7-19-2016

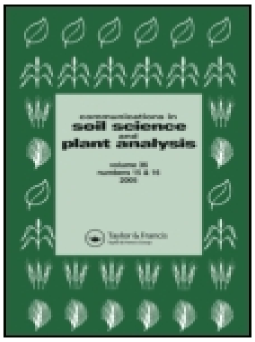
Impacts of Plant Community Changes on Soil Carbon Contents in Northeastern Illinois

Xiaoyong CHEN

Karen D'Arcy

Recommended Citation

CHEN, Xiaoyong and D'Arcy, Karen, "Impacts of Plant Community Changes on Soil Carbon Contents in Northeastern Illinois" (2016). *Faculty Research and Creative Activity*. 38.
https://opus.govst.edu/faculty/38



Taylor & Francis
Taylor & Francis Group

Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: http://www.tandfonline.com/loi/lcss20

Impacts of Plant Community Changes on Soil Carbon Contents in Northeastern Illinois

Xiaoyong Chen & Karen D’Arcy

To cite this article: Xiaoyong Chen & Karen D’Arcy (2016) Impacts of Plant Community Changes on Soil Carbon Contents in Northeastern Illinois, Communications in Soil Science and Plant Analysis, 47:13-14, 1644-1649, DOI: 10.1080/00103624.2016.1206121

To link to this article: http://dx.doi.org/10.1080/00103624.2016.1206121

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2016, VOL. 47, NOS. 13–14, 1644–1649
http://dx.doi.org/10.1080/00103624.2016.1206121

Impacts of Plant Community Changes on Soil Carbon Contents in Northeastern Illinois

Xiaoyong Chen and Karen D'Arcy

Division of Chemistry and Biological Science, College of Arts and Sciences, Governors State University, University Park, Illinois, USA

ABSTRACT

Land-cover changes not only affect regional climates through alteration in surface energy and water balance, but also affect key ecological processes, such as carbon (C) cycling and sequestration in plant ecosystems. The object of this study was to investigate the effects of land-cover changes on the distribution of soil organic carbon (SOC) contents under four plant community types (deciduous forests, pine forests, mixed pine-deciduous forests, and prairies) in northeastern Illinois, USA. Soil samples were collected from incremental soil depths (0–10, 10–20, 20–30, and 30–50 cm) under the studied plant communities. The results showed that SOC concentration decreased with increases of soil depth in the studied forests and prairies. No significant differences of SOC concentrations were found at the upper soil layers (0–10 cm) among the four plant types. However, SOC concentrations were statistically higher at the lower soil depth (30–40 cm) in prairies than in other three forest types. The SOC storage (0–40 cm soil depth) was reduced in an order prairies (250.6) > mixed pine-deciduous forests (240.7) > pine forests (190.1) > deciduous forests (163.4 Mg/ha). The characteristics of relative short life cycle, restively high turnover rate of roots, and large partition of photosynthetic production allocated to belowground were likely attributed to the higher accumulation of C in soils in tallgrass prairies than in forests. Our data indicated the conversion of native tallgrass prairies to pure forest plantations resulted in a considerable decline of SOC storage. Results suggest that land-cover changes have a significant impact on SOC storage and sequestration in plant ecosystems.

ARTICLE HISTORY
Received 20 March 2015
Accepted 27 March 2016

KEYWORDS
Forest; land-cover change; plant community; prairie; soil carbon

Introduction

Soils are the dominant pool of carbon (C) in terrestrial ecosystems (Lal 2004; Post et al. 1982). It is estimated that soils contain twice as much C as the atmosphere and about 75% of the total terrestrial C pool is stored in the world's soils (Johnston et al. 2004). Sequestration of carbon dioxide (CO_2) in the soils as soil organic carbon (SOC) has been considered one of the ecosystem services and as an approach to reduce atmospheric CO_2 concentrations in order to mitigate climate change (IPCC 2001; Lal 2004). Given such a huge amount of SOC at the global scale, even minor changes in the balance between soil C storage and release could have significant impacts on the global C budget. The soil C pool is determined by the balance between C input through litter and rhizodeposition and C output through decomposition in terrestrial vegetation ecosystems. Changes in SOC storage have been reported, depending on soil properties (Melillo et al. 2002), climate factors (Powlson 2005), C stabilization (Torn et al. 2002), forest managements (JandL et al. 2007), and land use/land-cover changes (Foley et al. 2005). Land-cover changes not only affect local and regional climate through altering the relation of surface energy and water balance, but also modify soil C contents through

