

Soils research and education linked to climate change in USDA's National/Agriculture and Food Research Initiative (NRI/AFRI) Programs

Nancy Cavallaro^A

^ANational Program Leader for Soils and Global Change, National Institute of Food and Agriculture, Washington, DC, USA, Email ncavallaro@nifa.usda.gov

Abstract

Federal funding for soil science research in the United States has changed over the last several decades, shifting from largely agriculture related work funded by the US Department of Agriculture to more interdisciplinary and environment oriented science funded by multiple federal agencies. Now that soils are recognized as a critical component of the global carbon cycle, much research is directed at understanding coupling between carbon cycle and climate change. When USDA's NRI first initiated a program-wide Strategic Issue to address aspects of global and climate change, the reaction from the scientific research community was enthusiastic, and nearly a third of the proposals submitted to the Soil Processes program were climate change related. Although the Strategic Issue concept was later dropped, the theme continued to be prominent in the proposals submitted to the Soil Processes program. In 2009, recognizing the decline in undergraduate soils majors and the increased interest in environmental studies at major universities, the USDA's AFRI prioritized increasing the relevance of soils curricula to climate change by promoting the incorporation of the many sub-disciplines of soil science into climate change related curricula. This paper presents significant highlights of the NRI and AFRI funded soils and global change research, and presents some of the key issues and uncertainties that will influence soil science research and teaching in the future.

Key Words

Soil carbon, climate change, research funding, education.

Introduction

Scientists now recognize the pervasive influence of human activities on all ecosystems and that these global changes will become more pressing in the future. Because soil processes exert a major influence on the terrestrial carbon cycle, as well as on CO₂, methane, nitrous oxide, and other greenhouse gas fluxes from terrestrial ecosystems, and on water availability and quality, they are central to many issues of managed and unmanaged ecosystem responses and feedbacks to climate change. Global climate change was one of three overarching Strategic Issues in the 2003 US Department of Agriculture's National Research Initiative's (NRI) request for applications, and in 2004 the first program was established to address this issue within the NRI as an interagency solicitation on carbon cycle science as it related to climate change. Since then there have been five additional interagency solicitations: in land use and land cover change, land use and invasive species, ecosystems services, and two follow-on carbon cycle calls for proposals. The National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), and Department of Energy (DOE) have been key partner agencies with USDA in these solicitations. Years after NRI and its successor program, the Agriculture and Food Research Initiative (AFRI) abandoned the Global Change program-wide Strategic Issue, applicants and awarded projects of the Soil Processes program continued to include many projects related to soils and climate change. Several of the recipients of research awards from the NRI and AFRI Global Change program were for projects involving soil organic carbon changes, greenhouse gas fluxes to and from soils, and other climate change issues involving soil processes. These small programs have produced some important advances, some of which will be described in this paper. Also presented are suggested soils research needs for informed soil management and adaptations to mitigate climate change and greenhouse gas emissions.

Key highlights of NRI and AFRI climate related soil research

Agricultural Ecosystems: Crop and animal production systems are often assumed to contribute to increases in atmospheric greenhouse gases whereas forests are believed to be carbon sinks. Yet the net effect of any ecosystem on greenhouse gases depends on ecosystem productivity and management as well as on type and intensity of disturbances such as forest fires, soil manipulations, pests and diseases, and these depend in part on soil factors. Stephen Ogle, and co-investigators at Colorado State University, funded by the NRI-NASA Global Change program, addressed uncertainties of carbon fluxes from agricultural lands in the U.S. Mid-

West. Working with the U.S. Natural Resources Conservation Service (NRCS), they developed sampling and analysis protocols for soil carbon assessments and decision support tools for land owners and carbon aggregators. The importance of this project is that it includes new refinements of carbon flux models, by coupling natural and crop vegetation and soil process models, thus increasing confidence in modeling ecosystem carbon changes using the integrated CASA-Century model (Ogle *et al.* 2010). This will allow farmers and carbon project aggregators to use the model in estimates of carbon changes as part of government regulatory programs and for future carbon trading. The integrated model may also be used for governmental reporting of carbon stock changes in agricultural lands to the United Nations Framework Convention on Climate Change. The sampling protocols developed will contribute to improving the NRCS's National Resources Inventory carbon stock change estimates across diverse climate regimes. The USDA soil monitoring network developed from the project's pilot sampling campaign will also be an asset for evaluating future carbon policies as greater demands are placed on soil resources for biofuel feedstocks, and to meet increasing demand for food, forage and fiber production with a growing world population.

