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Organization: Michigan State University
Submitted By: G. Philip Robertson, Principal Investigator
Title: The KBS LTER Project: Long-term Ecological Research in Row-crop Agriculture

Project Participants

Department abbreviations
CSS – Crop & Soil Sciences (now PSM)  PBL – Plant Biology
PSM – Plant, Soil, & Microbial Sciences  ZOL – Zoology
MMG – Microbiology & Molecular Genetics  TE – Teacher Education
ENT - Entomology  FW – Fish & Wildlife
AEC – Agricultural Economics (now AFRE)  GEO – Geography
AFRE – Agriculture, Food and Resource Economics  ENE – Civil & Environmental Engineering
GLG – Geological Sciences  ANS – Animal Science
SOC – Sociology  PLP – Plant Pathology (now PSM)
MSUE – MSU Extension

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Organizational Partners
MSU AgBioResearch: Supports research facilities, instrumentation, and salaries.
Michigan State University Extension: Provides education and research for outreach activities
Participants in the KBS K-12 Partnership for Science Literacy
Comstock Public Schools Lawton Community Schools
Delton-Kellogg Community Schools Martin Public Schools
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Activities and Findings

Research and Education Activities:

Activities and Findings

Over the second year of the current phase of the KBS LTER program (2011-2016), we have concentrated efforts on maintaining long-term investigations and have continued to address issues identified in our proposal reviews. Additionally, we have made major progress on our first site synthesis volume and are on schedule for a late fall submission to Oxford University Press. Overall research productivity continues to be strong: since the beginning of the current award period we have published or in press 70 journal articles (up from 39 last year), 12 book chapters (up from 9 last year), and 7 theses and dissertations (up from 3 last year), as listed elsewhere. Some 26 projects funded with non-LTER funds are active on site (listed below), including a major DOE Bioenergy Research Center for which KBS LTER is the principal field site. Below we highlight progress in selected areas of our major research areas, and report on externally-funded projects active on site.

1. Agronomic Dynamics (S. Snapp, lead)

Highlights

- The feasibility of scaling ‘plot’ results from the KBS Main Cropping System Experiment (MCSE) to a farm scale has been demonstrated through a unique approach involving randomized implementation of management practices across 27 commercial fields at KBS; results show treatments are broadly scalable.
- A sensitive early indicator of soil carbon accumulation was successfully identified through a multi-institutional effort lead by KBS to assess chemically-labile soil C pools that reflect management intensity.

Agronomic knowledge emerging from our Main Cropping System Experiment (MCSE) continues to inform the provision of ecosystem services from row crop ecosystems. The most important service from a crop production system is yield, and grain yields from our rotated crops have been close to averages for rainfed production in the North Central region for corn, soybean and wheat. A key question that has arisen is the feasibility of ‘scaling out’ the alternative management treatments. To test this, a unique scaling experiment was initiated in 2006, when 27 arable fields were placed in a corn-soybean-wheat rotation and managed following the protocols of treatments 1, 3 or 4 (27 fields = 3 replications x 3 crop phases x 3 treatments). Treatment 1 follows conventional management practices, treatment 3 follows ‘low input’ practices where biology supports a 40% reduction in nitrogen fertilizer, and treatment 4 follows ‘organic’ practices that completely rely on biological processes. Corn yield response in the scale-up fields is shown in Fig. 1. Reduced input treatment 3 is performing remarkably well, with a mean response similar to conventional (14% reduction, compared to conventional).
with high spatial variability). The zero chemical input treatment 4 on the other hand produces 40% of conventional. This is remarkably similar to the results from the main site.

Additionally, we have created and tested a simple and sensitive analytical tool for documenting early soil carbon change in ecosystems undergoing rapid change. The permanganate oxidizable carbon (POXC) method (Culman et al. 2012) measures labile soil C with enough sensitivity to detect changes otherwise difficult to detect with even 5-10 years of C accumulation. In a cross-site analysis of 1,400 soil samples from 53 sites encompassing a wide range of agricultural systems across North America we found POXC closely related to smaller-sized C fractions (Fig. 2), which have been shown to be associated with a processed pool of labile soil C. The POXC method is a promising inexpensive approach to assessing active soil C and by extension an early indicator of soil C change.

2. Biogeochemical Dynamics (S. Hamilton, lead)

Highlights

- We have developed new advances in stable isotope experiments for understanding how wetlands affect water quality (O’Brien et al. 2012a).
- A major unsolved question from the LINX stream experiments—the long-term fate of assimilated nitrogen—has been investigated using novel experimental methods (O’Brien et al. 2012b) that suggests little additional denitrification of added nitrate initially captured by stream biota.
- A 20-year analysis of MCSE results show that successional vegetation, once equilibrated, can provide biofuel feedstock at levels similar to those of purpose-grown monocultures with substantial greenhouse gas mitigation potential and no carbon debt.
- While not explicitly LTER related, knowledge of LTER has contributed substantially to advising the EPA and Enbridge on cleanup of the Kalamazoo River after the largest oil spill in the Midwest and the first major tar sands spill.

