit and Lindstrom, 1987; Reicosky et al., 1995; Deen and Kataki, 2003).

Soil Functions and Soil Organic Matter

SOM has a central role in three broad groups of soil functions: (1) chemical (cation exchange capacity, nutrient supply); (2) physical (aggregation, water holding capacities, soil color, resistance to physical damage, to erosion, and to compaction); and (3) biological (biological activity) (Powlson, 1996). There are strong interactions and interdependencies between these groups.

Soil Structure and Soil Organic Matter

SOM affects soil structure through soil aggregation and aggregate stability (the ability of soil aggregates to withstand the degrading action of impacting and flowing water). A well aggregated soil has better aeration, water infiltration, and soil water holding capacity and provides good soil structural conditions for root growth. Water holding capacity is controlled by the number of pores, pore size distribution, and the specific surface area of the soil (Haynes and Naidu, 1998; Carter, 2002). Bulk density is also affected by aggregation and it generally decreases with organic amendments. Black (1973) reported that bulk density of the 0 to 76-cm soil depth decreased significantly as residue levels increased. Bulk density can also decrease due to manure additions caused by mixing of lower particle density organic material with the denser mineral fraction of the soil (Haynes and Naidu, 1998).

Soil Organic Matter and Nutrients

Since SOM is or has been part of living tissues, it holds C, hydrogen, and oxygen in great quantity and nitrogen (N), phosphorus (P), and sulfur (S) in lesser quantity. Generally the C:N:P:S ratio is 107:7:1:1 (Stevenson, 1986; Janzen et al., 2002). N is a limiting element for productivity and is approximately 90-95% in organic form associated with SOM (Rice, 2002). Inorganic N is made available to the plants during decomposition of SOM - part of the N cycle. Mineralization or ammonification is the process by which organic N transforms to plant available inorganic ammonium (NH_4^+). The net N mineralization is the sum of the two concurrent processes: mineralization and immobilization. Immobilization is the process that transforms ammonium to organic N. Both of these processes are mediated by microorganisms (Norton, 2000). The C to N ratio of vegetation inputs is important because microorganisms degrading organic inputs with high C to N ratio require additional N (Rice, 2002).

Soil Organic Matter Management

Besides Jenny`s (1941) environmental factors SOM additions and losses depend on agricultural management practices. Changes in agricultural practices for the purpose of increasing SOM must either increase OM inputs to the soil and/or decrease oxidation and decomposition of OM (Follett, 2001; Paustian et al., 2000). Increased OM inputs can be achieved by adoption of improved practices, like use of crop rotations, perennial vegetation, improved crop nutrition, and organic amendments. On the other hand, decreased OM decomposition can be achieved by reduction in tillage intensity (Janzen et al., 1998).

Crop Management

Changes in SOC can be attributed to crop species grown and to crop rotations applied within a cropping system (Havlin et al., 1990). Different crop species have a variety of rooting depths that aid in distributing OM throughout the soil profile. In the 'Morrow plots' in Illinois, crop rotations decreased the decline in soil N and organic C compared with continuous corn (Russell et al., 1984). Cropping systems that eliminated summer fallowing maximized the amount of SOC in an experiment in the Great Plains (Sherrod et al., 2003).

The inclusion of nitrogen-fixing and deep-rooting plants in a rotation is especially useful for increasing soil N and C at depth (Farage et al., 2003). Stevenson (1965) reported that rotations including legumes maintained a higher OM level than continuous cropping with no leguminous row crops. Cropping systems than contained alfalfa had the highest, whereas the corn-soybean rotations had the lowest SOC stock in Iowa (Russell et al., 2005). The more than 100 years old 'Old Cotton Rotation' in Alabama indicated that winter legumes and crop rotations result in larger amount of C and N in soil, which ultimately contributes to higher cotton and corn yields regardless of other practices (Mitchell and Entry, 1998).

Soil Tillage

Tillage influences soil and surface conditions that both directly and indirectly influence SOMC (Jenny, 1941). Depending on its frequency and kind, tillage changes the soil biophysical environment in ways that affect the net mineralization of nutrients and the release of C (Izaurralde and Cerri, 2002). Generally tillage aerates the soil, and thus accelerates oxidation of soil C by increasing microbial activity. Additionally, intensive tillage reduces aggregate size and exposes new aggregate surfaces to microbial attack (Peterson et al., 1998; Beare et al., 1994). Reduced tillage, on the other hand, decreases soil disturbance and oxidation, thus it increases the amount of C stored in a soil (Peterson et al., 1998).

Reduced tillage systems were originally developed to help combat soil degradation but they were proved to also sequester C (Farage et al., 2003; Peterson et al., 1998). Paul et al. (1997) complied data on no-till (NT) systems, reduced tillage systems, and intensive tillage systems such as conventional till (CT) from several long-term field studies. In most cases they found an increase in SOC content under NT systems compared to the others. Soils under NT had greatest C content compare to five other management systems in Ohio (Bapst et al., 2003). Switching from CT wheat production to NT cropping could sequester up to 6 t C ha^{-1} in SOM and surface residues in 14 years in the semiarid Canadian prairies (Curtin et al., 2000). With NT, an estimated 233 kg C ha^{-1} was sequestered each year in an annual crop rotation system, compared with a loss of 141 kg C ha^{-1} using CT in the northern Great Plains (Halvorson et al., 2002). Zero till practices increased SOC levels and storage compared to CT operations for the surface layer in Ontario (Deen and Kataki, 2003).

Mineral Fertilization

Mineral fertilizer additions can enhance accumulation of organic C in different soils. For instance, Paustian et al. (1992) reported that fertilizer N addition increased the SOC level 15 to 19 percent by increasing net primary productivity and the residue C input. Robinson et al. (1996) observed a 22 percent increased SOC content (SOCC) due to application of N, P, and K fertilizer to a soil in Iowa. Rasmussen and Rode (1988) have also shown a direct linear relationship between long-term N addition and accumulation of organic C in some semiarid soils of Oregon. Franzluebbers et al., (1994) observed that the SOCC of the 0-55 mm depth was 62 percent more in wheat production, with fertilization than without. Paustian et al. (1992) reported that fertilizer N addition increased the SOC level by 15 to 19 percent by increasing net primary productivity and the residue C input. Liang and MacKenzie (1992) reported that soil C levels increased by 18 percent during a 6-year period using high levels of N fertilization.

Organic Fertilization

Organic fertilization can take place by adding compost, residues, or manure to the soil. Fortuna et al. (2003) reported that proper management of nutrients from compost, cover crops, and rotations can maintain soil fertility and increase C sequestration. Manure application, however, is the best means to introduce OM into soils to enhance C storage for most modern cropping systems. For the same C input, C storage is higher with manure application than with plant residues since manure is more resistant to microbial decomposition than plant residues. Farmyard manure fertilization sustained total SOCC in the top layers of the soil while mineral treatments alone or mixed with organic exhibited a minor influence on OM accumulation after 40 years of rotation experiment in Italy (Nardi et al., 2004). High application rates of manure, however, can cause problems in the soil through the accumulation of P, K, Na, and/or NH_4^+ (Haynes and Naidu, 1998).

Residue incorporation to soils can also maintain soil fertility and increase SOM levels. For instance, Larson et al. (1972) found that changes in SOC are linearly related to the amount of residue applied to the soil under continuous corn. Black (1973) added various quantities of wheat straw to a series of plots and showed that increased residue levels increased SOM levels. Barber (1979) compared corn stalk residue removal for 10 years with residue returned and about 11% of the C in the residues was synthesized into new OM. Rasmussen et al. (1980) in the northwest USA reported that soil C correlated highly with the amount of organic C supplied by each treatment regardless of the different kinds of residue applied. Christensen (1986) in Denmark showed that straw removal resulted in lower SOMC than when straw was retained. Robinson et al. (1996) in Iowa demonstrated that SOC content was linearly related to residue additions.

Soil Organic Matter and Soil Erosion

As mentioned previously SOM levels can be altered by environmental factors and by agricultural management practices. Soil erosion, which is a major process causing SOM loss, from soils, can result from both human and environmental factors. Soil erosion is the process of physical detachment of soil particles due to a kinetic energy transfer from rain and wind to soil particles. The soil surface is particularly vulnerable to intensive rainfall with incomplete plant or residue cover (Izaurralde and Cerri, 2002). Surface residues protect soil from erosion; consequently, when it is removed, exposure accelerates removal of the C rich surface soil (Peterson et al., 1998; Lal et al., 1999; Kimble et al., 2001).

Black (1973) reported that the nonerodible soil fraction (soil particles and aggregates > 0.84 mm) increased progressively in the 0-5 cm soil depth as residue level increased. Lindstrom (1986) reported that increased levels of corn stover harvest resulted in increased water runoff and soil erosion in the Midwest. Kimble et al. (2001) reported that the range of SOC lost by erosion in the top 25 cm of moderately and severely eroded soils was between 19 and 51 percent for Mollisols and 15 and 65 percent for Alfisols.

Research Needs

It has been discussed that climate, crop rotations, tillage, fertilization, and residue management practices all can be important in determining SOMC. Changes in SOMC are difficult to measure accurately over short periods for a variety of reasons including year-to-year variation in crop growth, and thus inputs of OM. The response to the effects of management changes on SOMC occur slowly over periods of decades (Reicosky et al., 1995). Since changes in SOM content take place slowly, long-term field experiments are the best means to predict soil management impacts on soil C levels. Long-term experiments have shown that there is a direct linear relationship between the quantity of C added to soil and the amount of SOC accumulated, other factors remaining constant (Havlin et al., 1990; Rasmussen and Collins, 1991; Cole et al., 1993; Duiker and Lal, 2000; Follett, 2001).

What quantity of residues can be removed to supply feedstock for biofuel production while conserving SOC of our soil resources? Unfortunately, none of the long-term experiments have been designed to evaluate the effects of residue removal on SOMC (Clapp et al., 2000). The implication of management practices and crop uses, including crop residue removal, should be explored, evaluated and fully understood before bio-based industries are established (Wilhelm et al. 2004). There seems a distinct need to study long-term experiments where treatments contain factors of crop rotation x fertilization x biomass removal. These types of empirical studies would definitely help identify limitations to residue removal while maintaining SOC levels. Another approach is the use of SOM models. SOM models are able to simulate different management scenarios, including biomass removal, effect on SOM change in different climates and soils. SOM models allow us to address the need to simulate data different management scenarios with concurrent residue removal and estimate the effect of residue removal on SOM levels in different agroecoregions using a range of management practices.

REFERENCES

Ajwa, H.A., C.W. Rice, D. Sotomayor. 1998. Carbon and nitrogen mineralization in tallgrass prairie and agricultural soil profiles. Soil Sci. Soc. Am. J. 62:942-951.

Bapst, P.B., K.R. Islam, W.W. Lewis, L.R. Miller, R. Lal, and N.R. Fausey. Soil carbon sequestration under different management practices. [Online]. Available at: http://southcenters.osu.edu/soil/Cseq.htm Accessed in 2003. (verified in 16. February, 2007). Ohio State University.

Barber, S.A. 1979. Corn residue management and soil organic matter. Agron. J. 71:625-627.

Batjes, N.H. and W.G. Sombroek. 1997. Possibilities for carbon sequestration in tropical and subtropical soils. Global Change Biol. 3:161-173.

Beare, M.H., M.L. Cabrera, P.F. Hendrix, and D.C. Coleman. 1994. Aggregate-protected and unprotected OM pools in conventional- and no-tillage soils. Soil Sci. Soc. Am. J. 58:787-795.

Benoit, G.R. and M.J. Lindstrom. 1987. Interpreting tillage-residue management effects. J. Soil Water Conserv. March-April: 87-90

Black, A.L. 1973. Soil property changes associated with crop residue management in a wheat-fallow rotation. Soil Sci. Soc. Am. J. 37:943-946.

Bruce, J.P., M. Frome, E. Haites, H. Janzen, R. Lal, and K. Paustian. 1999. Carbon sequestration in soils. J. Soil Water Cons. 54:382-389.

Carter, M.R. 2002. Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. Agron J. 94:38-47.

Christensen, B.T. 1986. Straw incorporation and soil organic matter in macro-aggregates and particle size separates. J. Soil Sci. 37:125-135.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. 2000. Soil organic carbon and C13 abundance as related to tillage, crop residue and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 55:127-142.

Cole, C.V., K. Paustian, E.T. Elliott, A. K. Metherell, D.S. Ojima, and W.J. Parton. 1993. Analysis of agroecosystems carbon pools. Water Air Soil Pollut. 70:357-371.

Curtin, D., H. Wang, F. Selles, B. G. McConkey, and C. A. Campbell. 2000. Tillage effects on carbon fluxes in continuous wheat and fallow-wheat rotations. Soil Sci. Soc. Am. 64:2080-2086.

Deen W. and P.K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. Soil Tillage Res. 74:143-150.

Farage, P., J. Pretty, and A. Ball. 2003. Biophysical aspects of carbon sequestration in drylands. [Online]. Available at: http://lada.vitualcentre.org/eims/download.asp?pub_id=93403&app=0. (Verified 15 February, 2007).

Follett, R.F. 2001. Soil management concepts and carbon sequestration in cropland soils. Soil Tillage Res. 61:77–92.

Fortuna, A., R. Harwood, K. Kizilkaya, and E.A. Paul. 2003. Optimizing nutrient availability and potential carbon sequestration in an agroecosystem. Soil Biol. Biochem. 35:1005-1013.

Franzluebbers, A.J., F.M. Hons, and D.A. Zuberer. 1994. Long-term changes in soil carbon and nitrogen pools in wheat management systems. Soil Soc. Am. J. 58:1639-1645.

Giampietro, M., S. Ulgiati, and D. Pimentel. 1997. Feasibility of large-scale biofuels production. BioScience. 147:587-600.

Halvorson, A.D., B.J. Wienhold, and A. L. Black. 2002. Tillage, nitrogen and cropping system effects on soil carbon sequestration. Soil Sci. Soc. Am. J. 66:906-912.

Havlin, J.L., D.E. Kissel, L.D. Maddux, M.M Claassen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54:448-452.

Haynes, R.J. and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr. Cycling Agroecosystems. 51:123-137.

Holt, R.F. 1979. Crop residue, soil erosion, and plant nutrient relationships. J. Soil Water Conserv. 34:96-98.

Izaurralde, R.C. and C.C. Cerri. 2002. Organic matter management. p. 910-916. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, Inc. New York, NY.

Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. McGrill, and R.P. Zentner. 1998. Management effects on soil C storage on the Canadian prairies. Soil Tillage Res. 47:181-195.

Janzen, H.H., B.H. Ellert, and D.W. Anderson. Organic matter in the landscape. 2002. p. 905-909. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, Inc. New York, NY.

Jenny, H. 1941. Factor of soil formation. McGraw-Hill, New York, NY.

Kimble, J.M., R. Lal, and M. Mausbach. 2001. p. 472-475. *In* D.E. Stott, R.H. Mohtar, and G.C. Steinhardt (ed.) Sustaining the global farm. Selected paper from the 10th International Soil Conservation Organization Meeting, 24-29 May, 1999. Purdue University and USDA-ARS.

Lal, R., R.F. Follett, J. Kimble, and C.V. Cole. 1999. Managing U.S. cropland to sequester carbon in soil. J. Soil Water Conserv. 54:375-381.

Larson, W.E. 1979. Crop residues: Energy production or erosion control? J. Soil Water Conserv. 34:74-76.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. 1972. Effects of increasing amounts of organic residues on continuous corn: II. organic carbon, nitrogen Phosphorus, and sulfur. Agron. J. 64:204-208.

Larson, W.E. and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. p. 37-51. *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. No. 35. SSSA. Madison, WI.

Liang, B.C. and A.F. MacKenzie. 1992. Changes in soil organic carbon and nitrogen after six years of corn production. Soil Sci. 153: 307-313.

Lindstrom, M.J. 1986. Effects of residue harvesting on water runoff, soil erosion and nutrient loss. Agric. Ecosyst. Envrion. 16:103-112.

Mitchell, C.C. and J.A. Entry. 1998. Soil C, N and crop yields in Alabama's long-term 'Old Rotation' cotton experiment. Soil Tillage Res. 47:331-338.

Nardi, S., F. Morari, A. Berti, M. Tosoni, and L. Giardini. 2004. Soil organic matter properties after 40 years of different use of organic and mineral fertilizers. Eur. J. Agron. 21:357-367.

Norton, J.M. 2000. Nitrogen mineralization immobilization turnover. p. C 148-160. *In* M.E. Summer. (ed.) Handbook of soil science. CRC Press, Boca Raton, FL.

Paul, E.A., E.T. Elliott, K. Paustian, and C.V. Cole. 1997. Soil organic matter in temperate agroecosystems. Long-term experiments in North-America. CRC Press. Boca Baton, FL.

Paustian, K., W.J. Parton, and J. Persson. 1992. Modeling soil organic matter in organic-amended and nitrogen-fertilized long-term plots. Soil Sci. Soc. Am. J. 56:476-488.

Paustian, K., J. Six, E.T. Elliott, and H.W. Hunt. 2000. Management options for reducing CO_2 emissions from agricultural soils. Biogeochem. 48:147–163.

Perlack, R.D., L.L Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass and feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory. Oak Ridge, TN. U.S. Department of Energy. [Online] Available at http://www.osti.gov/bridge (verified, Feb. 10. 2007).

Peterson, G.A., A.D. Halvorson, J.L. Havlin, O.R. Jones, D.J. Lyon, and D.L. Tanaka. 1998. Reduced tillage and increasing cropping intensity in the Great Plains conserves soil carbon. Soil Tillage Res. 47:207-218.

Post, W.M. 2002. Organic matter global distribution in world ecosystems. p. 899-904. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, Inc. New York, NY.

Potter, K.N., H.A. Torbert, O.R. Jones, J.E. Matocha, J.E. Morrison, and P.W. Unger Jr. 1998. Distribution and amount of soil organic carbon in long-term management systems in Texas. Soil Tillage Res. 47:309-321.

Powlson, D.S. 1996. Why evaluate soil organic matter models? p. 3-12. *In* D.S. Powlson, P. Smith, and J.U. Smith (ed.) Evaluation of soil organic matter models. Using existing long-term datasets. Springler-Verlag Berlin, Heidelberg.

Rasmussen, P.E., R.R. Allmaras, C.R. Rhode, and N.C. Roager Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44:596-600.

Rasmussen, P.E. and H.P. Collins. 1991. Long-term impacts of tillage, fertilizer and crop residue on soil OM in temperate semi-arid regions. Adv. Agron. 45:93-134.

Rasmussen, P.E. and C.R. Rohde. 1998. Long-term tillage and nitrogen fertilization effects on organic nitrogen and carbon in a semiarid soil. Soil Sci. Soc. Am. J. 52:1114-1117.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas Jr., and P.E. Rasmussen. 1995. Soil OM changes resulting from tillage and biomass production. J. Soil Water Conserv. 50:253-261.

Rice, C.W. Organic matter and nutrient dynamics. 2002. p. 925-928. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, Inc. New York, NY.

Robinson, C.A., R.M. Cruse, and M. Haffarzadeh. 1996. Cropping system and nitrogen effects on Mollisol organic carbon. Soil Sci. Soc. Am. J. 60:264-269.

Russell, T.O., S.W. Melsted, and W.M. Walker. 1984. Changes in organic carbon and nitrogen of Morrow plot soils under different treatments, 1904-1973. Soil Sci. 137:160-171.

Russell, A. E., D.A. Laird, T.B. Parkin, and A.P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern mollisols. Soil Sci. Soc. Am. J. 69:413-422.

Sherrod, L.A., G.A. Peterson, D.G. Westfall, and L.R. Ahuja. Cropping intensity enhances soil organic carbon and nitrogen in a no-till agroecosystems. 2003. Soil Sci. Soc. Am. J. 67:1553-1543.

Six, J. and J.D. Jastrow. 2002. Organic matter turnover. p. 936-942. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, Inc. New York, NY.

Stevenson, F.J. 1965. Origin and distribution of nitrogen in soil. p 1-42. *In* W.V., Bartholomew and F.E. Clark (ed.) Soil nitrogen. ASA. Madison, WI.

Stevenson, F.J. 1986. Cycles of soil: carbon, nitrogen, phosphorus, sulfur, micronutrients. John Wiley and Sons, New York, NY.

Tiessen, H., E. Cuevas, and P. Chacon. 1994. The role of soil organic matter in sustaining soil fertility. Nature. 371:783-785.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: A literature review. Agron J. 96:1-17.

CHAPTER 3. SOIL AND CROP MANAGEMENT AND BIOMASS REMOVAL EFFECTS ON SOIL ORGANIC MATTER CONTENT

A paper to be submitted to *The Soil Science Society of America Journal*

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ABSTRACT

Growing interest in biomass production for bioenergy has prompted the need for studies that evaluate above ground biomass removal effects on soil quality, especially soil organic matter (SOM) in agricultural systems. A multifactor 40-year field experiment was conducted in Kompolt, Hungary on a carbonate-free, slightly acidic chernozem brown forest soil (USDA: Typic Argiudoll) to analyze the effect of different management systems on SOM content (SOMC). The objective of this paper was to identify management practices that sustain SOM with concurrent above ground biomass removal. Data were collected in four sampling years (SY). The crop rotations (CR) were: corn (*Zea mays* L.) monoculture; corn-corn-wheat (*Triticum aestivum* L.)-wheat; and corn-spring barley (*Hordeum vulgare* L.) -green pea (*Pisum arvense* L.)-wheat. A manure application treatment applied at 35.2 Mg ha^{-1} farmyard beef manure to selected plots. The mineral fertilizer treatments included a 236 kg ha^{-1} NPK mix that contained 88 kg N ha^{-1}, 44 kg P_2O_5 ha^{-1}, and 104 kg K_2O ha^{-1}. Six fertilizer and biomass management (FBM) treatments were: biomass removal (BR); NPK + BR; manure + BR; manure + NPK + BR; biomass incorporation (BI); NPK + BI. Three fertilizer and alfalfa (*Medicago sativa* L.) managements (FAM) were: a sequence (4-year period) with continuous fertilizer application (manure: every sequence; NPK every year) followed by a sequence with no soil amendments; continuous fertilizer application; and a

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sequence of continuous fertilizer application followed by a sequence of an alfalfa stand. CR had no significant effect on SOM, FBM x FAM, FBM x SY, and CR x SY were significant interactions. FAM that included a 4-year alfalfa stand produced significantly greater SOM in 5 out of 6 FBM treatments. Continuous manure and manure + NPK resulted in significantly greater SOMC than FAM that included a sequence without soil amendments. SOM indicate that the impact of soil amendments were BR<NPK+BR<BI<manure+BR=NPK+manure+BR with SOMC of 2.75<2.82<2.87<2.92 (w/w) respectively. Manure had the most profound effect because its significance was most consistent across a range of management combinations and years. These results suggest that agricultural management systems that include alfalfa and manure application have the potential to sustain SOMC with concurrent above ground biomass removal in continental climates on Argiudoll with near level topography.