CONTACT Xiaoyong Chen ✉ xchen@govst.edu Full Professor of Biology, College of Arts and Sciences, Governors State University, 1 University Parkway, University Park, IL 60484, USA.

changes in the interactions between residue inputs to soil and the subsequent transformations mediated by soil microorganisms (Dameni, Wang, and Qin 2010; Dube et al. 2009; Guo and Gifford 2002; Post and Kwon 2000).

One-third to one-half of the Earth's land surface has been altered by human activities (Vitousek et al. 1997). The shifting dominant vegetation types at the regional levels have resulted in a significant alteration in terms of primary production, aboveground and belowground biomass allocation, roots distribution and turnover, and soil faunal communities, in turn affecting C cycle and SOC dynamics (Jobbagy and Jackson 2000). Based on a database of 74 publications, Guo and Gifford (2002) reported that soil C stocks were reduced by about 50% in the topsoil from native forest to cropland, while cropland restored to forest, soil C stock was recovered. Post and Kwon (2000) pointed out that the rapid loss of SOC due to various land uses resulted mainly from the reduction of aboveground and belowground organic matter inputs, increment of plant residues decomposability, and increasing human practice activities that destroy physical protection to decomposition in soils. The conversion of natural tallgrass prairies to agricultural crops has caused a substantial reduction of ecosystem services including C stocks in the United States since the onset of European settlement (Kucharik, Fayram, and Cahill 2006). It is particularly true in Illinois, where more than 99.9% of native tallgrass prairies have been eliminated since the onset of European settlement (Ladd 1995; Samson and Knopf 1994). The understanding of the relationship between SOC stocks and dynamics and the plant ecosystems is helpful to determine whether the plant ecosystems are sustainable in C issue, because land management affects the content and quality of soil C. However, there have been few comparative studies of the influence of land-cover changes on SOC storage in northeastern Illinois.

The purpose of this project was to investigate the influence of land-cover changes on SOC storage and distribution under four types of plant communities in Thorn Creek watershed, northeastern Illinois. The specific objectives of this study were: (1) to examine the vertical distribution patterns of SOC concentration in different land-cover types and (2) to provide the values of SOC storage under the four plant communities in the Midwest temperate forest region.

Materials and methods

The study area was located in Thorn Creek watershed in Park Forest (41° 27′ 32″N, 87°41′15″ W), about 40 km south of the city of Chicago, Illinois. The climate of the study area was continental. The mean annual temperature is 10.6°C with the maximum monthly temperature of 24.2°C in July and a minimum of −4.7°C in January. Mean annual precipitation is 972.8 mm, with the heaviest in the growing season and the lightest in midwinter. The bedrock of the Thorn Creek watershed primarily comprises Silurian dolomite and Ordovician Maquoketa shale. The soils in the study site are classified as mollisols rich in organic matter and have a black to dark brown color. The major tree species in the study area are white oak (Quercus alba L.), northern red oak (Quercus rubra L.), ironwood (Ostrya virginiana Mill.), sugar maple (Acer saccharum Marsh.), and slippery elm (Ulmus rubra Muhl.) in the upland forests; and Basswood (Tilia americana L.), slippery elm, sugar maple, and red oak in the floodplain forests (Authors, unpublished data).

In the present study, four major land-cover types were chosen in the study area. They were: (1) deciduous forests, (2) pine forests, (3) pine-deciduous mixed forests, and (4) prairie communities. One site (about 1 ha in size) with a relative homogenous topography that was located within the same and larger land-cover patches was identified for each land-cover type. Three plots (10 m × 10 m) were selected for each of the four land-cover types. The three plots were set up about 50 m apart. At each plot, three replicate holes were augured using a hand auger. Prior to soil sampling, all litter and other organic debris on the soil surface were removed. Soil samples were collected from the augured soil core at four depths of 0–10, 10–20, 20–30, and 30–50 cm, respectively. Plant and animal residuals and large rocks were carefully removed by hand from the soil samples. Soil samples were brought to the Governors State University laboratory for analysis. Soil samples were air dried at ambient conditions, passed through a 2-mm sieve, and then dried in an oven for 48 h at 60°C. After that soil samples were stored in sealed sample jars for preparation for chemical analysis.