Carbon cycling in forest ecosystems: Several recent Soil Processes program grants have led to a network of sites in eastern and western US forests as well as a site in Eastern Europe to study effects of forest litter and root inputs on soil carbon and nitrogen cycling (Crow *et al.* 2008). Another team has looked at soil processes under increased atmospheric CO₂ conditions (Cheng 2008). Both teams of researchers have shown the key role of nitrogen in controlling these processes. Another major finding was that increased carbon inputs as litter or roots, via management or through increased atmospheric CO₂, can have a priming effect on soil carbon decomposition, releasing greater amounts of CO₂, offsetting carbon fixed through photosynthesis or added via management practices. Although the net effect of this priming phenomenon over decadal time scales is uncertain, it is clear that this result and the mixed results regarding old growth forests as carbon sinks, has led to a rethinking of models and estimates for the impact of climate change and increasing CO₂ on organic matter in forest soils. These and other findings supported decisions to incorporate nitrogen as a factor in modeling the effects of increasing CO₂ on ecosystems and their feedbacks to climate change by the IPCC.

In the Western U.S., intense, stand-replacing fires are increasing due to warmer temperatures and longer growing seasons. Thomas Kolb and co-investigators from Northern Arizona University investigated effects of forest management and wildfires on CO₂ and methane fluxes from Ponderosa pine forests. They analyzed effects of prescribed burning and thinning on bark beetle attack, pest resistance, and tree mortality, providing forest managers with science-based information for management strategy decisions to optimize forest growth and carbon sequestration in soil and biomass, and reduce risk of stand-replacing fires that change these forest carbon sinks into carbon sources for over 10 years after the fire (Montes-Helu *et al.* 2009).

Soils and biofuel production: An important greenhouse gas mitigation strategy in agriculture and biofuels production is to reduce fertilizer use via increased efficiency and microbial nitrogen fixation in soils. Researchers at Cornell University showed that soil N-fixation rates by free-living (not symbiotic) microorganisms were correlated with the diversity of the diazotrophic community in soil. In long-term (>30 yr) experimental plots under continuous corn, diazotroph diversity and N-fixation rates were higher in fields where corn biomass was removed at harvest than where it was retained (Hsu and Buckley (2008). This has implications for crop selection and soil management for biofuel production. These findings demonstrate the need for long-term research trials and analysis since short term results of high C:N of biomass such as corn stover would be expected to stimulate N-fixation in soil.

Microbial ecology of soils: Cornell researchers funded by the NRI Soil Processes program recently developed methods for improving the technique of ¹³C and ¹⁵N DNA stable isotope probes (SIPs) (Buckley *et al.* 2008), overcoming previous constraints on the use of ¹⁵N labeled compounds in nucleic acid SIP, with far reaching implications for studying microbial processes in soils and identifying non-culturable microorganisms involved in major environmental processes. They used ¹⁵N₂-SIP of DNA to show that nonculturable free-living atmospheric nitrogen (N₂) fixers in soil can carry out nitrogen fixation *in situ*, and that ¹⁵N-DNA-SIP can be used to gain access to DNA specifically from these organisms. They identified three groups of free living (non-symbiotic) diazotrophs that are actively involved in N₂ fixation and provided evidence for N₂ fixation by previously unknown orders of microorganisms. They then examined their response to experimental manipulation *in situ*, beginning with carbon and energy sources thought to be major constraints on N fixation in soil, and were able to use ¹⁵N₂-DNA-SIP to explore carbon sources used by

specific populations of N₂ fixers under both aerobic and anaerobic atmospheres. Their results demonstrated, for the first time, nitrogen fixation by a specific group of methanotrophs, and that methane stimulates N₂ fixation in soils, suggesting the potential of using different carbon sources to manage this process. These data also explain observations of increased nitrogen concentrations in soils surrounding gas pipeline leaks. These findings link to climate change because methane and nitrous oxide are potent greenhouse gases, and conservation of soil nitrogen is critical to the maintenance and production of crops, pastures rangelands and forests to mitigate rising atmospheric CO₂ and greenhouse gases.

Soils and organic carbon dynamics: Stability and vulnerability of soil organic carbon fractions has become an important issue because soil carbon is the largest pool of terrestrial carbon, estimated to be about 1550 Pg C in the top 100 cm, and 2450 Pg C in the top 200 cm (Batjes 1996). This is three times the total carbon in the atmosphere, so the potential to influence CO₂ climate forcing via greater storage or the release from soils is high. Thus the program is supporting a network (National Soil Carbon Network) and searchable database for a community of researchers on soil carbon distribution and vulnerability. One potentially stable soil carbon form is biochar, a product of incomplete combustion of organic materials that occurs naturally in soils where fires are common. Recent advances in its detection have revealed that it constitutes a significant proportion of the total soil organic carbon in many soils. Biochar has come under scrutiny because it is a byproduct of a bioenergy production method, pyrolysis, and the recalcitrance and environmental effects of this form of biochar is unknown. Johannes Lehmann and coworkers received awards from the Carbon Cycle and Soil Processes programs to study biochar in soils. Early results from these projects suggest a mean residence time in soil of 1000-3000 years for forest fire biochar (Lehmann *et al.* 2008), but estimates vary in the literature and many questions remain about mechanisms for disappearance of this material from soils.