INTRODUCTION

The U.S. government "Vision for Bioenergy and Bio-based Products in the United States" set a goal that 5% of power, 20% of transportation fuels and 25% of chemicals will be produced from biomass by the year 2030 (DOE 2003). This goal is equivalent to 30 % of current national petroleum consumption and will require more than approximately one billion dry tons of biomass feedstock annually. The primary agricultural biomass resources include crop residues from major crops – corn stover and small grain straw, grains, perennial grasses, and perennial woody crops (Perlack et al., 2005).

Soil organic matter content (SOMC) is a soil quality indicator upon which agricultural production is dependent, while agricultural practices influence it (Larson and Pierce, 1994). Studies have shown that SOMC is directly related to the amount of residue applied to the soil (Rasmussen et al., 1980; Robinson et al., 1996). Barber (1979) showed that above ground biomass removal negatively affects SOM levels. Therefore, it is reasonable to assume that SOM will decrease if residues are removed and that large scale of above ground biomass removal can degrade our soil resources. Decrease in SOM however, can be mitigated or partially mitigated with appropriate management such as reduced tillage, improved crop nutrition, organic amendments, cover crops, and perennial vegetation (Janzen et al., 1998; Bruce et al., 1999). Several studies exist that evaluate SOM change as a function of different soil tillage (Mahboubi et al., 1993; Reicosky et al., 1995; Hunt, 1996; Deen and Kataki, 2003), tillage and cropping systems (Rasmussen et al., 1998); crop management (Halvorson et al., 2002; McConkey et al., 2003) with cover crops (Fortuna et al., 2003) and with legumes (Drinkwater et al., 1998); mineral fertilizer application (Halvorson et al., 1999; Russell et al., 2005), manure application (Sommerfeldt et al., 1988; Nardi et al., 2004), green manure application (Sisti et al., 2004) and residue management (Bohm et al., 2002; Rasmussen et al., 1980). Most of these studies investigated several combinations of above factors in different climates and soils such as in semi-arid Pacific Northwest (Rasmussen et al., 1998); in Canadian prairie soils (McConkey et al., 2003); in sandy southeastern Coastal Plain (Hunt et al., 1996); or in the Midwest (Russell et al., 2005).

SOMC at the long-term Morrow Plots in Illinois and at Sanborn Field in Missouri was maintained with the combination of proper management practices (Fenton et al., 1999). Crop rotation along with appropriate fertilization resulted in the highest crop yields and the highest soil nitrogen (N) and soil organic carbon (SOC) levels during 70 years on the Morrow Plots in Illinois (Odell et al., 1984). Changes in SOC were linearly related to the annual C input rates associated with N fertility management, and legume cereal crop sequences maintained SOMC without external N fertilization in southern Wisconsin (Vanotti et al., 1997). Clapp et al. (2000) examined the interaction among corn stover harvest, N fertilization, and SOC dynamics in a 13-years experiment in Minnesota. They reported that SOC in the no-till plots with corn stover harvest remained unchanged, while that with stover returned increased. They also found that the N fertilization effects on SOC were most evident when corn stover was returned to no-till plots.

Long term experiments are the best means to empirically study soil management impacts on SOC content. As described previously, several of these studies exist and have been extensively analyzed. However, such data published from long term research that investigates the interaction of residue harvest with various management practices such as crop rotations and mineral and manure fertilizer application are missing. Therefore the objective of this paper was to identify management practices that sustain SOM with concurrent above ground biomass removal using long term field data with a broad range of fertilizer and crop management practices.

MATERIALS AND METHODS

Field Site

The research was conducted at the Rudolf Fleischmann research station established in 1918 at Kompolt, Hungary. Kompolt is located 47°45' N and 20°15' E, about 110 km NE of Budapest and 25 km NE of Gyöngyös. The elevation of the research station is 125-m above sea level. The region has a continental climate that is moderately warm and is often dry with drought periods. The mean annual precipitation is 549 mm of which 309 mm fall within the growing season. The mean annual air temperature is 10°C. Mountain ranges NW and NE from Kompolt influence the research station's climate. The topography is nearly level and the water table depth is 11-12 m (Tóth et al, 1998). The soil is a carbonate-free, slightly acidic chernozem brown forest soil (USDA: Typic Argiudoll, Csatho et al., 2005). In 1961 the average SOMC was 2.87 % and the pH was 5.5 in the field plot area. The soil NH_4^+ content was 6.4 ppm, NO_3^-+ NO_2 was 5.4 ppm, P_2O_5 was 28.0 ppm, and the K_2O content was 216 ppm in the 0-25-cm depth.

Sampling Procedure

A multifactor 40-year long experiment was established in 1962 with three crop rotations (CR), 12 fertilizer and biomass management treatments (FBM) (Tab 2), and three fertilizer and alfalfa management treatments (FAM) in four replications. Based on the objectives of this paper the authors were interested in six of the 12 FBM treatments and only those will be introduced and discussed in this paper. In this experiment a four-year period was considered a sequence. During the experiment conventional soil tillage practices were used and above ground biomass was removed by hand. In this paper the term biomass refers to above ground biomass. The manure was farmyard beef with wheat straw composition. Manure was applied N based at a rate of 35.2 Mg ha^{-1} wet weight and 8.5 Mg ha^{-1} dry weight with 176 kg N ha^{-1} (Kismányoky, 1993). The mineral fertilizer applied was 236 kg ha^{-1} NPK mix that contained 88 kg N ha^{-1}, 44 kg P_2O_5 ha^{-1}, and 104 kg K_2O ha^{-1}. Based on the local practices, green pea vine residue and spring barley straw was always removed from the plots. Manure was applied in the 1st year within a sequence (once every four year).

The three different CR were: 1) corn (*Zea mays* L.) monoculture; 2) corn-corn-wheat (*Triticum aestivum* L.)-wheat; and 3) corn-spring barley (*Hordeum vulgare* L.) -green pea (*Pisum arvense* L.)-wheat. The different FBM treatments were used to split the main plots and the different FAM treatments were used as the second spilt. The six different FBM treatments used in the analysis are described in Table 3-1. The 3 FAM treatments within the different rotations were: a) a sequence with continuous fertilizer application followed by a sequence with no soil amendments; b) continuous fertilizer application; and c) a sequence of continuous fertilizer application followed by a sequence of alfalfa (*Medicago sativa* L.) stand. Table 3-2 describes the different FAM treatments within each crop rotation for the first 3 sequences (four-year period) from 1962 to 1973.

Alfalfa stands received N fertilizer every year but P and K was applied once, in the year of establishment. Green pea received 73% of the N fertilizer compare to the other crops. Plots were 54 m^2 (6m x 9m). Soil samples for SOM analysis were collected every 4th year of the experiment (0- 32 cm). SOM analyses were performed using Turin's methodology (Belchikova, 1965). For this study 4 sampling years (SY) 1969, 1977, 1981, and 2001 were used. SOMC is expressed as percent on a gravimetric basis.

Table 3-1. Fertilizer and Biomass Management Treatments

Soil Amendment		
NPK (Kg^{-1} ha)	Manure (Mg^{-1} ha)	Biomass
None	None	Removed
236	None	Removed
None	35.2	Removed
236	35.2	Removed
None	None	Incorporated
236	none	Incorporated

Statistical Analysis

The statistical design was a split-plot in time. The effects of CR were tested on the whole plots, the effects of FBM were tested on the individual plots, and the effects of FAM were tested on the split of the individual plots. Blocks were random; CR, FBM, FAM, and SY were fixed effects. Interactions with random block effects were used as error terms. Statistical analysis was performed using SAS version 9.1 (SAS Institute Inc., Cary, NC). Means were obtained with the least square mean (LSM) statement and significant interactions that occurred were evaluated using the LSM procedure. Least significant difference (LSD) statements allowed mean comparisons for FBM to examine the impact of mineral fertilization, manure application and biomass incorporation on SOMC. Differences in treatments were considered significant at a probability level of 0.05.

Table 3-2. Crop Rotations and Fertilizer and Alfalfa Management Treatments (1962-1973)

Year	Sequence	Crop Rotation								
		Monoculture			Two Crop Rotation			Four Crop Rotation		
		Fertilizer and Alfalfa Management								
		a†	b‡	c§	a	b	c	a	b	c
1962	I	corn	corn	corn	corn	corn	corn	corn	corn	corn
1963	I	corn	corn	corn	corn	corn	corn	barley	barley	barley
1964	I	corn	corn	corn	wheat	wheat	wheat	pea	pea	pea
1965	I	corn	corn	corn	wheat	wheat	wheat	wheat	wheat	wheat
1966	II	corn	corn	alfalfa	corn	corn	alfalfa	corn	corn	alfalfa
1967	II	corn	corn	alfalfa	corn	corn	alfalfa	barley	barley	alfalfa
1968	II	corn	corn	alfalfa	wheat	wheat	alfalfa	pea	pea	alfalfa
1969	II	corn	corn	alfalfa	wheat	wheat	alfalfa	wheat	wheat	alfalfa
1970	III	corn	corn	corn	corn	corn	corn	corn	corn	corn
1971	III	corn	corn	corn	corn	corn	corn	barley	barley	barley
1972	III	corn	corn	corn	wheat	wheat	wheat	pea	pea	pea
1973	III	corn	corn	corn	wheat	wheat	wheat	wheat	wheat	wheat

† 4-year fertilization 4-year break
‡ Yearly fertilizer application
§ 4-year fertilization 4-year alfalfa with fertilization

RESULTS AND DISCUSSION

Table 3-3 shows the analysis of variance (ANOVA) for gravimetric SOMC.

Table 3-3. ANOVA Table

Source	DF	Type III SS	Mean Square	F value	Pr > F
Block	3	0.42	0.14	5.69	0.0008*
CR†	2	3.25	1.63	2.78	0.1397
FBM‡	5	2.94	0.59	6.46	0.0001*
CR x FBM	10	0.89	0.09	0.98	0.4755
FAM§	2	3.86	1.93	96.71	<.0001*
CR x FAM	4	0.09	0.02	1.19	0.3208
FBM x FAM	10	0.56	0.06	2.83	0.0037*
CR x FBM x FAM	20	0.29	0.01	0.72	0.7987
SY¶	3	0.57	0.19	7.61	<.0001*
CR x SY	6	1.00	0.17	6.73	<.0001*
FBM x SY	15	1.07	0.07	2.88	0.0002*
CR x FBM x SY	30	0.80	0.03	1.07	0.3653
FAM x SY	6	0.20	0.03	1.34	0.2395
CR x FAM x SY	12	0.16	0.01	0.53	0.8927
FBM x FAM x SY	30	0.34	0.01	0.46	0.9942
CR x FAM x FBM x SY	60	0.51	0.01	0.34	1.0000

* Significant at probability level, P<0.05.
† Crop rotations
‡ Fertilizer and biomass management treatment
§ Fertilizer and alfalfa management treatment
¶ Sampling year

Fertilizer and Alfalfa Management

Differences between FAM treatments depended on FBM treatments. Table 3-4 shows SOMC in the different FAM and FBM treatments. FAM that included a 4-year alfalfa stand produced significantly greater SOMC (2.91-3.02) in 5 out of 6 FBM treatments. Similar results were observed in Iowa (Robinson et al., 1996; Russell et al., 2005) and in Hungary (Tóth and Kismányoky, 2001; Krisztián and Holló, 1995) where cropping systems with alfalfa proved to be viable management options for increasing SOC content. The treatment with biomass incorporation and NPK application showed no differences in SOMC between annual NPK application (2.88) and alfalfa stand (2.94). It seems that the continuous biomass incorporation provided extra SOMC of comparable value as alfalfa in increasing SOMC.

Table 3-4. Soil Organic Matter Content in Different Fertilizer and Alfalfa Management and Fertilizer and Biomass Management Treatments

Fertilizer and Biomass Management			Fertilizer and Alfalfa Management			
NPK	Manure	Biomass	a‡	b§	c¶	Mean
Kg ha^{-1}	Mg ha^{-1}		SOM %			
236	0	removed	2.76d†	2.79d	2.91e	2.82
0	35.2	removed	2.83d	2.90e	3.00f	2.91
236	35.2	removed	2.81d	2.94e	3.02f	2.92
0	0	incorporated	2.82d	2.84d	2.95e	2.87
236	0	incorporated	2.82d	2.88de	2.94e	2.88
Mean			2.79	2.84	2.95	2.86

† Within rows, values followed by the same letter are not significantly different using LS Mean test. $P<0.05$

‡. Continuous fertilizer application

§ A sequence (4 year period) with continuous fertilizer application followed by a sequence with no soil amendments

¶ A sequence (4 year period) of continuous fertilizer application followed by a sequence of alfalfa stand

Treatments with biomass removal and manure application showed significantly greater SOMC (2.90; 2.94) than treatments with a sequence of no soil amendments (2.83; 2.81). In summary, treatments with alfalfa stands and continuous manure application had the most profound positive effect on SOMC. Tóth and Kismányoky (1997) found similar results in Hungary in a similar long term experiment where they investigated the effects of fertilization and crop rotation on SOMC.

Fertilizer and Biomass Management

Differences between years depended on FBM. Table 3-5 shows SOMC in different FBM treatments and sampling years. The control treatment showed the lowest SOMC in 1977, 1981, and in 2001 (2.67-2.81). BI + NPK addition in 1969 (2.92), manure + BR and NPK + manure + BR in 1977 (2.91), manure + BR in 1981 (2.90), and NPK + manure + BR in 2001 (3.04) demonstrated the greatest SOMC. Application of manure + BR and manure + NPK + BR showed the greatest SOMC among the treatments (2.86-3.04) in 1977, 1981, and in 2001. However, SOMC was not statistically different across years in treatments with manure + BR. This suggests that treatments with manure + BR were able to maintain relatively high SOMC (compared with the other treatments) but were not able to increase these values over years (2.89-2.94). On the other hand in treatments with manure + NPK + BR, SOMC remained relatively high and tended to increase over the second half of the experiment (2.88-3.04). Similarly to treatments with manure + BR, treatments with NPK + BR were unable to increase SOMC over the years (2.80-2.85). When FBM treatments were averaged over the effects of SY and FAM, it showed that the control treatment produced the lowest (2.75) and NPK + manure + BR the greatest (2.92) SOMC.

Table 3-5. Soil Organic Matter Content in Different Fertilizer and Biomass Management Treatments and Sampling Year

Fertilizer & Biomass Management Treatments			Sampling Year				
NPK	Manure	Biomass	1969	1977	1981	2001	Mean
Kg ha^{-1}	Mg ha^{-1}		-------------------------------- SOM % ----------------------------				
0	0	removed	2.81†d	2.82d	2.67ef	2.71f	2.75
236	0	removed	2.82d	2.81d	2.80d	2.85d	2.82
0	35.2	removed	2.89d	2.91d	2.90d	2.94d	2.91
236	35.2	removed	2.88d	2.91d	2.86d	3.04e	2.92
0	0	incorporated	2.92d	2.88de	2.83ef	2.85df	2.87
236	0	incorporated	2.87d	2.88d	2.84de	2.93df	2.88
Average			2.86	2.87	2.82	2.89	2.86

† Within rows, values followed by the same letter are not significantly different using LS Mean test. $P<0.05$

Crop Rotation

Differences between years depended on the CR. Table 3-6 shows SOMC for different crop rotations across years. SOMC were the lowest when corn monoculture was used (2.77) and highest when either biculture or 4-crop rotations (2.90) were used. Similar results were observed in the Morrow plot in Illinois where crop rotation retarded the decline in SOC (Odell et al., 1984), in Nebraska where after 8 years, rotation significantly increased SOC across all cropping systems (Varvel, 2006) and in Hungary where crop rotation increased SOMC compared to monoculture corn (Tóth and Kismányoky, 2001). Robinson et al. (1996) found that monocultures of corn were the most detrimental to SOC in different soil management systems in Iowa.

Table 3-6. Soil Organic Matter Content in Different Crop Rotations and Sampling Years

	Sampling Year				
Crop Rotation	1969	1977	1981	2001	Mean
	---------- SOM % ----------				
Monoculture	2.78†^{d}	2.84^{e}	2.66^{f}	2.81^{de}	2.77
2-crop rotation	2.91^{d}	2.90^{d}	2.89^{d}	2.91^{d}	2.90
4-crop rotation	2.89^{d}	2.88^{de}	2.91^{d}	2.94^{df}	2.90

† Within rows, values followed by the same letter are not significantly different using LS Mean test. P<0.05

The Impact of Soil Amendments on Soil Organic Matter Content

The impact of mineral fertilization on SOMC was established by comparing mean values of NPK + BR with the control (no fertilizer application + BR) treatment. SOMC were significantly greater with mineral fertilizer application (2.82) than without soil amendments (2.75). This trend held in sampling years 1981 and 2001. Similar results were found in Iowa (Robinson et al., 1996) and in Hungary (Krisztián and Holló, 1995) where NPK treatments increased SOC compared with no fertilizer application. The impact of manure application on SOMC was established by comparing mean values of manure + BR with the control (no soil amendment + BR) treatment. SOMC were significantly greater with manure application (2.91) than without soil amendments (2.75) and this trend was consistent across the years. There were similar results from the Broadbalk experiment at Rothamsted in Great Britain where additions of farmyard beef manure increased total C content compared to the control treatment (Blair et al., 2006).

The impact of biomass incorporation on SOMC was determined by comparing mean values of no soil fertilizer application + BI with the control (no fertilizer application +BR) treatment. SOMC were significantly greater with biomass incorporation (2.87) than with biomass removal (2.75). This trend was true for SY 1969, 1981, and 2001. There were similar results found in Indiana (Barber, 1979) and in Minnesota (Allmaras et al., 2004) where corn stalk residue removal decreased SOMC when compared with residue returned to the soil. Effects of both mineral and organic amendment application on SOMC were established by comparing mean values of NPK + manure + BR with NPK + BI. SOMC were significantly greater where mineral fertilizer and manure (2.92) were used than where mineral fertilizer and biomass incorporation (2.88) occurred.

The impact of soil amendments including biomass incorporation were established by comparing mean values of NPK + BR with manure + BR and no soil fertilizer application + BI with NPK + BR. SOMC for manure + BR were significantly greater (2.91) than for NPK + BR (2.82) consistently across years. On the other hand SOMC for no soil fertilizer application + BI (2.87) were significantly greater than for NPK + BR (2.82). These results show that the value of biomass as soil amendment was greater than that of mineral fertilizer but less than that of manure amendment in increasing SOMC. There were no statistical differences between NPK + BI (2.88) and BI + no fertilization (2.87); between NPK + manure + BR (2.92) and manure + BR (2.91); and manure + BR (2.91) and NPK + BI (2.88). Results indicate that the impact of different management treatments on SOMC was: BR+no fertilization<NPK+BR<BI+no fertilization<manure+BR=NPK+manure+BR with SOM contents of 2.75<2.82<2.87<2.92 respectively.

The Impact of Soil Organic Matter on Bulk Density

It is well recognized that organic matter content affects soil physical properties. An increase in soil C content increases aggregation, decreases bulk density, increases water holding capacity, and hydraulic conductivity (Williams and Cooke, 1961; Tiarks et al., 1974; Gupta et al., 1977). In some soils, organic matter has a dominating effect on soil bulk density (Curtis and Post 1964; Saini, 1966). Although studies similar to this one on SOMC determined soil C differences among treatments based on concentrations (Barber, 1979; Odell et al., 1984; Reicosky et al., 1995) unless this effect is considered, quantitative SOM data based on a percentage of total soil weight can be misleading (Adams, 1973). If the study goal is to estimate treatment effects on mass of SOM, drawing conclusions based on values of concentration are subject to error if bulk density varies among treatments.

On the other hand, Adams (1973) suggested that the SOMC could be used to predict soil bulk density. We used Adams` equation to estimate bulk density differences among treatments:

$$BD = \frac{100}{\left(\frac{\%OM}{OMBD}\right) + \left(\frac{100 - \%OM}{MBD}\right)}$$ **Equation 1.**

where BD is bulk density (g cm^{-3}), OM is organic matter (%), OMBD is bulk density of organic matter (g cm^{-3}), and MDB is bulk density of mineral matter (g cm^{-3}). OMDB was assumed to be 0.244 g cm^{-3} (Mann, 1986; Post and Kwon, 2000). MBD is usually assumed to be 2.65 g cm^{-3}, which was used in Adams` calculation. We assumed that soil BD was 1.3 g cm^{-3} in the experiment. We further assumed that the percent OM was 2.86 %, the average OM content across treatments at the beginning of the experiment. BD then was calculated for treatments with the lowest and greatest percent SOM.

The results show that a difference in BD between those treatments would be 0.027 g cm^{-3}. The real influence of SOM, however, could be masked by the effect of soil structure on bulk density (Adams, 1973). In that conventional tillage practices were used in all treatments - for this region that means multiple passes starting with a fall moldboard plowing operation - the differences in structure due to the relatively small differences in SOMC seems quite unlikely, although it was not measured in this experiment. Overall, we concluded that difference in BD that may have existed and could have influenced the conclusions, would have been due only to changes in SOMC, and the greatest influence would be about 0.026 g cm^{-3}. According to the literature, the spatial variability in BD measurements in a common treatment is about 10 percent of the mean bulk density measure (Aljubury and Envans, 1961;

Warrick and Nielsen, 1980) - a value which is much greater that our estimate of SOMC bulk density impact between treatments. Therefore, we concluded that the results of this study using SOMC rather than a calculated mass of SOM between treatments truly reflects treatment impacts on SOM changes.

CONCLUSIONS

The result of this study shows that the greatest SOM gains were observed when crop rotations rather than a monoculture of corn were used, especially where alfalfa was included in the rotation. Monoculture systems with no soil amendments were the most detrimental to SOMC. SOMC data indicate that the ordered impact of management treatments was: BR<NPK+BR<BI<manure+BR=NPK+manure+BR with SOM contents of 2.75<2.82<2.87<2.92 (w/w) respectively. These results show that the value of biomass as soil amendment was greater than that of mineral fertilizer but less than that of manure amendment in increasing SOMC. Manure had the most profound effect because its significance was most consistent across a range of management combinations and years.

This experiment was able to identify management practices that sustain SOM with concurrent above ground biomass removal. The impacts of biomass removal on SOMC could be mitigated with a proper amount and combination of manure and mineral fertilizer application. Furthermore, these results imply that agricultural management systems that include alfalfa and manure application have the potential to sustain SOMC with concurrent above ground biomass removal in continental climates on chernozem brown forest soils with near level topography.

REFERENCES

Adams, W.A. 1973. The effect of organic matter on the bulk and true densities of some uncultivated podzolic soils. J. Soil Sci. 24:10-17.

Aljibury, F.K. and D.D. Evans. 1961. Soil sampling for moisture retention and bulk density measurements. Soil Sci. Soc. Am. Proc. 25:180-183.

Allmaras, R.R., D.R. Linden, and C.E. Clapp. 2004. Corn-residue transformations into root and soil carbon as related to nitrogen, tillage, and stover management. Soil Sci. Soc. Am. J. 68:1366-1375.

Barber, S.A. 1979. Corn residue management and soil organic matter. Agron. J. 71:625-627.

Bel`chikova, N.P. 1965. Determination of the humus of soils by I.V. Tyurin's method. p 75-101. *In* Agrochemical Methods in Study of Soils. Academy of Sciences of the USSR. V.V. Dokuchaev Institute of Soil Science. INSDOC, New Delhi.