The soil bulk density was measured using a stainless steel cylinder (Paltineanu and Starr 1997). The steel ring was inserted into the soil at four depth intervals (0–10, 10–20, 20–30, and 30–50 cm), respectively, and then excavated using a small spade. The soil samples were dried at 105°C for 48 h. Two samples were collected for each land-cover type. The concentration of SOC was determined by the Walkley Black Wet Digestion Method (Peverill, Sparrow, and Reuter 1999).

The effects of the four land-cover types on SOC concentration and storage were statistically examined using analysis of variance (ANOVA) by the SAS (Statistical Analysis System) statistical program (SAS Institute Inc. Cary, NC). A confidence level of $p < 0.05$ was employed to determine whether significant differences existed among the four land-cover types.

Results

In general, the concentrations of SOC decreased with increasing soil depth along the soil profile in each plant community (0–40 cm) (Figure 1). The SOC concentration decreased by about 70, 9, 62, and 58% at 40 cm depth when compared with that in the surface (5 cm depth) in the deciduous forest, prairie, mixed forest, and pine forest, respectively.

No significant differences of SOC concentration were found in the surface (5 cm depth) among the four land-cover categories ($p < 0.05$) (Figure 1). At 40 cm depth, the SOC concentration was significantly higher in prairie than in the other three forest types ($p < 0.05$), while no statistically significant differences were found in terms of SOC concentration at 40 cm depth among the three land-cover types. On average, prairies had the highest value of SOC concentration in the soil profile, followed by the mixed forests, pine forests, and the deciduous forests.

The total SOC storage at 0–40 cm depth of each land-cover type was in the order prairie > mixed forest > pine forest > deciduous forest. SOC storage was significantly higher in prairie and mixed forest than in pine forests and deciduous forest ($p < 0.05$). There was an approximate 4, 24, and 35% decrease in SOC storage that resulted from the conversion of prairie to mixed forest, pine forest, and deciduous forests, respectively, in the study area (Table 1).

Discussion

We observed that the distribution of SOC concentration and content varied in different plant types in the study area (Figure 1 and Table 1). In other words, the conversion of prairies to forests resulted

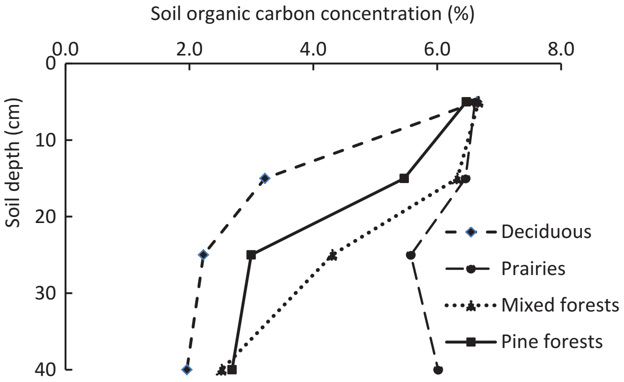


Figure 1. Vertical distribution of SOC concentration in the four plant community types in the study site.

Table 1. Soil organic carbon content in the four plant community types in the study site (Mg/ha).