Soil carbon and permafrost: Another key climate change question is the potential impact of the melting of permafrost soils and subsequent release of this thermally stabilized store of carbon. Understanding soil processes controlling the fate of carbon in thawing permafrost is key to predicting impacts and feedbacks of global warming in boreal areas. Preliminary results from a recently funded project (E. Kasishke, University of Maryland, and A.D. McGuire, U.S. Geological Survey) indicate that these areas of the North American boreal forest are becoming weaker sinks or stronger sources primarily due to increased fire. The effects of fire and release of melting permafrost carbon are offset in part by increased plant growth, but questions remain about the balance over decadal timescales and the potential of a priming effect on this soil carbon. A recent article by McGuire and others (2009) reviews the sensitivity of Arctic carbon dynamics to climate change and calls for linking observations of carbon dynamics to the processes that control them, and soil behavior and processes with changing climate is central to that. The potential release of methane hydrates in and beneath permafrost soils is also of interest, as is the effect of temperature rise on methane and nitrous oxide release from wetlands. Soil microbial community capacities to reduce or exacerbate these and other greenhouse gases under a changing climate, and accompanying responses of humans and ecosystems are important and understudied questions that soil scientists are poised to address.

Soil science education: Despite growing interest in soils in the research community, and the relevance of soil science to environmental issues such as climate change, many university soil science departments in the U.S. are being lost, renamed or merged with other disciplines, resulting in less visibility. This is partly due to an overall decline in undergraduate student enrollment in soil science both nationally and internationally. Many professors note that graduate students in soil science often do not have undergraduate soils degrees and thus many lack fundamental coursework required in soils programs. At the same time, earth systems scientists now recognize the major role soils play many environmental issues, and major strides have been made in developing new methods and applying sophisticated and non-traditional methods to the study of soil science.

One way to address these issues is to improve the relevance of soil science courses and curricula to emerging and urgent environmental and socio-economic issues such as global change. Also, there is a particular need to incorporate fundamental soil science education into climate/global change analyses in order to understand the long-and short-term consequences of climate change and evaluate adaptation and mitigation strategies that include land use and soil management. The 2007 US National Research Council recommendations to the U.S. Global Change Research Program include addressing the need of the education community for a climate education framework, tools, and other resources for both formal and informal education. Whether students move on to careers in research, education, extension, business, policy or government, they will need a clear understanding of the links between climate change and soils in order to make responsible, environmentally

sound decisions in the context of changing conditions. In 2009, the AFRI Soil Processes program included a new priority and project type to support soil science education and its linkage to the issue of climate change, resulting in two funded projects: at the University of New Hampshire and Colorado State University. The program at New Hampshire will use a studio teaching approach with activity-based instruction including hands-on exercises, hypothesis driven experiments, and computer-based simulations, visualizations and data gathering exercises. The Summer Soils Institute at Colorado State University involves renowned faculty and focuses on hands-on experience with field and lab techniques, and emphasis on appreciation of critical issues in soil sustainability in the face of global change and societal pressures. This program is a small step, but it is hoped that this emphasis on soils education specifically linked to key societal issues such as climate change can continue and inspire students and faculty across the United States on the importance of soil science.

References

- Batjes NH (1996) Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science* **47**, 151-163.
- Buckley DH, Huangyutitham V, Hsu S-F, Nelson TA (2008) ¹⁵N₂-DNA-stable isotope probing of diazotrophic methanotrophs in soil. *Soil Biology and Biochemistry* **40**, 1272-1283.
- Cheng W (2008) Rhizosphere priming effect: Its functional relationships with microbial turnover, evapotranspiration, and C-N budgets. *Soil Biology and Biochemistry* **41**, 1795-1801.
- Crow SE, Lajtha K, Bowden RD, Yano Y, Brant J, Caldwell BA, Sulzman E (2008) Increased coniferous needle inputs accelerate decomposition of soil organic matter in an old-growth forest. *Forest Ecology and Management* **258**, 2224-2232.
- Hsu SF, Buckley DH (2008) Evidence for the functional significance of diazotroph community structure in soil. *International Society for Microbial Ecology* **3**, 124-136.
- Lehmann J, Skjemstad JO, Sohi S, Carter J, Barson M, Falloon P, Coleman K, Krull E (2008) Australian climate-carbon cycle feedback reduced by soil black carbon *Nature Geoscience* **1**, 832-835.
- McGuire AD, Anderson LG, Christensen TR, Scott D, Laodong G, Hayes DJ, Martin H, Lorenson TD, Macdonald RW, Nigam R (2009) Sensitivity of the carbon cycle in the Arctic to climate change. *Ecological Monographs* **79**, 523-555.
- Montes-Helu M, Kolb TE, Dore S, Sullivan B, Hart S, Koch G, Hungate B (2009) Persistent effects of fire-induced vegetation change on energy partitioning and evapotranspiration in ponderosa pine forests. *Agricultural and Forest Meteorology* **149**, 491-500. doi:10.1016/j.agrformet.2008.09.011
- Ogle SM, Breidt FJ, Easter M, Williams S, Killian K, Paustian K (2010) Scale and uncertainty in modeled soil organic carbon stock changes for US croplands using a process-based model. *Global Change Biology* **16**, 810-822.