Blair, N., R.D. Faulkner, A.R. Till, and P. Poulten. 2006. Long-term management impacts on soil C, N and physical fertility. I. Broadbalk experiment. Soil Till Res. 91:30-38.

Bohm, S.U., C.W. Rice, and A.J. Schlegel. 2002. Soil carbon turnover in residue managed wheat and grain sorghum p. 255-262. *In* J.M. Kimble, R. Lal, and R.F. Follett (ed.) Agriculture practices and policies for carbon sequestration in soil. CRC Press LLC. Boca Bacon, FL.

Bruce, J.P., M. Frome, E. Haites, H. Janzen, R. Lal, and K. Paustian. 1999. Carbon sequestration in soils. J. Soil Water Conserv. p. 54:382-389.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. 2000. Soil organic carbon and C13 abundance as related to tillage, crop residue and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 55:127-142.

Csatho, P., Zs. Magyar, K. Debreczeni, and K. Sardi. 2005. Correlation between soil P and wheat shoot P contents in a network of Hungarian long-term field trials. Commun. Soil sci. plant anal. 36:275-293.

Curtis, R.O. and B.W. Post. 1964. Estimating bulk density from organic matter content in some Vermont forest soils. Soil Sci. Soc. Amer. Proc. 28:285-286.

Deen W. and P.K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. Soil Tillage Res. 74:143-150.

DOE (U.S. Department of Energy). 2003. Roadmap for agriculture biomass feedstock supply in the Untied States. DOE/NE-ID-11129. U.S. Department of Energy, November.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature (London). 396:262-265

Fenton, T.E., J.R. Brown, and M.J. Mausbach. 1999. Effects of long-term cropping and organic matter content of soils: implications for soil quality. p. 95-124. *In* Lal R (ed.) Soil quality and erosion. CRC Press, Boca Raton, FL.

Fortuna, A., R. Harwood, K. Kizilkaya, and E.A. Paul. 2003. Optimizing nutrient availability and potential carbon sequestration in an agroecosystem. Soil Biol. Biochem. 35:1005-1013.

Gupta, S.C., R.H. Dowdy, and W.E. Larson. 1977. Hydraulic and thermal properties of a sandy soil as influenced by incorporation of sewage sludge. Soil Sci. Soc. Am. Proc. 41:601-605.

Halvorson, A.D., C.A. Reule, and R.F. Follett. 1999. Nitrogen fertilization effects on soil carbon and nitrogen in a dryland cropping system. Soil Sci. Soc. Am. J. 63:912-917.

Halvorson, A.D., B.J. Wienhold, and A. L. Black. 2002. Tillage, nitrogen and cropping system effects on soil carbon sequestration. Soil Sci. So. Am. J. 66:906-912.

Hunt, P.G., D.L. Karlen, T.A. Matheny, and V.L. Quisenberry. 1996. Changes in carbon content of a Norfolk loamy sand after 14 years of conservation or conventional tillage. J. Soil Water Conserv. 51(3):255-258.

Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. McGrill, and R.P. Zentner. 1998. Management effects on soil C storage on the Canadian prairies. Soil Tillage Res. 47:181-195.

Kismányoky, T. 1993. Fertilization with Manure. p. 195-236. *In* L. Nyiri. (ed.) Soil Management. 2nd ed. (In Hungarian.) Mezőgazda Kiadó, Budapest.

Krisztián J. and S. Holló. 1995. Changes in humus content in a three-decennial long-term experiment on chernozem brown forest soil. (In Hungarian, with English abstract.) Növénytermelés. Tom 44:411-418.

Larson, W.E. and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. p. 37-51. *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (ed.) Defining soil Quality for a Sustainable Environment. SSSA Spec. Publ. No. 35. SSSA. Madison, WI.

Mahboubi, A.A., R. Lal, and N.R. Faussey. 1993. Twenty-eight years of tillage effects on two soils in Ohio. Soil Sci. Soc. Am. J. 57:506-512.

Mann, L.K. 1986. Changes in soil carbon storage after cultivation. Soil Sci. 142:279-288.

McConkey, B.G., B.C. Liang, C.A. Campbell, D. Curtin, A. Moulin, S.A. Brandt, and G.P. Lafond. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. Soil Tillage Res. 74:81-90.

Nardi, S., F. Morari, A. Berti, M. Tosoni, and L. Giardini. 2004. Soil organic matter properties after 40 years of different use of organic and mineral fertilizers. Eur. J. Agron. 21:357-367.

Odell, R.T., S.W. Melsted, and W.M. Walker. 1984. Changes in organic carbon and nitrogen of Morrow plow soils under different treatments, 1904–1973. Soil Sci. 137:160–171.

Post, W.M. and K.C. Kwon. 2000. Soil carbon sequestration and land-use change: processes and potential. Global Change Biol. 6:317-127

Rasmussen, P.E., S.L. Albrecht, and R.W. Smiley. 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil Tillage Res. 47:197-205.

Rasmussen, P.E., R.R. Allmaras, C.R. Rhode, and N.C. Roager Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44:596-600.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil Water Conserv. 50:253-261.

Robinson, C.A., R.M. Cruse, and M. Haffarzadeh. 1996. Cropping system and nitrogen effects on Mollisol organic carbon. Soil Sci. Soc. Am. J. 60:264-269.

Russell, A. E., D.A. Laird, T.B. Parkin, and A.P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern mollisols. Soil Sci. Soc. Am. J. 69:413-422.

Saini, G.R. 1966. Organic matter as a measure of bulk density of soil. Nature, Lond. 210:1295-1296.

SAS Institute. 2003. SAS user's guide: Statistics v. 9.1. SAS Inst., Cary, NC.

Sisti, C.P.J., H.P. dos Santos, R Kohhann, B.J.R. Alves, S. Urquiage, and R.M. Boddey. 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil Tillage Res. 76:39-58.

Sommerfeldt, T.E., C. Chang, and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Sci. Soc. Am. J. 52:1688-1672.

Tiarks, A.E., A.P. Mazurak, and L. Chesnin. 1974. Physical and chemical properties of soil associated with heavy applications of manure from cattle feedlots. Soil Sci. Soc. Am. Proc. 38:826-830.

Tóth, S., I. Bócsa, A. Fehér, S. Holló, T. Hörömpöli, I. Murányi, E. Vízer. 1998. Fleischmann Rudolf Agricultural Research Institute, Kompolt. 1818-1998. (In Hungarian). REGIOCON Kft. Kompolt.

Tóth, Z. and T. Kismányoky. 1997. Long-term effect of fertilization and crop rotation on wheat yields and on the aggregate size distribution and organic matter content on soil. Agrokémia és Talajtan. 46:107-112.

Tóth, Z. and T. Kismányoky. 2001. Fertilization impact on soil organic matter content and soil structure in different crop rotations and corn monoculture. (In Hungarian.) Agrokémia és Talajtan. Tom. 50:207-223.

Vanotti, B.M., L.G. Bundy, and A.E. Peterson. 1997. Nitrogen fertilizer and legume-cereal rotation effects on soil productivity and organic matter dynamics in Wisconsin. p. 105-128. *In* E.A Paul, K. Paustian, E.T. Elliott, C.V. Cole. Soil organic matter in temperate agroecosystems. Long-term experiemtns in North America. CRC Press, Boca Raton.

Varvel, G.E. 2006. Soil organic carbon changes in diversified rotations of the Western Corn Belt. Soil Sci. Soc. Am. J. 70:426-433.

Warrick, A.W. and D.R. Nielsen. 1980. Spatial variability of soil physical properties in the field. p. 319-344. *In* D. Hillel (ed.) Applications of soil physics. Academic Press, New York, NY.

Williams, R.J.B. and G.W. Cooke. 1961. Some effects of farmyard manure and of grass residues on soil structure. Soil Sci. 92:30-39.

CHAPTER 4. ESTIMATING SOIL MANAGEMENT IMPACTS ON SOIL ORGANIC CARBON CONTENT CHANGE

A paper to be submitted to *The Soil Science Society of America Journal*

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ABSTRACT

Interest is growing in evaluating and developing agricultural management practices that are both effective at maintaining soil organic matter content (SOMC) and providing above ground residues for the lignocellulosic biofuel industry. This study was established to compare two SOM models, EPIC and SCI, against field data with different management scenarios when biomass was removed vs. incorporated. The models were tested using 40 years of field data collected at a Hungarian research site with a diverse set of management scenarios. Crop rotations in this study were continuous corn (*Zea mays* L.), corn-corn-wheat (*Triticum aestivum* L.)-wheat, and corn-spring barley (*Hordeum vulgare* L.) -green pea (*Pisum arvense* L.)-wheat. Fertilizer and Biomass Managements (FBM) were: 1) no soil amendment + biomass removal (BR); 2) NPK + BR; 3) Manure + BR; 4) Manure + NPK + BR; 5) biomass incorporation (Bi) and 6) NPK + BI. Both EPIC and SCI successfully identified the least and most effective treatments for increasing soil organic carbon (SOC) content over time. Mineral fertilization application increased SOC stocks in both biomass removal and incorporation treatments. In contrast, EPIC predicted SOC decrease in treatments with mineral fertilizer applications. Both EPIC and SCI successfully predicted that manure additions would be more effective at maintaining SOC than would mineral fertilizer additions. In general, EPIC predicted the correct direction of SOC change in four out of six FBM treatments. In contrast SCI predicted only positive SOC change in all treatments even where observed values showed detrimental treatment effects. Overall, EPIC

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was found to better estimate SOC changes for agricultural systems with different crop rotations and fertilizer management treatments when biomass is either removed or incorporated.

INTRODUCTION

Interest is growing in evaluating and developing agricultural management practices that are both effective at maintaining soil organic matter content (SOMC) and providing above ground residues for the lignocellulosic biofuel industry. Maintaining SOMC is important since it sustains soil quality upon which agricultural production is dependent (Larson and Pierce, 1994). Organic matter (OM) additions and losses in soils depend on climatic conditions, vegetation, and land use (Batjes and Sombroek, 1997; Farage et al., 2003). Previous research of different field studies showed that agricultural management practices can either increase or decrease OM inputs to soil and/or increase or decrease oxidation and decomposition of SOM (Follett, 2001; Paustian et al., 2000). While field studies provide essential data addressing this SOM issue, they are time-consuming and costly to perform across all possible climatic conditions, agricultural management options, cropping system combinations, and landscapes.

Agroecosystem models with a SOM component, however, are important tools that allow us to evaluate the effect of different agricultural management scenarios on SOM levels for different combinations of soils, landscapes, climates, and crops. While models are very valuable in making these evaluations and comparisons, model testing and evaluation is a critical verification step establishing model credibility and applicability for selected conditions. Two of these agroecosystem models with a SOM component are the Soil Conditioning Index (SCI) model and The Environment Policy Impact Calculator (EPIC).

EPIC has been used to evaluate the impacts of climate change on soil carbon sequestration (Thomson et al., 2006); effects of tillage on erosion and soil carbon content (Lee et al., 1993); nitrogen fertilization on soil C sequestration and soil carbon dynamics (He et al., 2006); and nutrient losses due to tillage, fertilization and manure amendments (Phillips et al., 1993; King et al., 1996; Edwards et al., 1994). Izaurralde et al., (2006) conducted tests of the C and N components in EPIC using experimental data of different duration. They reported that EPIC has capably explained the variability in crop production, C inputs and soil organic carbon (SOC) and N cycling over a wide range of soil, cropping and climatic conditions for periods from 6-61 years. EPIC has been used to evaluate a wide variety of management combinations on SOC, however, never with concurrent biomass removal contrasted with incorporation.

The Soil Conditioning Index (SCI) model has been used to evaluate SOMC changes against long-term experimental data in several regions of the USA (Hubbs el al., 2002), and in various cropping systems and managed and native grasslands on the southern High Plains in Texas (Zobeck et al., 2006). Hubbs et al. (2002) reported that SCI showed potential to predict trends in SOMC for conservation planning and carbon (C) sequestration. Overall testing and evaluating of SCI, however, has been limited and there is a need to test SCI under different field conditions over a wide range of management scenarios integrated with biomass removal or incorporation.

Recently Abrahamson-Beese et al. (2006) determined correlation between SOC change predicted by EPIC vs. SCI for four management systems in the southeastern USA. They reported that predictions of SOC sequestration with SCI were comparable to those with EPIC and predictions of SCI gives reasonable estimates of potential SOC changes in the southeastern USA. However model evaluations based on actual field conditions with a variety of management combinations with above ground biomass removal and incorporation is still in need, and is what this study proposes to investigate. The objective of this study was to evaluate EPIC and SCI predicted soil SOC changes against data from a long term field study with a wide range of management practices including comparisons of above ground biomass removal vs. incorporation.

MATERIALS AND METHODS

Field Site Description

The experimental site was established in 1962 at the Rudolf Fleischmann research station at Kompolt, Hungary (47°45' N and 20°15' E). The research station is 125-m above sea level. The region has a continental climate that is moderately warm and is often dry with drought periods. The mean annual precipitation is 549 mm of which 309 mm fall within the vegetation period. The mean annual air temperature is 10°C. The topography is nearly level and the water table depth is 11-12 m (Tóth et al, 1998). The soil is a carbonate-free, slightly acidic chernozem brown forest soil (USDA: Typic Argiudoll; Csatho et al., 2002).

A multifactor 40-year long experiment was designed to evaluate the impact of different crop rotations, fertilizer rates, fertilizer managements, and residue managements on different soil quality indicators, including SOMC over a 40-year time period. The experiment was established with 3 crop rotations (CR), 12 fertilizer and biomass management treatments (FBM), and with 3 fertilizer and alfalfa management treatments (FAM) in 4 replications. The effects of CRs were investigated on the main plot, the effect of the FBM treatments were investigated in the splits of the main plots, and the FAM treatments were investigated in split splits. Data against which the simulations will be compared is reported in Chapter 3 of this dissertation. For modeling purposes the authors used only 6 FBM treatments of the original experiment. In this paper the term biomass refers to above ground biomass. During the experiment conventional soil tillage practices were used.

Crop rotations were: 1) corn (*Zea mays* L.) monoculture; 2) corn-corn-wheat (*Triticum aestivum* L.)-wheat; and 3) corn-spring barley (*Hordeum vulgare* L.) -green pea (*Pisum arvense* L.)-wheat. The 6 FBM were: 1) control or no fertilizer addition + biomass removal (BR); 2) 236 kg ha^{-1} mineral fertilizer (NPK) + BR; 3) 35.2 Mg ha^{-1} manure + BR; 4) 35.2 Mg ha^{-1} manure + 236 kg ha^{-1} NPK + BR; 5) biomass incorporation (Bi) + no fertilizer amendment; 6) 236 kg ha^{-1} NPK + BI. A 4-year period was considered as a sequence in this experiment. The 3 FAM treatments were: a) a sequence with annual fertilizer application followed by a sequence with no soil amendments; b) annual fertilizer application; and c) a sequence of annual fertilizer application followed by a sequence of alfalfa (*Medicago sativa* L.) stand. The manure was farmyard beef with wheat straw composition. Manure was applied nitrogen (N) based in every four years at a rate of 176 kg N ha^{-1}. The mineral fertilizer was an NPK mix that contained 88 kg N ha^{-1}, 44 kg P_2O_5 ha^{-1}, and 104 kg K_2O ha^{-1}. Alfalfa stands received N fertilizer every year but P and K was applied once, in the year of establishment. Green pea received 73% of the N fertilizer compare to the other crops. Based on the local practices, green pea vine residue and spring wheat straw was always removed from the plots.

Model Description

The SCI model was designed to aid USDA-Natural Resources Conservation Service and Soil Conservation District staffs in planning and designing cropping systems and residue management practices to resolve low SOM, poor soil tilth, and other soil quality-related problems during conservation planning in different geographic locations (Zobeck et al., 2006; Hubbs et al., 2002). The SCI is a Windows based model that can predict relative changes of SOM in different agricultural systems. The SCI model has three main components: 1) the amount of manure added, or biomass returned to or removed from the soil (OM); 2) the effects of tillage and field operations on OM decomposition (FO); and 3) the effect of predicted soil erosion associated with the management system (ER). The formula SCI uses to estimate the combined effect of its three components is: SCI = OM + FO + ER. The value SCI gives is an overall rating based on the combined effects of these components. The SCI ratings are assumed to be an indicator of improved or degraded soil quality; if the rating is a negative value, the level of SOM is predicted to decline under the production system. If the rating is positive, the SOM level is predicted to increase under the system. Values near zero suggest that SOM will be maintained near the current level (SQI, 2003). The magnitude of the SCI value is more related to the probability of achieving a change rather than determining an absolute value of that change (Causarano et al., 2005). A more detailed description of each component is presented by Hubbs et al., (2002).

The EPIC model (Williams et al., 1984) is a biophysical process based model, that operates on a continuous basis using a daily time-step and was originally designed to simulate the impacts of soil erosion on soil productivity (Williams, 1990). EPIC has since evolved into a comprehensive agroecosystem model that features enhanced carbon cycling routines (Izaurralde et al., 2001) and is capable of describing the effect of agricultural management strategies on production and soil and water resources (Williams, 1995; Gassman et al., 2004) at farm (Foltz et al., 1993), watershed (Chung et al., 1999), and regional scales (Bernardo et al., 1993). An overview of EPIC is presented in Gassman et al. (2003).

Model Input Preparation

Weather Inputs

In EPIC a 14-year (1978-1991) database of daily records of precipitation (mm), and maximum and minimum air temperature (°C) of Miskolc (USDA-ARS Hydrolab), Hungary (48°08' N and 20°77' E) was used for generating weather for the 40-year long simulation. Miskolc is 75 km from Kompolt. Weather data from Miskolc was used because daily weather data was lacking from the experimental station in Kompolt. Daily values of precipitation and air temperature of the 14-year long weather record from Miskolc were processed by WXPARM, a program to generate weather parameters needed to run EPIC. Some of the weather parameters that are needed to run EPIC are average daily maximum and minimum air temperature, standard deviation (STD) of maximum and minimum air temperature, average daily precipitation, and STD of daily precipitation. Monthly average maximum and minimum temperature and precipitation generated by WXPARM used for the 40-year EPIC simulation are shown in Table 4-1. Weather inputs in SCI are predetermined in a table called cities which includes climate data for over 800 locations in the U.S. For this simulation Spokane, WA (47°37' N and 117°30' W) (location code: 47751) was chosen because of similarities in climate with Kompolt.

Table 4-1. Monthly Average Weather Parameters for the 40-year EPIC simulation

Parameters	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Max temperature (°C)	2.1	5.1	13.4	17.6	22.2	25.1	25.9	23.9	19.5	11.5	4.0	0.7
Min temperature (°C)	1.3	-0.5	2.4	5.7	10.3	13.0	13.5	11.4	7.7	2.8	0.1	-0.5
Precipitation (mm)	31.0	31.0	33.0	40.0	57.0	72.0	54.0	56.0	40.0	43.0	52.0	40.0

Soil Inputs

Physical composition of the soil was measured to a depth of 135 cm for different depth intervals (0 to 0.3; 0.3 to 0.4; 0.4 to 0.6; 0.6 to 0.8, and 0.8 to 1.35m) (Szabó, L. personal communication, 2006). Percent sand of different soil layers ranged from 14.6 to 23.8, percent silt from 26.3 to 34.5, and percent clay ranged from 41.7 to 56.8. In SCI soil texture input can be determined by choosing the proper soil type from the soil table. In EPIC properties of different depths were needed for the simulation (Table 4-2). Soil bulk density was not available and was thus estimated using a similar soil profile description (Soil Survey Staff USDA-NRCS, 2007). Soil pH, soil water content at wilting point and field capacities were measured to a depth of 135 cm at different intervals (Szabó L., personal communication, 2006) (Table 4-2).

Slopes on the experimental plots were visually estimated to be between 0 to 1 percent. Therefore neither the simulations in SCI nor in EPIC include impact of erosion on SOM changes. EPIC simulations were run with the water and wind erosion equations turned off (Izaurralde et al., 2001), while in SCI the effect of predicted soil erosion associated with the management system (ER) were set to zero.

Table 4-2. Initial Soil Input Parameters for the 40-year EPIC simulation

Parameters		Soil Layer				
	Unit†	1	2	3	4	5
Layer depth	m	0.3	0.4	0.6	0.8	1.35
Bulk density	Mg m^{-3}	1.37	1.40	1.43	1.45	1.55
Wilting point	m m^{-1}	0.14	0.19	0.18	0.18	0.19
Field capacity	m m^{-1}	0.22	0.27	0.25	0.25	0.27
Sand	%	24	15	17	16	17
Silt	%	34	23	27	27	26
Clay	%	42	62	56	57	57
pH		6.3	6.1	6.2	6.4	6.7
Organic C	%	1.61	1.14	0.88	0.68	0.47

† Units shown are required by the EPIC model

Field Management Inputs

In SCI and EPIC manure was applied based on dry weight using the appropriate dry fraction for nutrient content (ISU Extension Publ., 2003). Based on dry weight 5387.5 kg ha^{-1} 4 yr^{-1} was applied with total N fraction of 0.0325. In EPIC potential heat units (PHU) for different crops were generated by the PHU program using output of weather data generated by the WXPARM program. Field management inputs were the same for both SCI and EPIC. Fall moldboard plowing and tandem disking was used for tillage. Tillage used was conventional tillage with use of fall moldboard plow and tandem disk. In EPIC biomass was removed in selected treatments after harvest with a baling operation (R.C. Izaurralde, personal communication, 2006). In SCI biomass was removed and manure was added in selected treatments in the model component where ‘organic material added and/or removed’ is calculated for the index value. In EPIC winter pea was simulated where spring-planted green pea was applicable because EPIC had only winter pea available in its supporting crop table. Crop rotations were repeated yearly, every 4, and every 8 years depending on the rotation and management scenarios. Table 4-3 summarizes the timing of different management activities used in the field and simulated with the models, and shows annual PHU values for each of the crop used in the experiment.

Table 4-3. Summary of Management Activities for the Simulations in EPIC and SCI

Date	Management Activity	PHU
March 10-April 10	Spring tillage	
March 10-April 10	Spring N application	
March 10-15	Green pea planting	1143.1
March 10-15	Spring barley planting	1256.7
April 10-15	Corn planting	1229.8
April 10-15	Alfalfa seeding	1003.7
May 28-30, July 5-7, Sept 1-7, October 5-7	Alfalfa cuttings	
July 1-3	Green pea harvest	
July 5-7	Spring barley harvest	
July 10-15	Winter wheat harvest	
July 30-Sept 30	Summer tillage	
October 1-15	Corn harvest	
October 5-25	Winter wheat planting	1331.7
September 20-October 31	P and K application	
October 1-5	Fall N application	
September 20-October 30	Manure application	
October 1-November 1	Fall tillage	

Model Simulation

For EPIC simulations version 3060 and for SCI version 25 the Microsoft Excel worksheet was used. Crop yields were not available from the field data, thus EPIC was used to simulate crop yields and these yields were used as SCI inputs. Initialized conditions of different C pools in EPIC were assumed to be calculated by the model, given that simulations were four decades long (R.C. Izaurralde, personal communication, 2006). Fifty four simulations were conducted in both models to represent all field management scenarios and crop rotations used in this study.