Soil depth (cm)	Deciduous forests	Pine forests	Mixed forests	Prairies
0–10	59.3	66.3	54.1	55.1
10–20	38.5	55.6	81.4	93.3
20–30	32.9	42.3	66.9	49.5
30–40	32.6	25.9	38.3	52.7
Total	163.4	190.1	240.7	250.6

in a reduction of SOC storage. Specifically, SOC storage reduced from prairie to deciduous forest by about 35%, to pine forest by about 24%, and to mixed forest by about 4%. The results are consistent with the findings from many previous studies, which have indicated the decline of SOC storage due to the conversion of grasslands and prairies to forests or increase of SOC stocks from the restoration of prairie communities. For example, Huygens et al. (2005) reported a 31% increase and a 42% decrease of SOC stocks at 0–30 cm depth for the conversion from second-growth Nothofagus obliqua forest to grass and grass to phosphorus (P) radiate forest, respectively. Dube et al. (2009) found that the SOC content increased by 33% resulting from the conversion of second-growth Nothofagus pumilio forest to a degraded natural prairie and a 14% decrease from degraded natural prairie to Pinus ponderosa plantations. After conducting a meta-analysis, Guo and Gifford (2002) pointed out C stocks in soils increased after land-use changes from native forest to pasture (+8%). The soil C stocks declined after land-use changes from pasture to plantation (−10%), native forest to plantation (−13%), native forest to crop (−42%), and pasture to crop (−59%).

Although the exact mechanisms controlling the changes in SOC storage in different land-cover types were not achieved in the present study due to the short time of investigation, a number of factors might have contributed to the increase and decrease of SOC from the conversion between forests and prairies. First, prairies have a relative shorter life cycle as compared with trees, contributing to more C resources coming from both aboveground and belowground litters. Trees are perennial, while the aboveground parts of most prairie species die back each year. In addition, the turnover rate of the roots in prairies was rapid. Thus, the increased litter loads and rapid root turnover processes have input large quantities of organic matter to the soil. This was one reason why the prairie soils were often so fertile (Ladd 1995). Second, more photosynthetic productions were allocated to the belowground parts in prairies than in forests. The participation ratio of roots to shoots was in prairies (Ladd 1995). On average, forests put 20% of annual net productivity (2.6 t/ha year) to the belowground parts, while this proportion was 60% in grasslands (9.0 t/ha year) (Heal and Ineson 1984). Because of the difference of biomass allocation and rooting depth, soil organic matter was nearly double in prairies than in forests in the temperate zone: 220 versus 120 t/ha (Heal and Ineson 1984; Schlesinger 1977). Third, there were fundamental differences of the decomposition of organic inputs to the soil between forests and prairies. The major organic inputs were aboveground litter in forests, which did not get incorporated to the soil in the short term. However, the primary organic inputs were the decomposition of fine roots in prairies (Sauer, Cambardella, and Meek 2006). Prairie and grass communities were often dominated by deep-rooted species. The extensive and deep rooting systems can reach more than 1.8 m deep in soil in most prairies (Risser et al. 1981), which facilitated the survival, growth, and development of prairie plants under extreme heat, droughts, and fires. Fourth, the annual turnover rate of SOC from roots was rapid in prairies and grasslands than in forests (Jobbagy and Jackson 2000), which caused prairies to have more SOC than native forests and forest plantations (Buol et al. 1997).

The tallgrass prairies were ever the largest vegetation type in North America, but 80–99% of this plant community has been eliminated in size (Samson and Knopf 1994). The Illinois State was called "The Prairie State". Historic records indicated that prairie communities (about 9 million ha) accounted for over 60% of the total Illinois lands (about 14.5 million) prior to extensive European settlement in 1820 (Iverson et al. 1989). Although Illinois used to be a vast landscape of prairies, only one-hundredth of 1% of the Illinois prairie still remains (Ladd 1995). Therefore, the tallgrass prairies represented one of the most critically endangered plant ecosystem types in North America (McPhee et al. 2015). From a climate change and C issue perspective, prairie restoration is not only to rescue this state's heritage, but also to enhance the removal of CO_2 from the atmosphere and sequestrate C within the soil as SOC (Matamala et al. 2008). Our results suggested that the conversion of prairies to forests caused a substantial decline of SOC contents, implying the huge losses of SOC from Illinois's prairie lands since the last two centuries. It was estimated that about 55–75 Gt C have been released from the global soils as a result of land conversion during the postindustrial era (Lal 2004). As a consequence, tallgrass prairie restoration serves not only as an important approach to restore native floristic diversity, but also as a practicable tool for C management.