Model Output and Data Analysis

There are several differences in outputs between EPIC and SCI and in observed data. EPIC expresses carbon (C) change as SOC, whereas field data were measured as SOM, and SCI gives an index value based on anticipated organic matter change. SOM however, can be indirectly estimated through multiplication of the organic carbon (C) concentration by the ratio of OM to organic C commonly found in soils (SOC x 1.724 = SOM). Thus changes in SOM reflect change in the same direction and with the same relative quantity as with SOC. Furthermore, in EPIC carbon change is expressed as mass per unit area (Mg ha^{-1}), in SCI it is expressed by the index number, and in the field data as mass per unit mass basis (g kg^{-1}, %). To determine C change in the field, the first soil C measurement was subtracted from the last soil C measurement. Field data then was converted from SOM to SOC and from mass per unit mass basis to mass per unit area. Moreover, while EPIC generates SOC change over time (up to several decades), SCI gives a direction of change over the length of a crop rotation. Since SCI has no temporal scale, EPIC simulated SOC values were averaged over years of simulation, while field data was averaged over the number of years between the first and last soil measurements to obtain average yearly change in SOC.

Data analysis was focused on FBM treatments in order to be able to address the objective. Therefore to investigate SOC change differences between FBM treatments, observed and predicted SOC change data were averaged over CR and FAM treatment. Relative changes between FBM treatments observed data were compared with relative changes between FBM treatments predicted data using qualitative evaluation.

RESULTS AND DISCUSSION

Realistic modeling of crop yields (Izaurralde et al., 2006) as well as accurate soil information is required for a correct quantification of C additions to the soil. National average yields were 6.9 Mg ha^{-1} for corn, 4.1 Mg ha^{-1} for wheat, 3.7 Mg ha^{-1} for barley, and 5.1 Mg ha^{-1} for alfalfa from 1990 to 2006 in Hungary (Hungarian Central Statistical Office, 2006). Green pea is not a main field crop and it is not included into the statistical report. A regional average for green peas is between 1 to 2 Mg ha^{-1} (L. Fodor, personal communication, 2006). Depending on the treatment, yields projected by EPIC were between 1.6 to 8.4 Mg ha^{-1} for corn; 0.9 to 4.0 Mg ha^{-1} for winter wheat; 0.6 to 5.1 Mg ha^{-1} for spring barley; 0.9 to 1.0 Mg ha^{-1} for pea; and 0.9 to 4.3 Mg ha^{-1} for alfalfa. The greatest yields were simulated in plots receiving both inorganic and manure fertilizer addition, while the lowest were simulated in the control plots where no fertilizer was applied. EPIC generated yields overlapped national averages for corn and spring barley and were somewhat lower for winter wheat and alfalfa. Generated yields for pea were also lower than regional estimated averages but this discrepancy could have resulted from winter pea being used in the simulation instead of spring planted pea.

Treatment with Biomass Removal

Table 4-4 shows observed and modeled SOC change in different FBM treatments. Observed field data showed that the control treatment was the least while the treatment with manure and mineral fertilizer addition was the most successful to increase SOC over time. Both models were successful in predicting the least and most effective biomass incorporation treatments based on the field data. The relative trend among treatments with biomass removal based on the observed data, ordered from least to most positive effects was: Mineral fertilizer addition< Manure addition<Manure + mineral fertilizer addition. In other worlds, mineral fertilizer was less effective than manure additions at sustaining SOC content.

Table 4-4. Observed and Modeled Soil Organic Carbon Change in Different Fertilizer and Biomass Management Treatments

	Change in Soil Organic Carbon		
	Observed	Simulated	
Treatment		EPIC	SCI
	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Index
Biomass Removal			
Control	-0.38	-0.14	0.07
Mineral fertilizer addition	0.10	-0.07	0.10
Manure addition	0.13	0.01	0.24
Manure + mineral fertilizer addition	0.54	0.03	0.33
Biomass Incorporation			
No fertilizer addition	-0.22	-0.10	0.27
Mineral fertilizer addition	0.19	-0.04	0.33

Observed data showed that in treatments with biomass removal both inorganic and manure soil additions increased SOC contents over time. On the other hand EPIC predicted that mineral fertilizer additions would decrease SOC content over time, which was not observed. In contrast SCI predicted positive index values or SOM increase for all biomass removal treatments, including the control. This could have happened because FBM treatments are values averaged over FAM treatments, for which one of the management components is alfalfa even included the control treatment (Appendix A).

Treatment with Biomass Incorporation

Field data showed that the treatment with mineral fertilizer additions increased, while the treatment without nutrient addition was unable to increase SOC over time. Both models successfully predicted the least and most effective biomass incorporation treatments as they relate to field-observed SOC changes. Observed data showed that the treatment with biomass incorporation increased SOC contents while the treatment without fertilizer addition decreased SOC contents over time. In contrast, EPIC predicted that both biomass incorporation treatments would decrease SOC with time and SCI predicted only positive index values or SOM increase in both biomass incorporation treatments.

CONCLUSIONS

This study's objective was to compare two SOM models, EPIC and SCI, against field data with different management scenarios when biomass was removed vs. incorporated. Simulated estimates of these SOM models were compared with actual field data collected at a Hungarian site under different management scenarios.

The control treatment with biomass removal and no soil fertilization was the least while the treatment with manure and mineral fertilizer addition combined was the most successful to increase SOC over time. Both EPIC and SCI successfully predicted the least and most effective treatments for sustaining SOC content over time. Mineral fertilization application increased SOC stocks in both biomass removal and incorporation treatments. In contrast, EPIC predicted SOC decrease in treatments with mineral fertilizer applications. Both EPIC and SCI successfully predicted that manure additions would be more effective at maintaining SOC than would mineral fertilizer additions. In general, EPIC predicted the correct direction of SOC change in four out of six FBM treatments. In contrast SCI predicted only positive SOC change in all treatments even where observed values showed detrimental treatment effects. Overall, EPIC was found to better estimate SOC changes for agricultural systems with different crop rotations and fertilizer management treatments when biomass is either removed or incorporated.

REFERENCES

Adams, W.A. 1973. The effect of organic matter on the bulk and true densities of some uncultivated podzolic soils. J. Soil Sci. 24:10-17.

Abrahamson-Beese, D. M. Norfleet, H. Causarano, J. Williams, J. Shaw, and A. Franzluebbers. 2006. Simulating soil organic carbon sequestration in cotton production systems with EPIC and the Soil Conditioning Index in the Southeastern USA. *In* Abstracts, Annu. Meet., Soil and Water Conservation Society, Keystone, CO. 22-26 July, 2006. Soil Water Cons. Soc., Ankeny, IA.

Aljibury, F.K. and D.D. Evans. 1961. Soil sampling for moisture retention and bulk density measurements. Soil Sci. Soc. Am. Proc. 25:180-183.

Batjes, N.H. and W.G. Sombroek. 1997. Possibilities for carbon sequestration in tropical and subtropical soils. Global Change Biol. 3:161-173.

Bernardo, D.J., H.P. Mapp, G.J. Sabbagh. S. Geleta, K.B. Watkins, R.L. Elliott, and J.F. Stone. 1993. Economic and environmental impacts of water quality protection policies 2. application to the Central High Plains. Water Resour. Res. 29(9):3081-3091.

Brown R.A. and N.J. Rosenberg, 1999. Climate change impacts on the potential productivity of corn and winter wheat in their primary United States growing regions. Climatic Change 41(1):73-107.

Causarano, H.J., A.J. Franzluebbers, D.W. Reeves, J.N. Shaw, and M.L. Norfleet. 2005. Soil carbon sequestration in cotton production systems. p.192-200. *In* Poster Proceedings, Southern Conservation Tillage Systems Conference. Clemson University.

Chung, S.W. P.W. Gassman, L.A. Kramer, J.R. Williams, and R. Gu. Validation of EPIC for two watersheds in southwest Iowa. 1999. Working paper, 99-WP 215. Center for Agricultural and Rural Development, Iowa State University, Ames, IA. [Online]. Available at: http://www.card.iastate.edu/publications/DBS/PDFFiles/99wp215.pdf (verified 20 Feb. 2007).

Csatho, P., Zs. Magyar, K. Debreczeni, and K. Sardi. 2005. Correlation between soil P and wheat shoot P contents in a network of Hungarian long-term field trials. Commun. Soil sci. plant anal. 36:275-293.

Edwards, D.R., V.W. Benson, J.R. Williams, T.C. Daniel, J. Lemunyon, and R.G. Gilbert. 1994. Use of EPIC model to predict runoff transport of surface-applied inorganic fertilizer and poultry manure constituents. Trans. ASAE. 37(2):403-409.

Farage, P., J. Pretty, and A. Ball. 2003. Biophysical aspects of carbon sequestration in drylands. [Online]. Available at: http://lada.vitualcentre.org/eims/download.asp?pub_id=93403&app=0. (verified 15 Feb. 2007).

Favis-Mortlock, D.T., R. Evans, J. Boardman, and T.M. Harris. 1991. Climate change, winter wheat yield and soil erosion on the English South Downs. Agric. Syst. 37:415-433.

Follett, R.F. 2001. Soil management concepts and carbon sequestration in cropland soils. Soil Tillage Res. 61:77–92.

Foltz, J.C., J.G. Lee, and M.A. Martin. 1993. Farm-level economic and environmental impacts of Eastern Corn Bet cropping systems. J. Prod. Agric. 6:290-296.

Gassman, P.W., T. Campbell, C. Izaurralde, A.M. Thomson, and J.D. Atwood. 2003. Regional estimation of soil carbon and other environmental indicator using EPIC and i_EPIC. Technical Report 03-TR 46. Center of Agricultural and Rural Development, Iowa State University, Ames, IA. [Online]. Available at: http://www.card.iastate.edu/publications/DBS/PDFFiles/03tr46.pdf (verified 20 Feb. 2007).

Gassman, P.W., J.R. Williams, V.W. Benson, R.C. Izaurralde, L.M. Hauck, C.A. Jones, J.D. Atwood, J.R. Kiniry, and J.D. Flowers. 2005. Historical development and applications of the EPIC and APEX models. Working paper, 05-WP 397. Center of Agricultural and Rural Development, Iowa State University, Ames, IA. [Online]. Available at:

http://www.card.iastate.edu/publications/DBS/PDFFiles/05wp397.pdf (verified 20 Feb. 2007).

He, X., R.C. Izaurralde, M.B. Vanotti, J.R. Williams, and A.M. Thomson. 2006. Simulating long-term and residual effects of nitrogen fertilization on corn yields, soil carbon sequestration, and soil nitrogen dynamics. J. Environ. Qual. 35:1608-1619.

Hubbs, M.D., M.L. NOrfleet, and D.T. Lightle. Interpreting the Soil Conditioning Index. *In* E.van Santen (ed.). 2002. Making conservation tillage conventional: Building a future on 25 years of research. Proceedings of 25th Annual Southern Conservation Tillage Conference of Sustainable Agriculture. 24-26 June 2002. Auburn, AL.

Hungarian Central Statistical Office. 2006. Stadat-tables: Harvest production and average yield of main field crops. [Online]. Available at: http://portal.ksh.hu/pls/ksh/docs/eng/xstadat/tabl2_02_01_03.html (verified 20 Feb. 2007).

Iowa State University Extension. 2003. Managing manure nutrients for crop production. University Extension Pm-1811. Iowa State University. Ames. IA.

Izaurralde, R.C., J.R. Williams, W.B. McGill, and N.J. Rosenberg. 2001. Simulating soil carbon dynamics, erosion, and tillage with EPIC. Working paper, National Energy Technology Laboratory. [Online]. Available at: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/5c2.pdf (verified 15 Feb. 2007).

Izaurralde, R.C. J.R. Williams, W.B. McGill, N.J. Rosenberg, and M.C. Quiroge Jakas. 2006. Simulating soil C dynamics with EPIC: Model description and testing against long-term data. 2006. Ecological modeling. 192:362-384.

King, K.W., C.W. Richardson, and J.R. Williams. 1996. Simulation of sediment and nitrate loss on a vertisol with conservation tillage practices. Trans. ASAE 39(6):2139-2145.

Larson, W.E. and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. p. 37-51. *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. No. 35. SSSA. Madison, WI.

Lee J.J., D.L Phillips, and R. Liu. 1993. The effect of trends in tillage practices on erosion and carbon content of soils in the U.S. Corn Belts. Water Air Soil Poll. 70:389-401.

Paustian, K., J. Six, E.T. Elliott, and H.W. Hunt. 2000. Management options for reducing CO_2 emissions from agricultural soils. Biogeochem. 48:147–163.

Phillips, D.L., P.D. Hardin, V.W. Benson, and J.V. Baglio. 1993. Nonpoint source pollution impacts of alternative agriculture management practices in Illinois: a simulation study. J. Soil and Water Conser. 48(5):449-457.

Soil Survey Staff Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online]. Available at http://soils.usda.gov/technical/classification/osd/index.html. (accessed, Feb. 10. 2007).

SQI. 2003. Interpreting the soil conditioning index. A tool for measuring soil organic matter trends. Agronomy Technical Note. No 16. USDA, Soil Quality Institute.

Stockle, C.O., P.T. Dyke, J.R. Williams, C.A. Jones, and N.J. Rosenberg. 1992. A method for estimating the direct and climatic effects of rising atmospheric carbon dioxide on growth and yield of crops. Part II: sensitivity analysis at three sites in the Midwestern USA. Agric. Syst. 38:239-56.

Thomson, A.M., R.C. Izaurralde, N.J. Rosenberg, and X. He. 2006. Climate change impacts on agricultural and soil carbon sequestration potential in the Huang-Hai Plain of China. Agric. Ecosyst. Environ. 114(1-2):195-209.

Tóth, S., I. Bócsa, A. Fehér, S. Holló, T. Hörömpöli, I. Murányi, E. Vízer. 1998. Fleischmann Rudolf Agricultural Research Institute, Kompolt. 1818-1998. (In Hungarian). Regiocon Kft. Kompolt.

Warrick, A.W. and D.R. Nielsen. 1980. Spatial variability of soil physical properties in the field. p. 319-344. *In* D. Hillel (ed.) Applications of soil physics. Academic Press, New York, NY.

Williams, J.R. 1990. Erosion productivity impact calculator (EPIC) model: a case history. Phil Trans. R. Soc. Lond. 329:421-428.

Williams, J.R. 1995. The EPIC Model. 1995. p. 909–1000. *In* V.P. Singh (ed.) Computer models of watershed hydrology. Water Resources Publications. Highlands Ranch, CO.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Trans ASAE 27(1):129-144.

Zobeck, T., J. Crownover, M. Dollar, R. Van Pelt, V. Acosta-Martinez, K. Bronson, and D. Upchurch. 2006. Southern high plains conservation systems effects on the soil conditioning index and other soil quality indexes. p. 269. *In* Abstracts, 28th Southern Conservation Systems Conference, Bushland, TX. 26-28 June 2006.

CHAPTER 5. SOIL AND CROP MANAGEMENT AND BIOMASS REMOVAL EFFECTS ON SOIL ORGANIC CARBON CONTENT – A MODELING STUDY

A paper to be submitted to *The Soil Science Society of America Journal*

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ABSTRACT

Growing interest in biomass as a bioenergy industry feedstock has prompted the need for studies that estimate above ground biomass removal effect on soil quality in agricultural systems. The development of the bioenergy industry could impact regions differently depending on soil, climate, and management practices used. Since Iowa has great biomass resources, a simulation study with EPIC v 3060 was conducted for Central Iowa on Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), Clarion (fine-loamy, mixed, superactive, mesic Typic Hapludoll), and Webster (fine-loamy, mixed, superactive, mesic Typic Endoaquoll) soils with the goal of investigating whether and how biomass could be produced and harvested under different management scenarios while soil organic carbon (SOC) content is maintained. Crop rotations considered in this study were: corn (*Zea mays* L.) monoculture; corn-soybean (*Glycine max* L.); and corn-corn-corn/switchgrass-(*Panicum virgatum* L.) switchgrass-switchgrass; tillage managements were: conventional tillage and no-tillage; residue managements were: biomass removed, and incorporated; and fertility management treatments included no soil nutrient additions; manure; and inorganic NPK. No fertilization with concurrent biomass removal was the most detrimental; while plots with biomass incorporation and inorganic fertilizer addition were the most beneficial to SOC levels. SOC can be increased with biomass incorporation and inorganic fertilizer or manure addition, especially in corn monoculture and corn-switchgrass crop rotation. In general, no-

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till was a better management choice in all management scenarios since it illustrated greater SOC increase or lower SOC loss. Overall, this simulation study showed that Central Iowa faces SOC conservation challenges if above-ground biomass is removed even with previously proven SOC-positive management practices being utilized.

INTRODUCTION

Growing interest in biomass production for bioenergy industry feedstocks has prompted the need for studies that estimate above ground biomass removal effect on environmental quality in agricultural systems. The US Department of Energy and the US Department of Agriculture reported that the United States are capable of producing a sustainable supply of biomass sufficient to displace 30 percent or more of the country's present petroleum consumption in the coming decades. Based on this report agricultural lands can provide nearly one billion dry tons of sustainably collectable biomass and continue to meet food, feed and export demands (Perlack at al., 2005).

In agricultural systems, one of the sustainability indicators is the soil organic matter content (SOMC). Soil organic matter determines the success of agricultural production, while agricultural practices influence it (Larson and Pierce, 1994). Studies have shown that SOMC is directly related to the amount of residue applied to the soil (Rasmussen et al., 1980; Robinson et al., 1996) and that above ground biomass removal negatively affects SOM (Barber, 1979). Therefore, it is reasonable to assume that SOMC would decrease if residues are removed and that large scale above ground biomass removal could deplete our soil resources of current soil organic carbon (SOC) stocks. Decrease in SOMC however, can be mitigated or partially mitigated with appropriate management (Janzen et al., 1998; Bruce et al., 1999). Several studies have evaluated SOM change as a function of different soil tillage (Mahboubi et al., 1993; Reicosky et al., 1995; Hunt, 1996; Deen and Kataki, 2003), tillage and cropping systems (Rasmussen et al., 1998); crop management (Halvorson et al., 2002; McConkey et al., 2003) with cover crops (Fortuna et al., 2003) and with legumes

(Drinkwater et al., 1998); mineral fertilizer application (Halvorson et al., 1999; Russell et al., 2005), manure application (Sommerfeldt et al., 1988; Nardi et al., 2004), green manure application (Sisti et al., 2004) and residue management (Bohm et al., 2002; Rasmussen et al., 1980). The general consensus is that SOMC is positively influenced as tillage is reduced and as organic materials are added to the system, whether the organic material is in the form of crop materials or manure additions.

In the US Department of Energy and the US Department of Agriculture's report on biomass as feedstock for a bioenergy and bioproducts industry, the biomass resource base is composed of a wide variety of agricultural resources that includes grain, animal manure, and crop residues derived primarily from corn and small grains (Perlack at al., 2005). The development of the bioenergy industry, however, could have different impacts on SOMC in different regions depending on the quantities of biomass removed, soil, climate, and management practices used in the particular region. Agroecosystem models with a soil carbon component are useful tools to evaluate the impact of management practices with biomass removal for different combinations of soils, landscapes, and climates in different region. The Environment Policy Impact Calculator, EPIC, model (Williams et al., 1990) is one such model and has been successfully used to estimate regional soil carbon changes in response to variations in management practices, cropping systems, climate inputs, and soil types (Gassman et al., 2003), and with a wide range of cropping practices with and without residue removal (Chapter 4).

Iowa is one of the main corn producing states in the Corn Belt, and could be greatly affected by the development of the bioenergy industry. Larson et al. (1972) investigated corn stover removal on SOC content in Iowa and reported that the amount of cornstalk residue needed to prevent loss of SOC was an estimated 6 Mg ha^{-1} yr^{-1}. A simulation study with CENTURY model (Parton et al., 1987) suggested that Iowa could produce almost 8 billion liters of stover-derived ethanol per year while SOMC would drop slightly in the early years of stover collection but would stay stable over the 90-year simulation if all farmers would switch to continuous no-till corn production Sheehan et al. (2003). Wilhelm et al. (2004) summarized published works addressing potential impacts of wide-scale corn stover collection and removal on corn production capacity in the Corn Belt and concluded that within limits, corn stover can be harvested for bioenergy production without loss of productivity. None of these studies, however, estimated the interaction of biomass removal, crop rotation, tillage, and nutrient management impacts on SOMC in Iowa.

To be able to mitigate potential negative impacts of large scale biomass removal in Iowa, studies that explicitly investigate management impacts of crop residue removal on SOMC are in great need. Establishing such a set of trials and determining effects of a wide range of treatments would be very expensive and take several years. Alternatively, modeling can be used to indicate likely outcomes of such treatments in a much shorter time frame. Therefore a simulation study with EPIC was established to investigate whether and how biomass could be produced for the bioenergy industry while SOC content is maintained. The objective of this simulation study was to estimate the long term impact of different crop rotations, tillage, and nutrient management scenarios with concurrent biomass removal vs. incorporation on SOMC for three Central Iowa soils.

METHODS

Model Description

The Environment Policy Impact Calculator (EPIC) model (Williams et al., 1990) is a well-developed agroecological model that has been widely used to predict the effects of various land management practices on environmental quality. EPIC is capable of simulating fields that are characterized by homogenous weather, soil, landscape, crop rotation, and management system parameters. EPIC was originally developed to assess the impact of soil erosion on crop productivity (Williams et al., 1984). Izaurralde et al. (2006) described the new C and N modules developed in EPIC built on concepts from the CENTURY model

(Parton et al., 1987) to connect simulation of soil C dynamics to crop management, tillage methods, and erosion processes. They added C and N routines that interact directly with soil moisture, temperature, erosion, tillage, soil density, leaching, and translocation functions in EPIC.

EPIC has been widely used and tested to predict irrigation impacts on crop yields (Cabelgunne et al., 1995; Rinaldi, 2001); nitrogen fertilization impacts on crop yields, soil carbon (C) sequestration and soil C dynamics (He et al., 2006); losses of inorganic and organic fertilizer application (Edwards et al., 1994; Pierson et al., 2001); nitrate-nitrogen losses via subsurface tile drainage (Chung et al., 2001); nutrient losses as a function of different management systems (King et al., 1996); soil carbon (C) sequestration as a function of tillage (Lee et al., 1993); soil erosion (Phillips et al., 1993; Potter et al., 1998); and simulation of soil C dynamics (Izaurralde et al., 2006). The flexibility of EPIC has also led to its adoption within several integrated economic and environmental modeling systems that have been used to evaluate agricultural policies at the farm (Foltz et al., 1993), watershed (Chung et al., 1999), and regional scale (Bernardo et a. 1993).

Simulations Methodology and Input Data

A set of EPIC version 3060 simulations were conducted for soils in Central Iowa (42°10' N and 93°37' W). The simulations were run using management system combinations of three crop rotations, two tillage managements, two residue managements, and three fertilizer treatments in three different soils. Crop rotations used in the simulations were: 1) corn (*Zea mays* L.) monoculture (CC); 2) corn-soybean (*Glycine max* L.) rotation (CSB); and 3) corn-corn-corn/switchgrass-(*Panicum virgatum* L.) switchgrass-switchgrass (CSG) (K. Moore, personal communication, 2007). Tillage management systems were: 1) conventional tillage (CT) and 2) no-tillage (NT). Different residue management treatments used were: 1) biomass removed (BR) and 2) biomass incorporated (BI). Finally the different fertilizer applications used in the simulation were: 1) unfertilized, 2) manure amended, and 3) inorganic fertilizer application (NPK). EPIC was run to estimate SOC change over 100 year in each of the 36 treatment combinations.

To run EPIC crop parameters, location-specific weather data, and management operation inputs were required. A 30-year long daily climate data record of precipitation (mm) and maximum and minimum air temperature (°C) of Ames, IA was used to generate climate data needed to run EPIC. The climate data were acquired from the Iowa Environmental Mezonet. Daily values of precipitation and air temperature (maximum and minimum) were processed by WXPARM, a program to generate weather parameters needed to run EPIC (Table 5-1). The total average annual precipitation in Central Iowa is 858 mm. Of this, 635 mm falls in April through September. The growing season for most crops falls within this period.

Table 5-1. Monthly Average Weather Parameters, Ames, IA.

Parameters	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Max temperature (°C)	-2.0	1.3	8.5	17.0	22.8	27.5	29.2	27.9	25.0	17.5	7.8	0.1
Min temperature (°C)	-12.0	-8.7	-2.7	3.7	10.0	15.2	17.6	16.1	11.5	4.6	-2.5	-9.2
Precipitation (mm)	17.4	20.8	51.9	89.7	112.5	121.8	114.7	117.2	78.3	60.5	50.4	23.5

Simulations were conducted for three different soil series; Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), Clarion (fine-loamy, mixed, superactive, mesic Typic Hapludoll), and Webster (fine-loamy, mixed, superactive, mesic Typic Endoaquoll) (Soil Survey Staff USDA-NRCS, 2007). These soil types were chosen because they are the most common soils in the area. The main difference between the soils used in the simulations is their location on the landscape and drainage. Clarion is a well drained soil that occurs on the higher more sloping areas. Nicollet is somewhat poorly drained soil and occurs on concave to slightly convex slopes, while Webster is a poorly drained soil that occurs in low areas and drainage ways. Simulations, however, did not include the impact of erosion on SOC, since this study was conducted to strictly investigate the potential impact of treatments on SOC content change.

Soil properties necessary to run EPIC were obtained from the Soil Survey of Story County, Iowa (DeWitt, 1984) (Table 5-2). Organic carbon concentration of different soils is only determined in the upper soil layer by the Soil Survey. Organic carbon content of deeper soil layers was estimated after Russell et al. (2005) who measured vertical SOC concentration of soils from Kanawha, Iowa, a location with the same soil association used in this study.

Table 5-2. Initial Soil Input Parameters for Soils Used in the Simulations

		Soil								
		Clarion			Nicollet			Webster		
		Soil Layer								
Parameters	Unit	1	2	3	1	2	3	1	2	3
Layer depth	m	0.3	0.8	1.5	0.4	0.9	1.5	0.4	1.0	1.5
Bulk density	Mg m^{-3}	1.42	1.60	1.75	1.20	1.30	1.40	1.37	1.45	1.60
Sand	%	40	45	65	20	30	40	30	15	50
Silt	%	39	28	18	50	40	35	39	55	26
Clay	%	21	27	17	30	30	25	31	30	24
pH		6.4	6.7	7.9	6.4	6.7	7.6	6.9	7.2	7.9
Organic C	%	2.1	1.0	0.3	3.3	1.5	0.3	3.9	1.5	0.3

Corn nitrogen (N) fertilizer application rates simulated in EPIC followed Iowa State University's fertilizer recommendation (Blackmer et al., 1997) and was set at 200 kg N ha^{-1} for corn in CC and CSG rotation, and 150 kg N ha^{-1} for corn in CSB rotations. Nitrogen fertilizer application for switchgrass was set at 150 kg N ha^{-1} (Hall et al., 1982; Hintz et al., 1998). Phosphorus (P) and potassium (K) fertilizer application rates simulated in EPIC followed survey results complied by the Leopold Center for Sustainable Agriculture (Duffy, 1996) and was 53 kg P ha^{-1} and 65 kg K ha^{-1} for all crops. Manure application was N based and was set at the level equal with the inorganic N fertilizer rate applied in the simulation. Manure used was liquid swine (grow-finish, dry feed) manure and was dry weight applied 4358.8 kg ha^{-1} yr^{-1} for corn in CC and CSG rotation, and 3269.1 kg ha^{-1} yr^{-1} for corn in CSB and for switchgrass in CSG rotation assuming that moisture content of liquid swine manure was 86.9 percent (P. Gassman, personal communication, 2007). This resulted in P application rates of 73.6 kg P ha^{-1} for corn in CC and SSG rotations, and 55.3 kg P ha^{-1} for corn in CSB and for switchgrass in CSG rotation (ISU Extension Publ., 2003). Liquid swine manure was used in the simulation because it is available in large quantities in Iowa and could quite conceivably be used to offset SOM losses caused by biomass removal. Both manure and mineral fertilizer was fall applied in the simulations.

Plant density was set to 8 m^{-2} for corn, 40 m^{-2} for soybean, and 10 m^{-2} for switchgrass in the simulations. The potential heat unit (PHU) for corn and soybean was generated by the PHU program using inputs of weather data generated by WXPARM. Switchgrass which is not part of the PHU program, units were set to 1400 (J. Kiniry, personal communication, 2007). Switchgrass was harvested for biomass every year but the year of establishment (R. Hintz, personal communication, 2007). Management characteristics and PHUs of the simulation are given in Table 5-3.

Table 5-3. Summary of Simulated Management Activities, Ames, IA.

Date	Management Activity	PHU
Corn		
April 20 - 22	Spring tillage	
May 1 - 5	Planting	1577.7
October 20	Harvesting	
October 5 – November 5	Fertilizer application	
October 10 - November 10	Fall tillage	
Soybean		
April 20 – 22	Spring tillage	
May 1 - 5	Planting	1361.6
October 1	Harvesting	
October 10 - 20	Fall tillage	
Switchgrass		
May 5	Planting	1400
October 20	Harvesting	
October 30 – November 1	Fertilizer application	

Field operations including planting and harvesting dates were the same for each soil. Conventional tillage included fall operations with a chisel plow for the corn phase and disk for the soybean phase. Both inorganic N (anhydrous ammonia) and manure were injected below the surface in the simulations. Biomass was removed with baling operations in the simulations (R.C. Izaurralde, personal communication, 2006). Initialized conditions of different C pools in EPIC were assumed to be calculated by the model given that simulations were ten decades long (R.C. Izaurralde, personal communication, 2006). Thirty six simulations were conducted in EPIC to represent all the management scenarios and were run for 100 years.

RESULTS AND DISCUSSIONS

Realistic modeling of crop yields (Izaurralde et al., 2006) as well as accurate soil information is required for a correct quantification of C additions to the soil. Average wet weight crop grain yield over the last 10 years was 10.2 Mg ha^{-1} for corn, and 3.0 Mg ha^{-1} for soybean in central Iowa (Natl. Agric. Stat. Serv., 2007; T. Kalaus, personal communication, 2007). Switchgrass biomass yield are not reported by the National Agricultural Statistics Service, but the average estimated dry matter yield is between 4 Mg ha^{-1} and 7 Mg ha^{-1} in Iowa (R. Hintz, personal communication, 2007). Table 5-4 shows EPIC simulated fertilized average dry weight yields averaged over tillage treatments and soils.

Table 5-4. Average EPIC Simulated Fertilized Dry Weight Yields

Fertilizer & Residue Management	Corn Monoculture	Soybean	Switchgrass
	------------------------------Mg ha^{-1}	------------------------------	------------------------------
Biomass Removal			
Manure addition	6.9†	2.6	4.2
NPK addition	10.6	2.4	4.2
Biomass Incorporated			
Manure addition	5.9	2.3	3.5
NPK addition	9.3	2.0	3.7

† Yield averaged over tillage treatments and different soils.

Generally, simulated yields were lower in treatments where residue was incorporated. This could have happened because increasing residue rates increased total N uptake (immobilization) from the soil. This suggests that an increased N fertilizer is needed when residues are incorporated to avoid soil mining for residue decomposition. Simulated average corn crop yields were lower in treatments with manure addition, and greater in treatments with mineral fertilizer addition. In other words, simulated data shows that liquid swine manure application was less effective at increasing corn yields than was mineral fertilizer addition.

Table 5-5 shows the simulated annual rate of SOC change in different treatments and crop rotations for different soils. No-till management resulted in greater SOC increase or lower SOC loss in different treatments, crop rotations and soils. Paustian et al. (2002) simulated Iowa climate, soils, land use, and management practices with CENTURY, a process based model that is widely used to estimate SOC dynamics (Parton et al., 1987). They estimated soil C gains of 0.25 Mg ha^{-1} yr^{-1} by changing from intensive to moderate tillage practices. These EPIC estimates also predicted an average 0.25Mg ha^{-1} yr^{-1} C change when changing from conventional to no-till tillage practices on these three Central Iowa soils. Similarly, Clapp et al. (2000) found that when the soil was moldboard plowed, residue with additional N fertilization did not increase SOC content.

When annual C changes were averaged over different managements, tillage, and crop rotations, Clarion was less (-0.27 Mg ha^{-1} yr^{-1}) while Webster (-0.58 Mg ha^{-1} yr^{-1}) was more vulnerable to SOC loss in the simulations. When annual C changes were averaged across managements, tillage, and soils, the CSG rotation was less (-0.30 Mg ha^{-1} yr^{-1}), while CSB rotation was more susceptible to SOC loss (-0.55 Mg ha^{-1} yr^{-1}) in the EPIC runs. CC rotation showed an average annual C change (-0.39 Mg ha^{-1} yr^{-1}) which is close to those changes simulated in CSG rotation. Russell et al. (2005) investigated cropping system effects on SOC content and they reported that SOC content were significantly less in the CSB rotation than in the CC rotation. Liebig et al. (2005) conducted a study to evaluate SOC content within established switchgrass and in cultivated cropland. They found that SOC was greater in switchgrass stands than cropland especially deeper in the soil profile where switchgrass root biomass likely contributed to the increasing SOC trends.

Table 5-5. EPIC Predicted Annual Rate of Soil Organic Carbon Change (0-1.5 m)

Residue & Fertilizer Management	Crop Rotation						
	Corn Monoculture		Corn Soybean		Corn Switchgrass		
	Tillage						
	NT†	CT‡	NT	CT	NT	CT	Average
	----Mg ha^{-1} yr^{-1}----						
Clarion							
BR§	-0.66	-0.73	-0.49	-0.62	-0.41	-0.54	-0.57
BR Manure	-0.15	-0.13	-0.24	-0.33	-0.13	-0.09	-0.18
BR NPK	-0.19	-0.28	-0.30	-0.45	-0.16	-0.20	-0.26
BI¶	-0.43	-0.56	-0.31	-0.41	-0.36	-0.43	-0.42
BI Manure	-0.09	0.02	-0.20	-0.17	-0.12	-0.01	-0.10
BI NPK	-0.03	-0.04	-0.17	-0.22	-0.07	-0.09	-0.10
Average	**-0.26**	**-0.29**	**-0.29**	**-0.37**	**-0.21**	**-0.23**	**-0.27**
Nicollet							
BR	-1.29	-1.49	-0.90	-1.26	-0.58	-0.94	-1.08
BR Manure	-0.14	-0.19	-0.36	-0.61	-0.15	-0.10	-0.24
BR NPK	-0.09	-0.44	-0.39	-0.88	-0.10	-0.24	-0.36
BI	-0.64	-1.06	-0.42	-0.80	-0.47	-0.69	-0.68
BI Manure	-0.06	0.04	-0.20	-0.28	0.12	0.02	-0.10
BI NPK	1.19	0.07	-0.14	-0.35	0.04	0.00	0.14
Average	**-0.17**	**-0.51**	**-0.39**	**-0.70**	**-0.23**	**-0.33**	**-0.39**
Webster							
BR	-1.84	-2.21	-1.41	-1.93	-0.85	-1.38	-1.60
BR Manure	0.12	-0.07	-0.18	-0.98	-0.04	-0.08	-0.20
BR NPK	-0.18	-1.07	-0.66	-1.47	-0.24	-0.62	-0.71
BI	-0.88	-1.55	-0.41	-1.26	-0.57	-1.00	-0.95
BI Manure	0.36	0.35	0.02	-0.31	0.06	0.10	0.10
BI NPK	0.38	-0.19	0.04	-0.70	0.06	-0.22	-0.10
Average	**-0.34**	**-0.79**	**-0.43**	**-1.11**	**-0.26**	**-0.53**	**-0.58**

† No tillage
‡ Conventional tillage
§ Biomass Removal
¶ Biomass Incorporation

Positive C change rate occurred in all rotations and soils for treatments with biomass incorporation and soil amendment with manure or inorganic fertilizer. The greatest annual C change (1.19 Mg ha^{-1} yr^{-1}) was simulated in CC rotation with no-till and inorganic fertilizer additions on Nicollet soil. BI with manure additions showed positive annual C change for nine times, while BI with inorganic fertilizer addition showed positive C changes for six times under different tillage, crop rotations, and soils in the simulations. When the annual rate of C change was averaged over different tillage, crop rotation, and soil treatments BI and inorganic fertilizer addition was the least degrading (-0.02 Mg ha^{-1} yr^{-1}) while BR and no fertilizer application (-1.09 Mg ha^{-1} yr^{-1}) was the most degrading to SOC content. The order of average annual rate of C change from greatest C loss to least C loss was: BR+no amendment< BI+no amendment< BR+NPK<BR+manure< BI+manure<BI+NPK, with rate of C change values of -1.09<-0.68<-0.44<-0.21<-0.03<-0.02 Mg ha^{-1} yr^{-1} respectively. The same sequence considering only no-till management scenarios would give the same order of treatments but C change values would be generally higher; -0.94<-0.50<-0.26<-0.13<-0.04<0.14, and positive for treatment with BI and inorganic fertilization.

Based on these simulations SOC can be increased with BI and inorganic fertilizer or manure addition, especially in corn monoculture and corn-switchgrass crop rotation if no-till management is followed. On the other hand these simulations also showed that treatment with continuous BR would decrease SOC stocks even if soils were fertilized or had manure additions. Karlen et al. (1994) found that 10 years of residue removal under no-till corn monoculture resulted in lower SOC contents. Lindstrom (1986) also reported loss of nutrients for high removal rates of residue in no-till corn, suggesting that increased fertilization rates will be needed to maintain soil fertility. Generally, a similar set of simulations with increased fertilizer inputs especially in biomass removal treatments might be able to more effectively increase SOC contents.

CONCLUSION

This simulation study was set up to investigate whether and how biomass could be produced for the lignocellulosic bioenergy industry while maintaining soil C stocks in Central Iowa. Iowa is one of the major corn producing states and will play major role supplying above ground biomass for the bioenergy industry. To be able to mitigate potential negative impact of the feedstock production on soil resources, it was important to investigate the long term impact of management practices with concurrent above ground biomass removal vs. incorporation on SOC content.

Annual SOC rate change showed greater positive or smaller negative change in management scenarios with biomass incorporation than the same management scenario with biomass removal. The results show that unfertilized plots with biomass removal were the most detrimental; while plots with biomass incorporation and inorganic fertilizer addition were the most beneficial to SOC levels. SOC can be increased with biomass incorporation and inorganic fertilizer or manure addition, especially in corn monoculture and corn-switchgrass crop rotation if no-till management is followed. In general, no-till was a better management choice in all management scenarios since it illustrated greater SOC increase or lower SOC loss. These simulations showed that continuous biomass removal would decrease SOC stocks on these three soils in Central Iowa with or without manure or fertilization. Overall, this simulation study suggests that Central Iowa faces conservation challenges to maintain current soil carbon levels if it becomes a feedstock supplier for the bioenergy industry through removal of above ground biomass as was simulated in this study.

REFERENCES

Barber, S.A. 1979. Corn residue management and soil organic matter. Agron. J. 71:625-627.

Bernardo, D.J., H.P. Mapp, G.J. Sabbagh. S. Geleta, K.B. Watkins, R.L. Elliott, and J.F. Stone. 1993. Economic and environmental impacts of water quality protection policies 2. application to the Central High Plains. Water Resour. Res. 29(9):3081-3091.

Bernardos, J.N., E.F. Viglizzo, V. Jouvet, F.A. Lértora, A.H. Pordomingo, and F.D. Cid. 2001. The use of EPIC model to study the agroecological change during 93 years of farming transformation in the Argentine pampas. Agric. Syst. 69:215-234.

Blackmer, A.M., R.D. Voss, and A.P. Mallarino. Nitrogen fertilizer recommendations for corn in Iowa. University Extension Pm-1714. Iowa State University. Ames. IA.

Bohm, S.U., C.W. Rice, and A.J. Schlegel. 2002. Soil carbon turnover in residue managed wheat and grain sorghum p. 255-262. *In* J.M. Kimble, R. Lal, and R.F. Follett (ed.) Agriculture practices and policies for carbon sequestration in soil. CRC Press LLC. Boca Bacon, FL.

Bruce, J.P., M. Frome, E. Haites, H. Janzen, R. Lal, and K. Paustian. 1999. Carbon sequestration in soils. J. Soil Water Conserv. p. 382-389.

Cabelguenne, M., C.A. Jones, and J.R. Williams. 1995. Strategies for limited irrigation of maize in southwest France – a modeling approach. Trans. ASAE. 38(2):507-511.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. 2000. Soil organic carbon and C13 abundance as related to tillage, crop residue and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 55:127-142.

Deen W. and P.K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. Soil Tillage Res. 74:143-150.

DeWitt, T. 1984. Soil Survey of Story County, Iowa. USDA and Soil Conservation Service.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature (London). 396:262-265

Duffy, M. 1996. Impact of manure on costs, returns, and energy use on corn fields in Iowa. Leopold Center for Sustainable Agriculture. [Online] Available at http://www.p2pays.org/ref/21/20995.htm (verified on Dec.15. 2006).

Edwards, D.R., V.W. Benson, J.R. Williams, T.C. Daniel, J. Lemunyon, and R.G. Gilbert. 1994. Use of EPIC model to predict runoff transport of surface-applied inorganic fertilizer and poultry manure constituents. Trans. ASAE. 37(2):403-409.

Foltz, J.C., J.G. Lee, and M.A. Martin. 1993. Farm-level economic and environmental impacts of Eastern Corn Bet cropping systems. J. Prod. Agric. 6:290-296.

Fortuna, A., R. Harwood, K. Kizilkaya, and E.A. Paul. 2003. Optimizing nutrient availability and potential carbon sequestration in an agroecosystem. Soil Biol. Biochem. 35:1005-1013.

Gassman, P.W., T. Campbell, C. Izaurralde, A.M. Thomson, and J.D. Atwood. 2003. Regional estimation of soil carbon and other environmental indicators using EPIC and i_EPIC. Technical Report 03-TR 46. CARD, Iowa State University. [Online] Available at http://www.card.iastate.edu. (Verified, Feb. 23. 2007).

Hall, K.E., J.R. George, and R.R. Riedl. 1982. Herbage dry matter yields of switchgrass, big bluestem, and Indiangrass with N fertilization. Agron. J. 74:47-51.

Halvorson, A.D., A.R. Mosier, C.A. Reule, and W.C. Bausch. 2006. Nitrogen and tillage effects on irrigated continuous yields. Agron. J. 98:63-71.

Halvorson, A.D., B.J. Wienhold, and A. L. Black. 2002. Tillage, nitrogen and cropping system effects on soil carbon sequestration. Soil Sci. So. Am. J. 66:906-912.

Halvorson, A.D., C.A. Reule, and R.F. Follett. 1999. Nitrogen fertilization effects on soil carbon and nitrogen in a dryland cropping system. Soil Sci. Soc. Am. J. 63:912-917.

He, X., R.C. Izaurralde, M.B. Vanotti, J.R. Williams, and A.M. Thomson. 2006. Simulating long-term and residual effects of nitrogen fertilization on corn yields, soil carbon sequestration, and soil nitrogen dynamics. J. Environ. Qual. 35:1608-1619.

Hintz, R.L., K.R. Harmoney, K.J. Moore, J.R. George, and E.C. Brummer. 1998. Establishment of Switchgrass and big bluestem in corn with atrazine. Agron. J. 90:591-596.

Hunt, P.G., D.L. Karlen, T.A. Matheny, and V.L. Quisenberry. 1996. Changes in carbon content of a Norfolk loamy sand after 14 years of conservation or conventional tillage. J. Soil Water Conserv. 51(3):255-258.

Iowa State University Extension. 2003. Managing manure nutrients for crop production. University Extension Pm-1811. Iowa State University. Ames. IA.

Izaurralde, R.C. J.R. Williams, W.B. McGill, N.J. Rosenberg, and M.C. Quiroge Jakas. 2006. Simulating soil C dynamics with EPIC: Model description and testing against long-term data. 2006. Ecological modeling. 192:362-384.

Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. McGrill, and R.P. Zentner. 1998. Management effects on soil C storage on the Canadian prairies. Soil Tillage Res. 47:181-195.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Each, J.L. Jordahl. 1994. Crop residue effects on soil quality following 10-years of no-till corn. Soil Tillage Res. 31:149-167.

King, K.W., C.W. Richardson, and J.R. Williams. 1996. Simulation of sediment and nitrate loss on a vertisol with conservation tillage practices. Trans. ASAE 39(6):2139-2145.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. 1972. Effects of increasing amounts of organic residues on continuous corn: II. organic carbon, nitrogen Phosphorus, and sulfur. Agron. J. 64:204-208.

Larson, W.E and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. p. 37-51. *In* Doran J.W., D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (ed.) Defining soil Quality for a Sustainable Environment. SSSA Spec. Publ. No. 35. SSSA. Madison, WI.

Liebig, M.A., H.A. Johnson, J.D. Hanson, A.B. Frank. 2005. Soil carbon under switchgrass stands and cultivated cropland. Biomass and Bioenergy. 28:347-354.

Lindstrom, M.J. 1986. Effects of residue harvesting on water runoff, soil erosion and nutrient loss. Agric. Ecosyst. Envrion. 16:103-112.

Lee J.J., D.L Phillips, and R. Liu. 1993. The effect of trends in tillage practices on erosion and carbon content of soils in the U.S. Corn Belts. Water Air Soil Poll. 70:389-401.

Mahboubi, A.A., R. Lal, and N.R. Faussey. 1993. Twenty-eight years of tillage effects on two soils in Ohio. Soil Sci. Soc. Am. J. 57:506-512.

McConkey, B.G., B.C. Liang, C.A. Campbell, D. Curtin, A. Moulin, S.A. Brandt, and G.P. Lafond. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. Soil Tillage Res. 74:81-90.

Nardi, S., F. Morari, A. Berti, M. Tosoni, and L. Giardini. 2004. Soil organic matter properties after 40 years of different use of organic and mineral fertilizers. Eur. J. Agron. 21:357-367.

National Agricultural Statistics Service. 2000. Agricultural statistics data base. U.S. and state data: crops [Online]. Available at http://www.nass.usda.gov/ (verified Feb. 23. 2007). USDA-NASS, Washington, DC.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analyses of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. 51:1173–1179.