Conclusions

This study found that SOC concentration and storage decreased from the conversion of tallgrass prairies to forests in northeastern Illinois. Particularly, the decline of SOC contents mainly occurred in the lower soil layer (20–40 cm depth) in the monoculture forests. Although the exact mechanisms controlling the dynamics of SOC storage in different plant community types could not be provided due to the short duration of this study, the characteristics of short life cycle, large partition of biomass allocated to belowground, and the relative high turnover rate of roots in prairies were probably attributed to the high accumulation of C in soils in prairies and grasslands. Generally, the amount of SOC results from the net balance between the rate of SOC inputs and the rate of mineralization in SOC pools. Several factors and processes are involved in the changes in SOC in a plant ecosystem, such as aboveground and belowground litter and other organic C debris input and decomposition processes and root exudation process. As a consequence, in order to completely evaluate the influence of land-use and land-cover changes on SOC budget and C sequestration at the ecosystem level, more empirical studies are needed in relation to the measurements of net primary productivity, respiration and decomposition processes at both aboveground and belowground parts of these vegetation ecosystems. In addition, a clear understanding of the characteristics of root turnover and root exudates is also needed for quantifying the transformation of organic C from roots to soils. Finally, long-term plant and ecology trials have been valuable for providing insights into the structure, function, and dynamic property of plant ecosystems (Callahan 1984; Rees et al. 2001). Conducting a long-term experiment that addresses SOC dynamics when land cover is changed from one type to another would be valuable in improving our better understanding of the C dynamics and enhance our ability in C management at temporal scales.

Acknowledgments

We are grateful to Dr. Joyce Mohberg, Mr. Ramanjaneyulu Garevidi, and Mr. Kamalnath Chowdary Vemuri for their assistance with field measurements and chemical analysis. We are also grateful to anonymous reviewers for helpful suggestions and comments.

Funding

This research was funded by a Research Grant of Governors State University to Dr. Chen.

References

Buol, S. W., F. D. Hole, R. J. McCracken, and R. J. Southard. 1997. *Soil Genesis and Classification*, 4th ed. Ames, Iowa: Iowa State University Press.

Callahan, J. T. 1984. Long-term ecological research. *BioScience* 34:363–67. doi:10.2307/1309727.

Dameni, H., J. Wang, and L. Qin. 2010. Soil aggregate and organic carbon stability under different land uses in the north China plain. *Communications in Soil Science and Plant Analysis* 41:1144–57. doi:10.1080/00103621003711297.

Dube, F., E. Zagal, N. Stolpe, and M. Espinosa. 2009. The influence of land-use change on the organic carbon distribution and microbial respiration in a volcanic soil of the Chilean Patagonia. *Forest Ecology and Management* 257:1695–704. doi:10.1016/j.foreco.2009.01.044.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. Stuart Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Pats, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequence of land use. *Science* 309:570–74. doi:10.1126/science.1111772.

Guo, L. B., and R. M. Gifford. 2002. Soil carbon stocks and land use change: A meta analysis. *Global Change Biology* 8:345–60. doi:10.1046/j.1354-1013.2002.00486.x.

Heal, O. W., and P. Ineson. 1984. Carbon and energy flow in terrestrial ecosystems: Relevance to microflora. In *Current perspectives in Microbial Ecology, 394-404 pp. Proceedings of the Third international Symposium on Microbial Ecology*, eds. M. J. Klug, and C. A. Reddy. Washington, DC: American Society for Microbiology.

Huygens, D., P. Boeckx, O. Van Cleemput, C. Oyarzun, and R. Godoy. 2005. Aggregate and soil organic carbon dynamics in South Chilean Andisols. *Biogeosciences* 2:159–74. doi:10.5194/bg-2-159-2005.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate change 2001: The Scientific Basis. In: J.T. Houghton,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, C.A. Johnson (Eds). *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, 1–881. Cambridge: Cambridge University Press.

Iverson, L. R., R. L. Oliver, D. P. Tucker, P. G. Risser, C. D. Burnett, and R. G. Rayburn. 1989. *The forest resources of Illinois: An atlas and analysis of spatial and temporal trends*. Urbana, Illinois: Illinois Natural History Survey Special Publication 11.