Paustian, K., J. Brenner, K. Killian, J. Cipra, S. Williams, E.T. Elliott, D. Eve, T. Kautza, and G. Bluhm. 2002. State-level analyses of C sequestration in agricultural soils. p. 193–204. *In* R. Lal et al. (ed.) Agricultural practices and policies for carbon sequestration in soil. CRC Press, Boca Raton, FL.

Perlack, R.D., L.L Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass and feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory. Oak Ridge, TN. U.S. Department of Energy. [Online] Available at http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf (verified on Feb. 11. 2007).

Phillips, D.L., P.D. Hardin, V.W. Benson, and J.V. Baglio. 1993. Nonpoint source pollution impacts of alternative agriculture management practices in Illinois: a simulation study. J. Soil and Water Conser. 48(5):449-457.

Pierson, S.T., M.L Cabrera, G.K. Evanylo, P.D. Schroeder, D.E. Radcliffe, H.A. Kuykendall, V.W. Benson, J.R. Williams, C.S. Hoveland, and M.A. McCann. 2001. Phosphorus losses from grasslands fertilized with broiler litter: EPIC simulations. J. Environ. Qual. 30:1790-1795.

Potter, K.N., J.R. Williams, F.J. Larney, and M.S. Bullock. 1998. Evaluation of EPIC`s wind erosion submodel using data from southern Alberta. Can. J. Soil Sci. 78:485-492.

Rasmussen, P.E., R.R. Allmaras, C.R. Rhode, and N.C. Roager Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44:596-600.

Rasmussen, P.E., S.L. Albrecht, and R.W. Smiley. 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil Tillage Res. 47:197-205.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil Water Conserv. 50:253-261.

Rinaldi, M. 2001. Application of EPIC model for irrigation scheduling of sunflower in southern Italy. Agric. Water Manage. 49:185-196.

Robinson, C.A., R.M. Cruse, and M. Haffarzadeh. 1996. Cropping system and nitrogen effects on Mollisol organic carbon. Soil Sci. Soc. Am. J. 60:264-269.

Potter, S.R. and J.R. Williams. 1994. Predicting daily mean temperatures in the EPIC simulation model. Agron. J. 86(6):1006-1011.

Russell, A. E., D.A. Laird, T.B. Parkin, and A.P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern mollisols. Soil Sci. Soc. Am. J. 69:413-422.

Sheehan, J., A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh, and R. Nelson. 2003. Energy and environmental aspects of using corn stover for fuel ethanol. J. Ind. Ecol. 7:117-146.

Sisti, C.P.J., H.P. dos Santos, R Kohhann, B.J.R. Alves, S. Urquiage, and R.M. Boddey. 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil Tillage Res. 76:39-58.

Soil Survey Staff Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online]. Available at http://soils.usda.gov/technical/classification/osd/index.html. (accessed, Feb. 10. 2007).

Sommerfeldt, T.E., C. Chang, and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Sci. Soc. Am. J. 52:1688-1672.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: A literature review. Agron J. 96:1-17.

Williams, J.R. 1990. Erosion productivity impact calculator (EPIC) model: a case history. Phil Trans. R. Soc. Lond. 329:421-428.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Trans ASAE 27(1):129-144.

CHAPTER 6. GENERAL CONCLUSIONS

Summary of Findings

This dissertation research addresses biomass removal effects on soil organic matter content (SOMC) as biomass removal interacts with variety of management practices including different crop rotations, nutrient management techniques, and tillage practices. In Hungary on an Agriudoll the average SOMC resulting from a combination of different fertilizer and biomass managements and crop rotations ranged from 2.75 to 2.92 percent after 40 years of different combinations of management practices. The results showed that for above ground biomass removal treatments, no fertilization addition was the least, while both manure and mineral fertilizer addition was more successful at maintaining or increasing SOM content over time. Agricultural management practices with farmyard beef manure additions and crop rotations with alfalfa sustained SOMC even with extensive above ground biomass removal. The results showed that soil incorporation of above ground biomass had more of a positive effect than mineral fertilizer on SOMC, but the effect was less than that of manure additions. In Central Iowa on Udoll and Aquoll soils a set of EPIC simulations showed that unfertilized treatment with biomass removal was the most, while treatments with biomass incorporation and inorganic fertilizer addition was the least detrimental to SOC loss. Treatments with above ground biomass incorporation and manure or inorganic fertilizer amendment were successful at maintaining or increasing SOC especially in corn monoculture and corn switchgrass rotation. Additionally this simulations study showed that SOC content can be increased or SOC content loss can be decreased if no-till soil management practices are followed. In contrast with the Hungarian data set, this simulation study indicated that continuous biomass removal would decrease SOC content on these Iowa soils even if soils were amended with manure, understanding that farmyard beef manure was used in the Hungarian study and liquid swine manure was simulate for Iowa.

This dissertation research also compared EPIC and SCI predictions of SOMC changes resulting from a variety of management practices with different crop rotation and nutrient managements with concurrent above ground biomass removal vs. incorporation. Both EPIC and SCI successfully identified the least and most effective treatments for managing SOMC over time. In general, EPIC predicted the correct direction of SOC change for four out of six fertilizer and biomass management treatments while SCI predicted positive SOMC impacts for all treatments, even where observed values showed detrimental treatment effects.

Overall Conclusions

The overall goal of this dissertation was to evaluate the relative effects of biomass production and removal on soil organic carbon changes within various agricultural management systems. The impact of residue removal and various management practices on soil organic carbon depends on the particular region's climate, soils, and other available resources (type of manure, crops). In the development of the bioenergy industry, site specific evaluations of biomass production practices are necessary to evaluate impacts of agricultural management practices on soil organic matter content in a particular region. Agroecosystem models are useful decision support tools for such research; however, model processes must be understood in translating results of model simulations. The overall results of this research showed, if biomass removal is to occur, practices that include additions of inorganic fertilizers or organic materials (manure in this study), crop rotations including alfalfa, and limited tillage will reduce negative impacts of biomass removal on SOMC. Depending on the location and details of the management practices, SOMC declines typically associated with biomass removal may even be avoided.

APPENDIX A. ADDITIONAL TABLE

Table A-1. Observed and Modeled Soil Organic Carbon Change in Different Fertilizer and Biomass Management and Fertilzer and Alfalfa Managmenet Treatments

Treatments		Change in Soil Organic Carbon		
		Observed	Simulated	
Fertilizer and Biomass Management	Fertilizer and Alfalfa Management		EPIC	SCI
		-------------Mg ha^{-1} yr^{-1}-----------		Index
Biomass Removal				
Control	4+4‡	-0.32†	-0.47	-0.02
	Continuous§	-0.41	-0.48	-0.02
	4+alfalfa¶	-0.41	0.53	0.25
Average		**-0.38**	**-0.14**	**0.07**
Mineral fertilizer addition	4+4	0.13	-0.44	-0.02
	Continuous	0.06	-0.37	0.05
	4+alfalfa	0.06	0.59	0.27
Average		**0.10**	**-0.07**	**0.10**
Manure addition	4+4	-0.06	-0.37	0.08
	Continuous	0.35	-0.28	0.19
	4+alfalfa	0.10	0.67	0.48
Average		**0.13**	**0.01**	**0.25**
Organic + mineral fertilizer addition	4+4	0.29	-0.33	0.12
	Continuous	0.67	-0.19	0.23
	4+alfalfa	0.64	0.62	0.65
Average		**0.54**	**0.03**	**0.33**
Biomass Incorporation				
No fertilizer addition	4+4	-0.38	-0.42	0.15
	Continuous	-0.19	-0.42	0.15
	4+alfalfa	-0.03	0.52	0.51
Average		**-0.22**	**-0.10**	**0.27**
Mineral fertilizer addition	4+4	0.13	-0.36	0.21
	Continuous	0.19	-0.27	0.27
	4+alfalfa	0.22	0.51	0.52
Average		**0.19**	**-0.04**	**0.33**

† Values averaged over crop rotations
‡ 4-year fertilization 4-year break
§ Yearly fertilizer application
¶ 4-year fertilization 4-year alfalfa with fertilization

APPENDIX B. RAW DATA

The SAS System 23:04 Monday, February 26, 2007 1

Obs	Obs	Year	Rotation	Block	Management	Treatment	SOM
1	1	1969	A	1	a	1	2.76
2	3	1969	A	1	a	3	2.95
3	4	1969	A	1	a	4	2.77
4	6	1969	A	1	a	6	2.80
5	7	1969	A	1	a	7	2.90
6	9	1969	A	1	a	9	2.81
7	13	1969	A	1	b	1	2.80
8	15	1969	A	1	b	3	2.79
9	16	1969	A	1	b	4	2.81
10	18	1969	A	1	b	6	2.65
11	19	1969	A	1	b	7	2.88
12	21	1969	A	1	b	9	2.87
13	25	1969	A	1	c	1	3.06
14	27	1969	A	1	c	3	3.08
15	28	1969	A	1	c	4	2.86
16	30	1969	A	1	c	6	3.03
17	31	1969	A	1	c	7	3.03
18	33	1969	A	1	c	9	3.22
19	37	1969	A	2	a	1	2.64
20	39	1969	A	2	a	3	2.73
21	40	1969	A	2	a	4	2.64
22	42	1969	A	2	a	6	2.61
23	43	1969	A	2	a	7	2.66
24	45	1969	A	2	a	9	2.85
25	49	1969	A	2	b	1	1.70
26	51	1969	A	2	b	3	2.66
27	52	1969	A	2	b	4	2.63
28	54	1969	A	2	b	6	2.73
29	55	1969	A	2	b	7	2.85
30	57	1969	A	2	b	9	2.77
31	61	1969	A	2	c	1	2.90
32	63	1969	A	2	c	3	2.91
33	64	1969	A	2	c	4	2.94
34	66	1969	A	2	c	6	3.01
35	67	1969	A	2	c	7	3.10
36	69	1969	A	2	c	9	3.02
37	73	1969	A	3	a	1	2.66
38	75	1969	A	3	a	3	2.72
39	76	1969	A	3	a	4	2.75
40	78	1969	A	3	a	6	2.73
41	79	1969	A	3	a	7	2.72
42	81	1969	A	3	a	9	2.74
43	85	1969	A	3	b	1	2.74
44	87	1969	A	3	b	3	2.83
45	88	1969	A	3	b	4	2.75
46	90	1969	A	3	b	6	2.77
47	91	1969	A	3	b	7	2.77
48	93	1969	A	3	b	9	2.74
49	97	1969	A	3	c	1	2.91
50	99	1969	A	3	c	3	2.93

51	100	1969	A	3	c	4	2.91
52	102	1969	A	3	c	6	2.83
53	103	1969	A	3	c	7	2.87
54	105	1969	A	3	c	9	2.89
55	109	1969	A	4	a	1	2.55
56	111	1969	A	4	a	3	2.56
57	112	1969	A	4	a	4	2.89
58	114	1969	A	4	a	6	2.97
59	115	1969	A	4	a	7	3.07
60	117	1969	A	4	a	9	2.82
61	121	1969	A	4	b	1	2.37
62	123	1969	A	4	b	3	2.61
63	124	1969	A	4	b	4	2.68
64	126	1969	A	4	b	6	2.80
65	127	1969	A	4	b	7	2.55
66	129	1969	A	4	b	9	2.76
67	133	1969	A	4	c	1	2.66
68	135	1969	A	4	c	3	2.42
69	136	1969	A	4	c	4	2.84
70	138	1969	A	4	c	6	2.76
71	139	1969	A	4	c	7	2.89
72	141	1969	A	4	c	9	2.63
73	145	1969	B	1	a	1	2.98
74	147	1969	B	1	a	3	2.76
75	148	1969	B	1	a	4	2.93
76	150	1969	B	1	a	6	3.18
77	151	1969	B	1	a	7	3.01
78	153	1969	B	1	a	9	2.95
79	157	1969	B	1	b	1	2.92
80	159	1969	B	1	b	3	3.02
81	160	1969	B	1	b	4	3.00
82	162	1969	B	1	b	6	3.06
83	163	1969	B	1	b	7	3.05
84	165	1969	B	1	b	9	2.96
85	169	1969	B	1	c	1	3.15
86	171	1969	B	1	c	3	2.97
87	172	1969	B	1	c	4	3.16
88	174	1969	B	1	c	6	3.19
89	175	1969	B	1	c	7	3.09
90	177	1969	B	1	c	9	3.01
91	181	1969	B	2	a	1	2.87
92	183	1969	B	2	a	3	2.76
93	184	1969	B	2	a	4	2.80
94	186	1969	B	2	a	6	2.96
95	187	1969	B	2	a	7	3.13
96	189	1969	B	2	a	9	2.99
97	193	1969	B	2	b	1	2.75
98	195	1969	B	2	b	3	2.79
99	196	1969	B	2	b	4	2.85
100	198	1969	B	2	b	6	3.07
101	199	1969	B	2	b	7	3.05
102	201	1969	B	2	b	9	3.29
103	205	1969	B	2	c	1	3.04
104	207	1969	B	2	c	3	2.97

105	208	1969	B	2	c	4	2.99
106	210	1969	B	2	c	6	2.95
107	211	1969	B	2	c	7	3.18
108	213	1969	B	2	c	9	3.09
109	217	1969	B	3	a	1	2.76
110	219	1969	B	3	a	3	2.68
111	220	1969	B	3	a	4	2.91
112	222	1969	B	3	a	6	2.71
113	223	1969	B	3	a	7	2.86
114	225	1969	B	3	a	9	2.51
115	229	1969	B	3	b	1	2.92
116	231	1969	B	3	b	3	2.70
117	232	1969	B	3	b	4	3.03
118	234	1969	B	3	b	6	2.89
119	235	1969	B	3	b	7	3.14
120	237	1969	B	3	b	9	2.83
121	241	1969	B	3	c	1	2.93
122	243	1969	B	3	c	3	2.97
123	244	1969	B	3	c	4	3.20
124	246	1969	B	3	c	6	3.07
125	247	1969	B	3	c	7	2.97
126	249	1969	B	3	c	9	2.98
127	253	1969	B	4	a	1	2.50
128	255	1969	B	4	a	3	2.58
129	256	1969	B	4	a	4	2.61
130	258	1969	B	4	a	6	2.72
131	259	1969	B	4	a	7	2.89
132	261	1969	B	4	a	9	2.87
133	265	1969	B	4	b	1	2.59
134	267	1969	B	4	b	3	2.66
135	268	1969	B	4	b	4	2.72
136	270	1969	B	4	b	6	2.73
137	271	1969	B	4	b	7	2.68
138	273	1969	B	4	b	9	3.02
139	277	1969	B	4	c	1	2.82
140	279	1969	B	4	c	3	2.88
141	280	1969	B	4	c	4	2.87
142	282	1969	B	4	c	6	2.86
143	283	1969	B	4	c	7	2.87
144	285	1969	B	4	c	9	2.97
145	289	1969	C	1	a	1	2.93
146	291	1969	C	1	a	3	2.81
147	292	1969	C	1	a	4	2.96
148	294	1969	C	1	a	6	3.03
149	295	1969	C	1	a	7	2.99
150	297	1969	C	1	a	9	2.90
151	301	1969	C	1	b	1	2.84
152	303	1969	C	1	b	3	2.90
153	304	1969	C	1	b	4	2.91
154	306	1969	C	1	b	6	2.90
155	307	1969	C	1	b	7	2.77
156	309	1969	C	1	b	9	2.80
157	313	1969	C	1	c	1	3.03
158	315	1969	C	1	c	3	3.01

159	316	1969	C	1	c	4	3.20
160	318	1969	C	1	c	6	2.99
161	319	1969	C	1	c	7	2.98
162	321	1969	C	1	c	9	3.01
163	325	1969	C	2	a	1	2.88
164	327	1969	C	2	a	3	2.68
165	328	1969	C	2	a	4	2.67
166	330	1969	C	2	a	6	2.52
167	331	1969	C	2	a	7	2.72
168	333	1969	C	2	a	9	2.54
169	337	1969	C	2	b	1	2.76
170	339	1969	C	2	b	3	2.65
171	340	1969	C	2	b	4	2.70
172	342	1969	C	2	b	6	2.72
173	343	1969	C	2	b	7	2.84
174	345	1969	C	2	b	9	2.60
175	349	1969	C	2	c	1	2.82
176	351	1969	C	2	c	3	2.87
177	352	1969	C	2	c	4	2.97
178	354	1969	C	2	c	6	2.88
179	355	1969	C	2	c	7	2.87
180	357	1969	C	2	c	9	2.83
181	361	1969	C	3	a	1	3.07
182	363	1969	C	3	a	3	2.94
183	364	1969	C	3	a	4	2.97
184	366	1969	C	3	a	6	2.75
185	367	1969	C	3	a	7	2.70
186	369	1969	C	3	a	9	2.62
187	373	1969	C	3	b	1	2.96
188	375	1969	C	3	b	3	3.09
189	376	1969	C	3	b	4	2.94
190	378	1969	C	3	b	6	2.86
191	379	1969	C	3	b	7	2.72
192	381	1969	C	3	b	9	2.74
193	385	1969	C	3	c	1	3.08
194	387	1969	C	3	c	3	3.16
195	388	1969	C	3	c	4	2.93
196	390	1969	C	3	c	6	2.92
197	391	1969	C	3	c	7	2.75
198	393	1969	C	3	c	9	2.76
199	397	1969	C	4	a	1	2.67
200	399	1969	C	4	a	3	2.76
201	400	1969	C	4	a	4	3.01
202	402	1969	C	4	a	6	2.90
203	403	1969	C	4	a	7	3.14
204	405	1969	C	4	a	9	2.89
205	409	1969	C	4	b	1	2.87
206	411	1969	C	4	b	3	2.74
207	412	1969	C	4	b	4	3.14
208	414	1969	C	4	b	6	3.02
209	415	1969	C	4	b	7	3.22
210	417	1969	C	4	b	9	3.11
211	421	1969	C	4	c	1	3.10
212	423	1969	C	4	c	3	3.00

213	424	1969	C	4	c	4	3.27
214	426	1969	C	4	c	6	2.94
215	427	1969	C	4	c	7	3.03
216	429	1969	C	4	c	9	2.94
217	433	1977	A	1	a	1	2.66
218	435	1977	A	1	a	3	2.81
219	436	1977	A	1	a	4	2.64
220	438	1977	A	1	a	6	2.68
221	439	1977	A	1	a	7	2.64
222	441	1977	A	1	a	9	2.70
223	445	1977	A	1	b	1	2.66
224	447	1977	A	1	b	3	2.71
225	448	1977	A	1	b	4	2.66
226	450	1977	A	1	b	6	2.83
227	451	1977	A	1	b	7	2.76
228	453	1977	A	1	b	9	2.83
229	457	1977	A	1	c	1	2.96
230	459	1977	A	1	c	3	2.79
231	460	1977	A	1	c	4	2.91
232	462	1977	A	1	c	6	2.84
233	463	1977	A	1	c	7	3.00
234	465	1977	A	1	c	9	2.95
235	469	1977	A	2	a	1	2.62
236	471	1977	A	2	a	3	2.68
237	472	1977	A	2	a	4	2.64
238	474	1977	A	2	a	6	2.65
239	475	1977	A	2	a	7	2.57
240	477	1977	A	2	a	9	2.76
241	481	1977	A	2	b	1	2.64
242	483	1977	A	2	b	3	2.64
243	484	1977	A	2	b	4	2.79
244	486	1977	A	2	b	6	2.93
245	487	1977	A	2	b	7	2.79
246	489	1977	A	2	b	9	2.81
247	493	1977	A	2	c	1	3.05
248	495	1977	A	2	c	3	2.90
249	496	1977	A	2	c	4	2.96
250	498	1977	A	2	c	6	3.05
251	499	1977	A	2	c	7	3.09
252	501	1977	A	2	c	9	2.98
253	505	1977	A	3	a	1	2.68
254	507	1977	A	3	a	3	2.98
255	508	1977	A	3	a	4	2.87
256	510	1977	A	3	a	6	2.74
257	511	1977	A	3	a	7	2.77
258	513	1977	A	3	a	9	2.85
259	517	1977	A	3	b	1	2.93
260	519	1977	A	3	b	3	2.98
261	520	1977	A	3	b	4	2.81
262	522	1977	A	3	b	6	2.93
263	523	1977	A	3	b	7	2.89
264	525	1977	A	3	b	9	2.91
265	529	1977	A	3	c	1	2.92
266	531	1977	A	3	c	3	2.98

267	532	1977	A	3	c	4	3.09
268	534	1977	A	3	c	6	3.05
269	535	1977	A	3	c	7	2.90
270	537	1977	A	3	c	9	2.92
271	541	1977	A	4	a	1	2.62
272	543	1977	A	4	a	3	2.51
273	544	1977	A	4	a	4	2.81
274	546	1977	A	4	a	6	2.79
275	547	1977	A	4	a	7	3.06
276	549	1977	A	4	a	9	3.04
277	553	1977	A	4	b	1	2.55
278	555	1977	A	4	b	3	2.68
279	556	1977	A	4	b	4	2.95
280	558	1977	A	4	b	6	3.09
281	559	1977	A	4	b	7	2.83
282	561	1977	A	4	b	9	2.95
283	565	1977	A	4	c	1	2.69
284	567	1977	A	4	c	3	2.54
285	568	1977	A	4	c	4	3.28
286	570	1977	A	4	c	6	3.09
287	571	1977	A	4	c	7	3.07
288	573	1977	A	4	c	9	2.94
289	577	1977	B	1	a	1	2.81
290	579	1977	B	1	a	3	2.94
291	580	1977	B	1	a	4	2.92
292	582	1977	B	1	a	6	2.90
293	583	1977	B	1	a	7	2.80
294	585	1977	B	1	a	9	2.88
295	589	1977	B	1	b	1	2.66
296	591	1977	B	1	b	3	2.85
297	592	1977	B	1	b	4	2.91
298	594	1977	B	1	b	6	3.10
299	595	1977	B	1	b	7	2.81
300	597	1977	B	1	b	9	2.93
301	601	1977	B	1	c	1	2.91
302	603	1977	B	1	c	3	2.98
303	604	1977	B	1	c	4	3.00
304	606	1977	B	1	c	6	2.93
305	607	1977	B	1	c	7	2.93
306	609	1977	B	1	c	9	2.98
307	613	1977	B	2	a	1	2.77
308	615	1977	B	2	a	3	2.79
309	616	1977	B	2	a	4	2.87
310	618	1977	B	2	a	6	2.82
311	619	1977	B	2	a	7	3.00
312	621	1977	B	2	a	9	2.76
313	625	1977	B	2	b	1	2.81
314	627	1977	B	2	b	3	2.87
315	628	1977	B	2	b	4	2.93
316	630	1977	B	2	b	6	3.02
317	631	1977	B	2	b	7	2.89
318	633	1977	B	2	b	9	3.14
319	637	1977	B	2	c	1	2.87
320	639	1977	B	2	c	3	3.19

321	640	1977	B	2	c	4	3.12
322	642	1977	B	2	c	6	2.95
323	643	1977	B	2	c	7	3.00
324	645	1977	B	2	c	9	3.00
325	649	1977	B	3	a	1	2.89
326	651	1977	B	3	a	3	2.68
327	652	1977	B	3	a	4	2.90
328	654	1977	B	3	a	6	2.60
329	655	1977	B	3	a	7	2.87
330	657	1977	B	3	a	9	2.74
331	661	1977	B	3	b	1	2.79
332	663	1977	B	3	b	3	2.71
333	664	1977	B	3	b	4	3.04
334	666	1977	B	3	b	6	3.04
335	667	1977	B	3	b	7	3.04
336	669	1977	B	3	b	9	2.95
337	673	1977	B	3	c	1	2.88
338	675	1977	B	3	c	3	2.85
339	676	1977	B	3	c	4	3.04
340	678	1977	B	3	c	6	3.04
341	679	1977	B	3	c	7	3.09
342	681	1977	B	3	c	9	2.94
343	685	1977	B	4	a	1	2.63
344	687	1977	B	4	a	3	2.77
345	688	1977	B	4	a	4	2.89
346	690	1977	B	4	a	6	2.88
347	691	1977	B	4	a	7	2.73
348	693	1977	B	4	a	9	2.94
349	697	1977	B	4	b	1	2.81
350	699	1977	B	4	b	3	2.77
351	700	1977	B	4	b	4	2.75
352	702	1977	B	4	b	6	2.90
353	703	1977	B	4	b	7	2.80
354	705	1977	B	4	b	9	3.00
355	709	1977	B	4	c	1	3.15
356	711	1977	B	4	c	3	2.92
357	712	1977	B	4	c	4	2.84
358	714	1977	B	4	c	6	2.96
359	715	1977	B	4	c	7	2.81
360	717	1977	B	4	c	9	2.96
361	721	1977	C	1	a	1	2.66
362	723	1977	C	1	a	3	2.60
363	724	1977	C	1	a	4	2.83
364	726	1977	C	1	a	6	2.83
365	727	1977	C	1	a	7	2.81
366	729	1977	C	1	a	9	2.64
367	733	1977	C	1	b	1	2.70
368	735	1977	C	1	b	3	2.68
369	736	1977	C	1	b	4	2.70
370	738	1977	C	1	b	6	2.81
371	739	1977	C	1	b	7	2.74
372	741	1977	C	1	b	9	2.79
373	745	1977	C	1	c	1	2.89
374	747	1977	C	1	c	3	2.76

375	748	1977	C	1	c	4	3.00
376	750	1977	C	1	c	6	3.00
377	751	1977	C	1	c	7	2.85
378	753	1977	C	1	c	9	2.90
379	757	1977	C	2	a	1	2.93
380	759	1977	C	2	a	3	2.83
381	760	1977	C	2	a	4	2.93
382	762	1977	C	2	a	6	2.85
383	763	1977	C	2	a	7	2.88
384	765	1977	C	2	a	9	2.68
385	769	1977	C	2	b	1	2.81
386	771	1977	C	2	b	3	2.74
387	772	1977	C	2	b	4	2.95
388	774	1977	C	2	b	6	3.06
389	775	1977	C	2	b	7	2.98
390	777	1977	C	2	b	9	2.89
391	781	1977	C	2	c	1	2.91
392	783	1977	C	2	c	3	2.90
393	784	1977	C	2	c	4	2.95
394	786	1977	C	2	c	6	3.12
395	787	1977	C	2	c	7	2.98
396	789	1977	C	2	c	9	2.88
397	793	1977	C	3	a	1	3.05
398	795	1977	C	3	a	3	2.77
399	796	1977	C	3	a	4	2.81
400	798	1977	C	3	a	6	2.64
401	799	1977	C	3	a	7	2.65
402	801	1977	C	3	a	9	2.77
403	805	1977	C	3	b	1	2.80
404	807	1977	C	3	b	3	2.86
405	808	1977	C	3	b	4	2.91
406	810	1977	C	3	b	6	2.92
407	811	1977	C	3	b	7	2.65
408	813	1977	C	3	b	9	2.56
409	817	1977	C	3	c	1	3.00
410	819	1977	C	3	c	3	2.98
411	820	1977	C	3	c	4	2.98
412	822	1977	C	3	c	6	2.86
413	823	1977	C	3	c	7	2.76
414	825	1977	C	3	c	9	2.73
415	829	1977	C	4	a	1	2.69
416	831	1977	C	4	a	3	2.85
417	832	1977	C	4	a	4	2.88
418	834	1977	C	4	a	6	2.79
419	835	1977	C	4	a	7	3.00
420	837	1977	C	4	a	9	2.88
421	841	1977	C	4	b	1	2.95
422	843	1977	C	4	b	3	2.76
423	844	1977	C	4	b	4	3.11
424	846	1977	C	4	b	6	3.05
425	847	1977	C	4	b	7	3.26
426	849	1977	C	4	b	9	3.07
427	853	1977	C	4	c	1	3.01
428	855	1977	C	4	c	3	2.96

429	856	1977	C	4	c	4	3.23
430	858	1977	C	4	c	6	3.14
431	859	1977	C	4	c	7	3.11
432	861	1977	C	4	c	9	3.17
433	865	1981	A	1	a	1	2.66
434	867	1981	A	1	a	3	2.83
435	868	1981	A	1	a	4	2.67
436	870	1981	A	1	a	6	2.70
437	871	1981	A	1	a	7	2.66
438	873	1981	A	1	a	9	3.09
439	877	1981	A	1	b	1	2.53
440	879	1981	A	1	b	3	2.81
441	880	1981	A	1	b	4	2.62
442	882	1981	A	1	b	6	2.72
443	883	1981	A	1	b	7	2.71
444	885	1981	A	1	b	9	2.24
445	889	1981	A	1	c	1	2.85
446	891	1981	A	1	c	3	2.64
447	892	1981	A	1	c	4	2.59
448	894	1981	A	1	c	6	2.79
449	895	1981	A	1	c	7	2.83
450	897	1981	A	1	c	9	2.38
451	901	1981	A	2	a	1	1.80
452	903	1981	A	2	a	3	2.69
453	904	1981	A	2	a	4	2.90
454	906	1981	A	2	a	6	2.58
455	907	1981	A	2	a	7	2.79
456	909	1981	A	2	a	9	2.71
457	913	1981	A	2	b	1	2.00
458	915	1981	A	2	b	3	2.70
459	916	1981	A	2	b	4	3.21
460	918	1981	A	2	b	6	2.69
461	919	1981	A	2	b	7	2.79
462	921	1981	A	2	b	9	2.76
463	925	1981	A	2	c	1	2.28
464	927	1981	A	2	c	3	3.12
465	928	1981	A	2	c	4	3.08
466	930	1981	A	2	c	6	2.87
467	931	1981	A	2	c	7	2.87
468	933	1981	A	2	c	9	2.77
469	937	1981	A	3	a	1	2.69
470	939	1981	A	3	a	3	2.87
471	940	1981	A	3	a	4	2.82
472	942	1981	A	3	a	6	2.80
473	943	1981	A	3	a	7	2.59
474	945	1981	A	3	a	9	2.71
475	949	1981	A	3	b	1	2.75
476	951	1981	A	3	b	3	2.94
477	952	1981	A	3	b	4	2.85
478	954	1981	A	3	b	6	2.94
479	955	1981	A	3	b	7	2.69
480	957	1981	A	3	b	9	2.56
481	961	1981	A	3	c	1	2.92
482	963	1981	A	3	c	3	2.91

483	964	1981	A	3	c	4	2.98
484	966	1981	A	3	c	6	2.95
485	967	1981	A	3	c	7	2.82
486	969	1981	A	3	c	9	2.46
487	973	1981	A	4	a	1	2.03
488	975	1981	A	4	a	3	2.31
489	976	1981	A	4	a	4	2.40
490	978	1981	A	4	a	6	2.51
491	979	1981	A	4	a	7	2.64
492	981	1981	A	4	a	9	2.41
493	985	1981	A	4	b	1	2.05
494	987	1981	A	4	b	3	2.30
495	988	1981	A	4	b	4	2.84
496	990	1981	A	4	b	6	2.43
497	991	1981	A	4	b	7	2.72
498	993	1981	A	4	b	9	2.51
499	997	1981	A	4	c	1	2.12
500	999	1981	A	4	c	3	2.25
501	1000	1981	A	4	c	4	2.55
502	1002	1981	A	4	c	6	2.90
503	1003	1981	A	4	c	7	2.70
504	1005	1981	A	4	c	9	2.40
505	1009	1981	B	1	a	1	2.79
506	1011	1981	B	1	a	3	2.93
507	1012	1981	B	1	a	4	2.70
508	1014	1981	B	1	a	6	2.79
509	1015	1981	B	1	a	7	2.66
510	1017	1981	B	1	a	9	2.86
511	1021	1981	B	1	b	1	2.61
512	1023	1981	B	1	b	3	2.76
513	1024	1981	B	1	b	4	2.79
514	1026	1981	B	1	b	6	2.96
515	1027	1981	B	1	b	7	2.59
516	1029	1981	B	1	b	9	2.75
517	1033	1981	B	1	c	1	2.93
518	1035	1981	B	1	c	3	2.82
519	1036	1981	B	1	c	4	2.96
520	1038	1981	B	1	c	6	2.90
521	1039	1981	B	1	c	7	2.71
522	1041	1981	B	1	c	9	2.71
523	1045	1981	B	2	a	1	2.95
524	1047	1981	B	2	a	3	2.89
525	1048	1981	B	2	a	4	3.36
526	1050	1981	B	2	a	6	2.66
527	1051	1981	B	2	a	7	3.03
528	1053	1981	B	2	a	9	3.25
529	1057	1981	B	2	b	1	2.93
530	1059	1981	B	2	b	3	3.12
531	1060	1981	B	2	b	4	3.15
532	1062	1981	B	2	b	6	3.40
533	1063	1981	B	2	b	7	3.11
534	1065	1981	B	2	b	9	3.11
535	1069	1981	B	2	c	1	3.06
536	1071	1981	B	2	c	3	3.19

537	1072	1981	B	2	c	4	3.15
538	1074	1981	B	2	c	6	3.33
539	1075	1981	B	2	c	7	3.33
540	1077	1981	B	2	c	9	3.60
541	1081	1981	B	3	a	1	3.01
542	1083	1981	B	3	a	3	2.71
543	1084	1981	B	3	a	4	3.31
544	1086	1981	B	3	a	6	2.65
545	1087	1981	B	3	a	7	3.01
546	1089	1981	B	3	a	9	2.88
547	1093	1981	B	3	b	1	3.22
548	1095	1981	B	3	b	3	2.95
549	1096	1981	B	3	b	4	3.10
550	1098	1981	B	3	b	6	2.78
551	1099	1981	B	3	b	7	2.92
552	1101	1981	B	3	b	9	2.99
553	1105	1981	B	3	c	1	3.27
554	1107	1981	B	3	c	3	3.16
555	1108	1981	B	3	c	4	3.11
556	1110	1981	B	3	c	6	3.06
557	1111	1981	B	3	c	7	3.11
558	1113	1981	B	3	c	9	3.05
559	1117	1981	B	4	a	1	2.27
560	1119	1981	B	4	a	3	2.50
561	1120	1981	B	4	a	4	2.47
562	1122	1981	B	4	a	6	2.55
563	1123	1981	B	4	a	7	2.67
564	1125	1981	B	4	a	9	2.88
565	1129	1981	B	4	b	1	2.36
566	1131	1981	B	4	b	3	2.42
567	1132	1981	B	4	b	4	2.39
568	1134	1981	B	4	b	6	2.68
569	1135	1981	B	4	b	7	2.72
570	1137	1981	B	4	b	9	3.19
571	1141	1981	B	4	c	1	2.43
572	1143	1981	B	4	c	3	2.63
573	1144	1981	B	4	c	4	2.41
574	1146	1981	B	4	c	6	2.77
575	1147	1981	B	4	c	7	2.72
576	1149	1981	B	4	c	9	2.86
577	1153	1981	C	1	a	1	2.37
578	1155	1981	C	1	a	3	2.58
579	1156	1981	C	1	a	4	2.68
580	1158	1981	C	1	a	6	2.73
581	1159	1981	C	1	a	7	2.71
582	1161	1981	C	1	a	9	2.99
583	1165	1981	C	1	b	1	2.11
584	1167	1981	C	1	b	3	2.62
585	1168	1981	C	1	b	4	2.78
586	1170	1981	C	1	b	6	2.82
587	1171	1981	C	1	b	7	2.70
588	1173	1981	C	1	b	9	3.10
589	1177	1981	C	1	c	1	2.50
590	1179	1981	C	1	c	3	2.51

591	1180	1981	C	1	c	4	2.91
592	1182	1981	C	1	c	6	2.78
593	1183	1981	C	1	c	7	2.71
594	1185	1981	C	1	c	9	3.21
595	1189	1981	C	2	a	1	2.96
596	1191	1981	C	2	a	3	2.86
597	1192	1981	C	2	a	4	3.11
598	1194	1981	C	2	a	6	2.91
599	1195	1981	C	2	a	7	3.16
600	1197	1981	C	2	a	9	2.93
601	1201	1981	C	2	b	1	3.02
602	1203	1981	C	2	b	3	3.07
603	1204	1981	C	2	b	4	3.11
604	1206	1981	C	2	b	6	3.10
605	1207	1981	C	2	b	7	3.08
606	1209	1981	C	2	b	9	2.93
607	1213	1981	C	2	c	1	3.02
608	1215	1981	C	2	c	3	3.25
609	1216	1981	C	2	c	4	3.13
610	1218	1981	C	2	c	6	3.35
611	1219	1981	C	2	c	7	3.21
612	1221	1981	C	2	c	9	3.21
613	1225	1981	C	3	a	1	3.26
614	1227	1981	C	3	a	3	2.71
615	1228	1981	C	3	a	4	2.73
616	1230	1981	C	3	a	6	2.65
617	1231	1981	C	3	a	7	2.55
618	1233	1981	C	3	a	9	2.46
619	1237	1981	C	3	b	1	2.90
620	1239	1981	C	3	b	3	2.88
621	1240	1981	C	3	b	4	2.76
622	1242	1981	C	3	b	6	2.62
623	1243	1981	C	3	b	7	2.50
624	1245	1981	C	3	b	9	2.58
625	1249	1981	C	3	c	1	2.86
626	1251	1981	C	3	c	3	2.66
627	1252	1981	C	3	c	4	2.74
628	1254	1981	C	3	c	6	2.96
629	1255	1981	C	3	c	7	2.60
630	1257	1981	C	3	c	9	2.58
631	1261	1981	C	4	a	1	2.64
632	1263	1981	C	4	a	3	3.11
633	1264	1981	C	4	a	4	3.08
634	1266	1981	C	4	a	6	3.24
635	1267	1981	C	4	a	7	3.10
636	1269	1981	C	4	a	9	2.98
637	1273	1981	C	4	b	1	2.82
638	1275	1981	C	4	b	3	2.98
639	1276	1981	C	4	b	4	3.31
640	1278	1981	C	4	b	6	3.47
641	1279	1981	C	4	b	7	3.18
642	1281	1981	C	4	b	9	3.10
643	1285	1981	C	4	c	1	3.24
644	1287	1981	C	4	c	3	3.10

645	1288	1981	C	4	c	4	3.50
646	1290	1981	C	4	c	6	3.08
647	1291	1981	C	4	c	7	3.16
648	1293	1981	C	4	c	9	2.96
649	1297	2001	A	1	a	1	2.62
650	1299	2001	A	1	a	3	2.87
651	1300	2001	A	1	a	4	2.70
652	1302	2001	A	1	a	6	3.10
653	1303	2001	A	1	a	7	2.58
654	1305	2001	A	1	a	9	2.91
655	1309	2001	A	1	b	1	2.49
656	1311	2001	A	1	b	3	2.71
657	1312	2001	A	1	b	4	2.80
658	1314	2001	A	1	b	6	3.08
659	1315	2001	A	1	b	7	2.68
660	1317	2001	A	1	b	9	2.98
661	1321	2001	A	1	c	1	2.82
662	1323	2001	A	1	c	3	2.93
663	1324	2001	A	1	c	4	2.85
664	1326	2001	A	1	c	6	3.23
665	1327	2001	A	1	c	7	2.91
666	1329	2001	A	1	c	9	3.14
667	1333	2001	A	2	a	1	2.54
668	1335	2001	A	2	a	3	2.58
669	1336	2001	A	2	a	4	2.64
670	1338	2001	A	2	a	6	2.76
671	1339	2001	A	2	a	7	2.76
672	1341	2001	A	2	a	9	2.75
673	1345	2001	A	2	b	1	2.48
674	1347	2001	A	2	b	3	2.56
675	1348	2001	A	2	b	4	2.93
676	1350	2001	A	2	b	6	3.07
677	1351	2001	A	2	b	7	2.78
678	1353	2001	A	2	b	9	2.75
679	1357	2001	A	2	c	1	2.70
680	1359	2001	A	2	c	3	2.83
681	1360	2001	A	2	c	4	2.94
682	1362	2001	A	2	c	6	3.03
683	1363	2001	A	2	c	7	2.97
684	1365	2001	A	2	c	9	2.91
685	1369	2001	A	3	a	1	2.61
686	1371	2001	A	3	a	3	2.67
687	1372	2001	A	3	a	4	2.72
688	1374	2001	A	3	a	6	2.97
689	1375	2001	A	3	a	7	2.70
690	1377	2001	A	3	a	9	2.84
691	1381	2001	A	3	b	1	2.63
692	1383	2001	A	3	b	3	2.76
693	1384	2001	A	3	b	4	2.89
694	1386	2001	A	3	b	6	2.92
695	1387	2001	A	3	b	7	2.82
696	1389	2001	A	3	b	9	3.07
697	1393	2001	A	3	c	1	2.60
698	1395	2001	A	3	c	3	2.87

699	1396	2001	A	3	c	4	3.03
700	1398	2001	A	3	c	6	3.24
701	1399	2001	A	3	c	7	2.99
702	1401	2001	A	3	c	9	2.91
703	1405	2001	A	4	a	1	2.46
704	1407	2001	A	4	a	3	2.49
705	1408	2001	A	4	a	4	2.81
706	1410	2001	A	4	a	6	2.56
707	1411	2001	A	4	a	7	2.73
708	1413	2001	A	4	a	9	2.67
709	1417	2001	A	4	b	1	2.45
710	1419	2001	A	4	b	3	2.59
711	1420	2001	A	4	b	4	2.98
712	1422	2001	A	4	b	6	2.93
713	1423	2001	A	4	b	7	2.77
714	1425	2001	A	4	b	9	2.84
715	1429	2001	A	4	c	1	2.62
716	1431	2001	A	4	c	3	2.77
717	1432	2001	A	4	c	4	3.21
718	1434	2001	A	4	c	6	3.17
719	1435	2001	A	4	c	7	2.80
720	1437	2001	A	4	c	9	3.01
721	1441	2001	B	1	a	1	2.79
722	1443	2001	B	1	a	3	2.82
723	1444	2001	B	1	a	4	2.77
724	1446	2001	B	1	a	6	2.94
725	1447	2001	B	1	a	7	2.78
726	1449	2001	B	1	a	9	2.82
727	1453	2001	B	1	b	1	2.60
728	1455	2001	B	1	b	3	2.83
729	1456	2001	B	1	b	4	2.87
730	1458	2001	B	1	b	6	3.12
731	1459	2001	B	1	b	7	2.85
732	1461	2001	B	1	b	9	2.79
733	1465	2001	B	1	c	1	2.80
734	1467	2001	B	1	c	3	2.90
735	1468	2001	B	1	c	4	3.17
736	1470	2001	B	1	c	6	3.17
737	1471	2001	B	1	c	7	2.99
738	1473	2001	B	1	c	9	2.97
739	1477	2001	B	2	a	1	2.73
740	1479	2001	B	2	a	3	2.80
741	1480	2001	B	2	a	4	2.72
742	1482	2001	B	2	a	6	2.90
743	1483	2001	B	2	a	7	2.95
744	1485	2001	B	2	a	9	2.90
745	1489	2001	B	2	b	1	2.68
746	1491	2001	B	2	b	3	2.85
747	1492	2001	B	2	b	4	2.71
748	1494	2001	B	2	b	6	3.06
749	1495	2001	B	2	b	7	2.86
750	1497	2001	B	2	b	9	3.11
751	1501	2001	B	2	c	1	2.87
752	1503	2001	B	2	c	3	3.06

753	1504	2001	B	2	c	4	2.99
754	1506	2001	B	2	c	6	3.16
755	1507	2001	B	2	c	7	3.13
756	1509	2001	B	2	c	9	3.13
757	1513	2001	B	3	a	1	2.70
758	1515	2001	B	3	a	3	2.74
759	1516	2001	B	3	a	4	3.03
760	1518	2001	B	3	a	6	2.91
761	1519	2001	B	3	a	7	2.91
762	1521	2001	B	3	a	9	2.81
763	1525	2001	B	3	b	1	2.62
764	1527	2001	B	3	b	3	2.91
765	1528	2001	B	3	b	4	3.03
766	1530	2001	B	3	b	6	3.11
767	1531	2001	B	3	b	7	2.90
768	1533	2001	B	3	b	9	2.99
769	1537	2001	B	3	c	1	2.99
770	1539	2001	B	3	c	3	2.98
771	1540	2001	B	3	c	4	2.97
772	1542	2001	B	3	c	6	3.24
773	1543	2001	B	3	c	7	3.24
774	1545	2001	B	3	c	9	3.13
775	1549	2001	B	4	a	1	2.52
776	1551	2001	B	4	a	3	2.79
777	1552	2001	B	4	a	4	2.73
778	1554	2001	B	4	a	6	2.88
779	1555	2001	B	4	a	7	2.70
780	1557	2001	B	4	a	9	2.99
781	1561	2001	B	4	b	1	2.70
782	1563	2001	B	4	b	3	2.94
783	1564	2001	B	4	b	4	3.13
784	1566	2001	B	4	b	6	3.15
785	1567	2001	B	4	b	7	2.82
786	1569	2001	B	4	b	9	3.00
787	1573	2001	B	4	c	1	2.92
788	1575	2001	B	4	c	3	2.88
789	1576	2001	B	4	c	4	2.95
790	1578	2001	B	4	c	6	2.98
791	1579	2001	B	4	c	7	2.70
792	1581	2001	B	4	c	9	2.99
793	1585	2001	C	1	a	1	2.68
794	1587	2001	C	1	a	3	2.85
795	1588	2001	C	1	a	4	2.92
796	1590	2001	C	1	a	6	2.98
797	1591	2001	C	1	a	7	2.90
798	1593	2001	C	1	a	9	2.96
799	1597	2001	C	1	b	1	2.69
800	1599	2001	C	1	b	3	2.80
802	1602	2001	C	1	b	6	3.05
803	1603	2001	C	1	b	7	2.85
804	1605	2001	C	1	b	9	2.98
805	1609	2001	C	1	c	1	2.99
806	1611	2001	C	1	c	3	2.87
807	1612	2001	C	1	c	4	3.16