JandL, R., M. Lindner, L. Vesterdal, B. Bauwens, R. Baritz, F. Hagedorn, D. W. Johnson, K. Minkkinen, and K. A. Byrne. 2007. How strongly can forest management influence soil carbon sequestration. *Geoderma* 137:253–68. doi:10.1016/j.geoderma.2006.09.003.

Jobbagy, E. G., and R. B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* 10:423–36. doi:10.1890/1051-0761(2000)010[0423:TVDOSO]2.0.CO;2.

Johnston, C. A., P. Groffman, D. D. Breshears, Z. G. Cardon, W. Currie, W. Emanuel, J. Gaudinski, R. B. Jackson, K. Lajtha, K. Nadelhoffer, D. Nelson, W. M. Jr, P. G. Retallack, and L. Wielopolski. 2004. Carbon cycling in soil. *Frontiers in Ecology and the Environment* 2:522–28. doi:10.1890/1540-9295(2004)002[0522:CCIS]2.0.CO;2.

Kucharik, C. J., N. J. Fayram, and K. N. Cahill. 2006. A paired study of prairie carbon stocks, fluxes, and phenology: Comparing the world's oldest prairie restoration with an adjacent remnant. *Global Change Biology* 12:122–39. doi:10.1111/gcb.2006.12.issue-1.

Ladd, D. 1995. *Tallgrass Prairie Wildflowers*. Nashville, TN: Falcon Press.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623–27. doi:10.1126/science.1097396.

Matamala, R., J. D. Jastrow, R. M. Miller, and C. T. Garten. 2008. Temporal changes in C and N stocks of restored prairie: Implications for C sequestration strategies. *Ecological Applications* 18:1470–88. doi:10.1890/07-1609.1.

McPhee, J., L. Borden, J. Bowles, and H. A. L. Henry. 2015. Tallgrass prairie restoration: Implications of increased atmospheric nitrogen deposition when site preparation minimizes adventive grasses. *Restoration Ecology* 23:34–42. doi:10.1111/rec.12156.

Melillo, J., P. Steudler, J. Aber, K. Newkirk, H. Lux, F. Bowles, C. Catricala, A. Magill, T. Ahrens, and S. Morrisseau. 2002. Soil warming and carboncycle. Feedbacks to the climate system. *Science* 298:2173–76. doi:10.1126/science.1074153.

Paltineanu, I. C., and J. L. Starr. 1997. Real-time soil water dynamics using multisensor capacitance probes: Laboratory calibration. *Soil Science Society of America Journal* 61:1576–85. doi:10.2136/sssaj1997.03615995006100060006x.

Peverill, K. I., L. A. Sparrow, and D. J. Reuter. 1999. *Soil Analysis*, 1–369. CSIRO Publishing.

Post, W. M., W. R. Emanuel., P. J. Zinke, and A. G. Stangenberger. 1982. Soil carbon pools and world life zones. *Nature* 298:156–59.

Post, W. M., and K. C. Kwon. 2000. Soil carbon sequestration and land-use change: Processes and potential. *Global Change Biology* 6:317–28.

Powlson, D. 2005. Will soil amplify climate change? *Nature* 433:204–05.

Rees, M., R. Condit, M. Crawley, S. Pacala, and D. Tilman. 2001. Long-term studies of vegetation dynamics. *Science* 293:650–55.

Risser, P. G., E. C. Birney, H. D. Blocker, S. W. May, W. J. Parton, and J. A. Wiens. 1981. *The true prairie ecosystem*. Stroudsburg, Pennsylvania: Hutchinson Ross Publishing Company.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. *BioScience* 44:418–21.

Sauer, T. J., C. A. Cambardella, and D. W. Meek. 2006. Spatial variation of soil properties relating to vegetation changes. *Plant and Soil* 280:1–5.

Schlesinger, W. H. 1977. Carbon balance in terrestrial detritus. *Annual Review of Ecology, Evolution, and Systematics* 8:51–81.

Torn, M. S., A. G. Lapenis, A. Timofeev, M. L. Fischer, B. V. Babikov, and J. W. Harden. 2002. Organic carbon and carbon isotopes in modern and 100-yearold-soil archives of the Russian steppe. *Global Change Biology* 8:941–53.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. *Science* 277:494–99.