808	1614	2001	C	1	c	6	3.18
809	1615	2001	C	1	c	7	2.93
810	1617	2001	C	1	c	9	2.97
811	1621	2001	C	2	a	1	2.74
812	1623	2001	C	2	a	3	2.91
813	1624	2001	C	2	a	4	2.90
814	1626	2001	C	2	a	6	2.98
815	1627	2001	C	2	a	7	2.85
816	1629	2001	C	2	a	9	2.52
817	1633	2001	C	2	b	1	2.73
818	1635	2001	C	2	b	3	2.98
819	1636	2001	C	2	b	4	3.02
820	1638	2001	C	2	b	6	3.08
821	1639	2001	C	2	b	7	2.82
822	1641	2001	C	2	b	9	2.86
823	1645	2001	C	2	c	1	2.77
824	1647	2001	C	2	c	3	3.15
825	1648	2001	C	2	c	4	2.99
826	1650	2001	C	2	c	6	3.19
827	1651	2001	C	2	c	7	2.98
828	1653	2001	C	2	c	9	3.01
829	1657	2001	C	3	a	1	2.81
830	1659	2001	C	3	a	3	2.90
831	1660	2001	C	3	a	4	2.82
832	1662	2001	C	3	a	6	2.92
833	1663	2001	C	3	a	7	2.70
834	1665	2001	C	3	a	9	2.96
835	1669	2001	C	3	b	1	2.85
836	1671	2001	C	3	b	3	3.01
837	1672	2001	C	3	b	4	2.96
838	1674	2001	C	3	b	6	3.17
839	1675	2001	C	3	b	7	2.71
840	1677	2001	C	3	b	9	2.93
841	1681	2001	C	3	c	1	2.87
842	1683	2001	C	3	c	3	3.08
843	1684	2001	C	3	c	4	3.17
844	1686	2001	C	3	c	6	3.22
845	1687	2001	C	3	c	7	2.90
846	1689	2001	C	3	c	9	3.05
847	1693	2001	C	4	a	1	2.80
848	1695	2001	C	4	a	3	2.96
849	1696	2001	C	4	a	4	2.93
850	1698	2001	C	4	a	6	2.99
851	1699	2001	C	4	a	7	2.76
852	1701	2001	C	4	a	9	2.91
853	1705	2001	C	4	b	1	2.75
854	1707	2001	C	4	b	3	2.90
855	1708	2001	C	4	b	4	3.16
856	1710	2001	C	4	b	6	3.04
857	1711	2001	C	4	b	7	2.89
858	1713	2001	C	4	b	9	2.91
859	1717	2001	C	4	c	1	3.03
860	1719	2001	C	4	c	3	3.13
861	1720	2001	C	4	c	4	3.10

862	1722	2001	C	4	c	6	3.04
863	1723	2001	C	4	c	7	2.93
864	1725	2001	C	4	c	9	2.92

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The GLM Procedure
Class Level Information

Class	Levels	Values
Block	4	1 2 3 4
Rotation	3	A B C
Treatment	6	1 3 4 6 7 9
Management	3	a b c
Year	4	1969 1977 1981 2001

Number of Observations Read 864
Number of Observations Used 864

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The GLM Procedure
Dependent Variable: SOM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	377	26.72139271	0.07087903	2.86	<.0001
Error	486	12.05740625	0.02480948		
Corrected Total	863	38.77879896			

R-Square	Coeff Var	Root MSE	SOM Mean
0.689072	5.508488	0.157510	2.859410

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Block	3	0.42328183	0.14109394	5.69	0.0008
Rotation	2	3.25524236	1.62762118	65.60	<.0001
Block*Rotation	6	3.51128449	0.58521408	23.59	<.0001
Treatment	5	2.93703438	0.58740688	23.68	<.0001
Rotation*Treatment	10	0.88929097	0.08892910	3.58	0.0001
Block*Rotati*Treatme	45	4.09123993	0.09091644	3.66	<.0001
Management	2	3.86361944	1.93180972	77.87	<.0001
Rotation*Management	4	0.09482153	0.02370538	0.96	0.4316
Treatment*Management	10	0.56486389	0.05648639	2.28	0.0130
Rotati*Treatm*Manage	20	0.28738264	0.01436913	0.58	0.9273
Bloc*Rota*Trea*Manag	108	2.15731250	0.01997512	0.81	0.9153
Year	3	0.56660683	0.18886894	7.61	<.0001
Rotation*Year	6	1.00200116	0.16700019	6.73	<.0001
Treatment*Year	15	1.07036053	0.07135737	2.88	0.0002
Rotatio*Treatme*Year	30	0.79837106	0.02661237	1.07	0.3653
Management*Year	6	0.19882685	0.03313781	1.34	0.2395
Rotatio*Managem*Year	12	0.15901829	0.01325152	0.53	0.8927
Treatme*Managem*Year	30	0.34332870	0.01144429	0.46	0.9942

Rota*Trea*Manag*Year	60	0.50750532	0.00845842	0.34	1.0000

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	3	0.42328183	0.14109394	5.69	0.0008
Rotation	2	3.25524236	1.62762118	65.60	<.0001
Block*Rotation	6	3.51128449	0.58521408	23.59	<.0001
Treatment	5	2.93703438	0.58740688	23.68	<.0001
Rotation*Treatment	10	0.88929097	0.08892910	3.58	0.0001
Block*Rotati*Treatme	45	4.09123993	0.09091644	3.66	<.0001
Management	2	3.86361944	1.93180972	77.87	<.0001
Rotation*Management	4	0.09482153	0.02370538	0.96	0.4316

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The GLM Procedure
Dependent Variable: SOM

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment*Management	10	0.56486389	0.05648639	2.28	0.0130
Rotati*Treatm*Manage	20	0.28738264	0.01436913	0.58	0.9273
Bloc*Rota*Trea*Manag	108	2.15731250	0.01997512	0.81	0.9153
Year	3	0.56660683	0.18886894	7.61	<.0001
Rotation*Year	6	1.00200116	0.16700019	6.73	<.0001
Treatment*Year	15	1.07036053	0.07135737	2.88	0.0002
Rotatio*Treatme*Year	30	0.79837106	0.02661237	1.07	0.3653
Management*Year	6	0.19882685	0.03313781	1.34	0.2395
Rotatio*Managem*Year	12	0.15901829	0.01325152	0.53	0.8927
Treatme*Managem*Year	30	0.34332870	0.01144429	0.46	0.9942
Rota*Trea*Manag*Year	60	0.50750532	0.00845842	0.34	1.0000

Tests of Hypotheses Using the Type III MS for Block*Rotation as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rotation	2	3.25524236	1.62762118	2.78	0.1397

Tests of Hypotheses Using the Type III MS for Block*Rotati*Treatme as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	5	2.93703438	0.58740688	6.46	0.0001
Rotation*Treatment	10	0.88929097	0.08892910	0.98	0.4755

Tests of Hypotheses Using the Type III MS for Bloc*Rota*Trea*Manag as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Management	2	3.86361944	1.93180972	96.71	<.0001
Rotation*Management	4	0.09482153	0.02370538	1.19	0.3208
Treatment*Management	10	0.56486389	0.05648639	2.83	0.0037
Rotati*Treatm*Manage	20	0.28738264	0.01436913	0.72	0.7987

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The GLM Procedure
Least Squares Means

Treatment	Management	SOM LSMEAN	LSMEAN Number
1	a	2.70229167	1
1	b	2.67291667	2
1	c	2.87916667	3
3	a	2.76062500	4
3	b	2.79333333	5
3	c	2.90854167	6
4	a	2.82958333	7
4	b	2.89687500	8
4	c	3.00375000	9
6	a	2.80645833	10
6	b	2.94312500	11
6	c	3.02187500	12
7	a	2.82208333	13
7	b	2.84208333	14
7	c	2.94708333	15
9	a	2.81916667	16
9	b	2.88229167	17
9	c	2.93812500	18

Least Squares Means for effect Treatment*Management
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: SOM

i/j	1	2	3	4	5	6	7	8	9
1		0.3614	<.0001	0.0702	0.0048	<.0001	<.0001	<.0001	<.0001
2	0.3614		<.0001	0.0066	0.0002	<.0001	<.0001	<.0001	<.0001
3	<.0001	<.0001		0.0003	0.0078	0.3614	0.1237	0.5820	0.0001
4	0.0702	0.0066	0.0003		0.3095	<.0001	0.0325	<.0001	<.0001
5	0.0048	0.0002	0.0078	0.3095		0.0004	0.2601	0.0014	<.0001
6	<.0001	<.0001	0.3614	<.0001	0.0004		0.0144	0.7169	0.0032
7	<.0001	<.0001	0.1237	0.0325	0.2601	0.0144		0.0369	<.0001
8	<.0001	<.0001	0.5820	<.0001	0.0014	0.7169	0.0369		0.0010
9	<.0001	<.0001	0.0001	<.0001	<.0001	0.0032	<.0001	0.0010	
10	0.0013	<.0001	0.0242	0.1546	0.6833	0.0016	0.4723	0.0051	<.0001
11	<.0001	<.0001	0.0472	<.0001	<.0001	0.2826	0.0005	0.1509	0.0599
12	<.0001	<.0001	<.0001	<.0001	<.0001	0.0005	<.0001	0.0001	0.5732
13	0.0002	<.0001	0.0765	0.0565	0.3717	0.0074	0.8157	0.0204	<.0001
14	<.0001	<.0001	0.2493	0.0116	0.1301	0.0393	0.6976	0.0890	<.0001
15	<.0001	<.0001	0.0352	<.0001	<.0001	0.2312	0.0003	0.1190	0.0786
16	0.0003	<.0001	0.0626	0.0693	0.4221	0.0057	0.7461	0.0160	<.0001
17	<.0001	<.0001	0.9226	0.0002	0.0059	0.4146	0.1018	0.6503	0.0002
18	<.0001	<.0001	0.0673	<.0001	<.0001	0.3580	0.0008	0.2001	0.0418

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Least Squares Means
Least Squares Means for effect Treatment*Management
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SOM

i/j	10	11	12	13	14	15	16	17	18
1	0.0013	<.0001	<.0001	0.0002	<.0001	<.0001	0.0003	<.0001	<.0001
2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
3	0.0242	0.0472	<.0001	0.0765	0.2493	0.0352	0.0626	0.9226	0.0673
4	0.1546	<.0001	<.0001	0.0565	0.0116	<.0001	0.0693	0.0002	<.0001
5	0.6833	<.0001	<.0001	0.3717	0.1301	<.0001	0.4221	0.0059	<.0001
6	0.0016	0.2826	0.0005	0.0074	0.0393	0.2312	0.0057	0.4146	0.3580
7	0.4723	0.0005	<.0001	0.8157	0.6976	0.0003	0.7461	0.1018	0.0008
8	0.0051	0.1509	0.0001	0.0204	0.0890	0.1190	0.0160	0.6503	0.2001
9	<.0001	0.0599	0.5732	<.0001	<.0001	0.0786	<.0001	0.0002	0.0418
10		<.0001	<.0001	0.6272	0.2684	<.0001	0.6928	0.0187	<.0001
11	<.0001		0.0147	0.0002	0.0018	0.9021	0.0001	0.0591	0.8765
12	<.0001	0.0147		<.0001	<.0001	0.0204	<.0001	<.0001	0.0095
13	0.6272	0.0002	<.0001		0.5342	0.0001	0.9278	0.0617	0.0003
14	0.2684	0.0018	<.0001	0.5342		0.0012	0.4763	0.2117	0.0030
15	<.0001	0.9021	0.0204	0.0001	0.0012		<.0001	0.0444	0.7806
16	0.6928	0.0001	<.0001	0.9278	0.4763	<.0001		0.0502	0.0002
17	0.0187	0.0591	<.0001	0.0617	0.2117	0.0444	0.0502		0.0831
18	<.0001	0.8765	0.0095	0.0003	0.0030	0.7806	0.0002	0.0831	

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The GLM Procedure
Least Squares Means

Treatment*Management Effect Sliced by Treatment for SOM

Treatment	DF	Sum of Squares	Mean Square	F Value	Pr > F
1	2	1.194987	0.597494	24.08	<.0001
3	2	0.579554	0.289777	11.68	<.0001
4	2	0.740551	0.370276	14.92	<.0001
6	2	1.140539	0.570269	22.99	<.0001
7	2	0.432800	0.216400	8.72	0.0002
9	2	0.340051	0.170026	6.85	0.0012

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

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The GLM Procedure
Least Squares Means
LSMEAN

Rotation	Year	SOM LSMEAN	Number
A	1969	2.78486111	1
A	1977	2.83708333	2
A	1981	2.65625000	3
A	2001	2.81222222	4
B	1969	2.91416667	5
B	1977	2.89777778	6
B	1981	2.88958333	7
B	2001	2.91069444	8
C	1969	2.89152778	9
C	1977	2.87597222	10
C	1981	2.90652778	11
C	2001	2.93625000	12

Least Squares Means for effect Rotation*Year
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SOM

i/j	1	2	3	4	5	6
1		0.0472	<.0001	0.2978	<.0001	<.0001
2	0.0472		<.0001	0.3441	0.0035	0.0212
3	<.0001	<.0001		<.0001	<.0001	<.0001
4	0.2978	0.3441	<.0001		0.0001	0.0012
5	<.0001	0.0035	<.0001	0.0001		0.5327
6	<.0001	0.0212	<.0001	0.0012	0.5327	
7	<.0001	0.0461	<.0001	0.0034	0.3495	0.7551
8	<.0001	0.0052	<.0001	0.0002	0.8948	0.6229
9	<.0001	0.0386	<.0001	0.0027	0.3889	0.8119
10	0.0006	0.1392	<.0001	0.0155	0.1463	0.4066
11	<.0001	0.0084	<.0001	0.0004	0.7712	0.7390
12	<.0001	0.0002	<.0001	<.0001	0.4006	0.1434

Least Squares Means for effect Rotation*Year
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SOM

i/j	7	8	9	10	11	12
1	<.0001	<.0001	<.0001	0.0006	<.0001	<.0001
2	0.0461	0.0052	0.0386	0.1392	0.0084	0.0002
3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
4	0.0034	0.0002	0.0027	0.0155	0.0004	<.0001
5	0.3495	0.8948	0.3889	0.1463	0.7712	0.4006
6	0.7551	0.6229	0.8119	0.4066	0.7390	0.1434
7		0.4217	0.9410	0.6044	0.5189	0.0761

8	0.4217		0.4657	0.1866	0.8740	0.3308
9	0.9410	0.4657		0.5538	0.5680	0.0891
10	0.6044	0.1866	0.5538		0.2450	0.0221
11	0.5189	0.8740	0.5680	0.2450		0.2581
12	0.0761	0.3308	0.0891	0.0221	0.2581	

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The GLM Procedure

Least Squares Means

Rotation*Year Effect Sliced by Year for SOM

Year	DF	Sum of Squares	Mean Square	F Value	Pr > F
1969	2	0.686645	0.343323	13.84	<.0001
1977	2	0.136119	0.068060	2.74	0.0654
1981	2	2.816893	1.408446	56.77	<.0001
2001	2	0.617586	0.308793	12.45	<.0001

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

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The GLM Procedure

Least Squares Means

Treatment	Year	SOM LSMEAN	LSMEAN Number
1	1969	2.80527778	1
1	1977	2.81555556	2
1	1981	2.67250000	3
1	2001	2.71250000	4
3	1969	2.82055556	5
3	1977	2.81138889	6
3	1981	2.79944444	7
3	2001	2.85194444	8
4	1969	2.89472222	9
4	1977	2.91388889	10
4	1981	2.89583333	11
4	2001	2.93583333	12
6	1969	2.87527778	13
6	1977	2.91333333	14
6	1981	2.86444444	15
6	2001	3.04222222	16
7	1969	2.91500000	17
7	1977	2.88361111	18
7	1981	2.83472222	19
7	2001	2.84833333	20
9	1969	2.87027778	21
9	1977	2.88388889	22
9	1981	2.83777778	23
9	2001	2.92750000	24

Least Squares Means for effect Treatment*Year
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: SOM

i/j	1	2	3	4	5	6	7	8
1		0.7820	0.0004	0.0128	0.6809	0.8693	0.8752	0.2094
2	0.7820		0.0001	0.0057	0.8929	0.9107	0.6645	0.3275
3	0.0004	0.0001		0.2818	<.0001	0.0002	0.0007	<.0001
4	0.0128	0.0057	0.2818		0.0038	0.0080	0.0196	0.0002
5	0.6809	0.8929	<.0001	0.0038		0.8051	0.5699	0.3983
6	0.8693	0.9107	0.0002	0.0080	0.8051		0.7478	0.2752
7	0.8752	0.6645	0.0007	0.0196	0.5699	0.7478		0.1580
8	0.2094	0.3275	<.0001	0.0002	0.3983	0.2752	0.1580	
9	0.0164	0.0335	<.0001	<.0001	0.0463	0.0252	0.0106	0.2498
10	0.0036	0.0083	<.0001	<.0001	0.0123	0.0060	0.0022	0.0959
11	0.0151	0.0311	<.0001	<.0001	0.0431	0.0234	0.0097	0.2377
12	0.0005	0.0013	<.0001	<.0001	0.0020	0.0009	0.0003	0.0243
13	0.0600	0.1083	<.0001	<.0001	0.1411	0.0859	0.0416	0.5300
14	0.0038	0.0087	<.0001	<.0001	0.0128	0.0063	0.0023	0.0989
15	0.1117	0.1885	<.0001	<.0001	0.2377	0.1536	0.0806	0.7365
16	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
17	0.0033	0.0076	<.0001	<.0001	0.0113	0.0055	0.0020	0.0901
18	0.0354	0.0674	<.0001	<.0001	0.0901	0.0523	0.0238	0.3941
19	0.4281	0.6059	<.0001	0.0011	0.7029	0.5300	0.3425	0.6429
20	0.2467	0.3777	<.0001	0.0003	0.4547	0.3202	0.1885	0.9226
21	0.0806	0.1411	<.0001	<.0001	0.1811	0.1133	0.0570	0.6217
22	0.0347	0.0663	<.0001	<.0001	0.0887	0.0514	0.0234	0.3900
23	0.3818	0.5497	<.0001	0.0008	0.6429	0.4775	0.3023	0.7029
24	0.0011	0.0027	<.0001	<.0001	0.0041	0.0019	0.0006	0.0424

Least Squares Means for effect Treatment*Year
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: SOM

i/j	9	10	11	12	13	14	15	16
1	0.0164	0.0036	0.0151	0.0005	0.0600	0.0038	0.1117	<.0001
2	0.0335	0.0083	0.0311	0.0013	0.1083	0.0087	0.1885	<.0001
3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
4	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
5	0.0463	0.0123	0.0431	0.0020	0.1411	0.0128	0.2377	<.0001
6	0.0252	0.0060	0.0234	0.0009	0.0859	0.0063	0.1536	<.0001
7	0.0106	0.0022	0.0097	0.0003	0.0416	0.0023	0.0806	<.0001
8	0.2498	0.0959	0.2377	0.0243	0.5300	0.0989	0.7365	<.0001
9		0.6059	0.9761	0.2687	0.6007	0.6164	0.4152	<.0001
10	0.6059		0.6269	0.5547	0.2988	0.9881	0.1835	0.0006
11	0.9761	0.6269		0.2818	0.5801	0.6376	0.3983	<.0001
12	0.2687	0.5547	0.2818		0.1035	0.5448	0.0551	0.0043

i/j	9	10	11	12	13	14	15	16
13	0.6007	0.2988	0.5801	0.1035		0.3058	0.7706	<.0001
14	0.6164	0.9881	0.6376	0.5448	0.3058		0.1885	0.0006
15	0.4152	0.1835	0.3983	0.0551	0.7706	0.1885		<.0001
16	<.0001	0.0006	<.0001	0.0043	<.0001	0.0006	<.0001	
17	0.5852	0.9761	0.6059	0.5749	0.2852	0.9642	0.1739	0.0007
18	0.7649	0.4152	0.7421	0.1602	0.8225	0.4238	0.6059	<.0001
19	0.1067	0.0335	0.1004	0.0067	0.2752	0.0347	0.4238	<.0001
20	0.2121	0.0781	0.2014	0.0188	0.4683	0.0806	0.6645	<.0001
21	0.5106	0.2407	0.4916	0.0781	0.8929	0.2467	0.8752	<.0001
22	0.7706	0.4194	0.7478	0.1624	0.8167	0.4281	0.6007	<.0001
23	0.1257	0.0409	0.1185	0.0085	0.3130	0.0424	0.4729	<.0001

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Least Squares Means
Least Squares Means for effect Treatment*Year
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SOM

i/j	9	10	11	12	13	14	15	16
24	0.3777	0.7141	0.3941	0.8225	0.1602	0.7029	0.0901	0.0021

Least Squares Means for effect Treatment*Year
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SOM

i/j	17	18	19	20	21	22	23	24
1	0.0033	0.0354	0.4281	0.2467	0.0806	0.0347	0.3818	0.0011
2	0.0076	0.0674	0.6059	0.3777	0.1411	0.0663	0.5497	0.0027
3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
4	<.0001	<.0001	0.0011	0.0003	<.0001	<.0001	0.0008	<.0001
5	0.0113	0.0901	0.7029	0.4547	0.1811	0.0887	0.6429	0.0041
6	0.0055	0.0523	0.5300	0.3202	0.1133	0.0514	0.4775	0.0019
7	0.0020	0.0238	0.3425	0.1885	0.0570	0.0234	0.3023	0.0006
8	0.0901	0.3941	0.6429	0.9226	0.6217	0.3900	0.7029	0.0424
9	0.5852	0.7649	0.1067	0.2121	0.5106	0.7706	0.1257	0.3777
10	0.9761	0.4152	0.0335	0.0781	0.2407	0.4194	0.0409	0.7141
11	0.6059	0.7421	0.1004	0.2014	0.4916	0.7478	0.1185	0.3941
12	0.5749	0.1602	0.0067	0.0188	0.0781	0.1624	0.0085	0.8225
13	0.2852	0.8225	0.2752	0.4683	0.8929	0.8167	0.3130	0.1602
14	0.9642	0.4238	0.0347	0.0806	0.2467	0.4281	0.0424	0.7029
15	0.1739	0.6059	0.4238	0.6645	0.8752	0.6007	0.4729	0.0901
16	0.0007	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0021
17		0.3983	0.0311	0.0732	0.2289	0.4024	0.0380	0.7365
18	0.3983		0.1885	0.3425	0.7196	0.9940	0.2176	0.2377
19	0.0311	0.1885		0.7141	0.3387	0.1860	0.9344	0.0128
20	0.0732	0.3425	0.7141		0.5547	0.3387	0.7763	0.0335
21	0.2289	0.7196	0.3387	0.5547		0.7141	0.3818	0.1239
22	0.4024	0.9940	0.1860	0.3387	0.7141		0.2148	0.2407
23	0.0380	0.2176	0.9344	0.7763	0.3818	0.2148		0.0160
24	0.7365	0.2377	0.0128	0.0335	0.1239	0.2407	0.0160	

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The GLM Procedure
Least Squares Means

Treatment*Year Effect Sliced by Year for SOM

Year	DF	Sum of Squares	Mean Square	F Value	Pr > F
1969	5	0.325648	0.065130	2.63	0.0235
1977	5	0.380922	0.076184	3.07	0.0097
1981	5	1.094352	0.218870	8.82	<.0001
2001	5	2.206472	0.441294	17.79	<.0001

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.