The central questions of our landscape biogeochemistry component are in complex agricultural landscapes, 1) how do land use patterns and management practices affect the fluxes of water and nutrients to lakes, streams, and wetlands, and 2) how are fluxes altered in transit? To address these questions we continue our work on the biogeochemistry of wetlands, streams, and lakes in agricultural landscapes, including consideration of how the cycles of C, N, P, Fe and S are coupled in ways that affect nutrient mobility and availability and consequent problems with eutrophication (Burgin et al. 2011 and 2012). We have studied how microbially mediated transformations of iron and sulfur control phosphorus retention and release in sediments of shallow waters, and the role of fluctuating water levels in mobilizing stored phosphorus pools (L. Kinsman-Costello and D. Kincaid, dissertations in progress).

We continue to examine how wetlands contribute disproportionately to biogeochemical transformations that affect downstream water quality. While most national and international work— including the multi-site Lotic Intersite Nitrogen Experiment (LINX) study that we participated in (Mulholland et al. 2008)—has focused on headwater streams, the majority of headwater streams in our region have wetlands and ponds along their courses. We have developed new approaches for whole-ecosystem tracer experiments in
these types of water bodies (O’Brien et al. 2012a) in order to resolve N transformations with the same
degree of resolution provided for streams by the ground-breaking LINC work.

New work commencing now with an NSF EAGER grant to Hamilton and co-I Nathaniel Ostrom will
develop far more sensitive measurement capabilities for the stable isotope ratio of dissolved N₂, which
will allow us to conduct LINC-style whole ecosystem ¹⁵N tracer experiments in larger, more
hydraulically complex water bodies than the small streams studied by LINC. Also related to the LINC
project, Hamilton spearheaded and now is advising a new effort to make the LINC data available
online, funded by an LTER supplement to AND.

In the past year we have conducted experiments to
answer a major unsolved question emerging from
our LINC studies: What is the long-term fate of N
that is assimilated by stream biota? This is
important because LINC results indicate that on
average only 16% of the total nitrate uptake is
directly denitrified (Mulholland et al. 2008), with
the balance incorporated into algal and microbial
biomass. Hence we need to know whether that assimilated N is merely temporarily detained, to later be
released as inorganic N, or if a substantial fraction of it is subject to eventual “indirect denitrification” via
coupled remineralization-nitrification-denitrification. We designed novel in-situ stream isotopic labeling
experiments to test hypotheses about the fate of assimilated N (O’Brien et al. 2012b); the results
summarized in Fig. 3 suggest little indirect denitrification.

Our renewal proposal calls for enhanced linkages between our plot- and field-based work and our ground-
and surface-water biogeochemistry research. We are moving in this direction with detailed studies of soil
hydrology including terrestrial water balances and nitrate leaching, and we are seeking to build a
groundwater hydrology component. TDR depth profiles and Electrical Resistivity Tomography imaging
of soil moisture are leading to new insights into crop and successional field water balances. Groundwater
flow modeling could link this soil root zone work to surface water hydrology. We have sought funding to
work with co-I Shu-Guang Li to apply such models to biogeochemical and ecological research questions,
including the role of groundwater discharge in sustaining wetlands of particular conservation interest.

A 21 year analysis of MCSE results has provided the opportunity to evaluate the greenhouse gas
consequences of using produced biomass for biofuel feedstocks. Our greenhouse gas analysis (Fig. 4)
shows that successional vegetation has by far the greatest climate benefit with a fossil fuel offset credit
that rivals that of purpose grown crops. The fact that successional vegetation is produced without carbon
debt suggests that it could provide a substantial fraction of the national cellulosic biofuel target and
furthermore, if grown on marginal lands will also avoid indirect land use costs (Gelfand et al., in review).

KBS LTER research results have also been used extensively to inform efforts to clean up the 2010 oil
spill in the Kalamazoo River, which drains the watershed in which our site resides. This spill is the largest
conterminous US spill to date, and dumped about a million gallons of tar sands crude oil into the river.
LTER results from stream, wetlands, and river research provided EPA the local background knowledge
needed for effective cleanup, which was advised by co-PI Hamilton. This cleanup is considered an
important test case in light of plans for the vast expansion of tar sands mining and transportation across
Canada and the U.S.
3. Microbial Dynamics (T. Schmidt, lead)

Highlights
- Nitrous oxide (N₂O) fluxes from row crop agriculture are not only influenced by increased fertilization, but also by the concomitant changes in the structure of the community of denitrifying bacteria responsible for N₂O production.

The earth’s N cycle has been influenced dramatically by modern agriculture, with more than half of the N₂O in Earth’s atmosphere now attributed to microbial processes in agricultural soils (Reay et al. 2012). Yet the connection between the structure of the community and the production of this greenhouse gas remains obscured. Clarifying the relationship between microbial communities and the flux of N₂O should advance the development of predictive models for N₂O flux and inform strategies for mitigation (Thomson et al. 2012).

A fundamental question regarding factors responsible for the structuring of microbial communities across the KBS LTER landscape is Can the composition of microbial communities in agricultural soils be explained adequately by a neutral model of community assembly or is there evidence for stronger selection on denitrifying bacteria? We have targeted denitrifying bacteria because they are responsible for the production of N₂O and because they are thought to respond to nitrogen fertilization. We addressed this question with an explicit test of the neutral model of community assembly and evolutionary analyses of targeted and shotgun metagenomes.

Based on the analysis of molecular surveys, we find that the composition of bacterial communities in agricultural soils cannot be explained by a neutral model of community assembly seeded with microbes from the adjacent forested sites. Rather, by comparing the ratio of non-synonymous to synonymous substitutions (dS/dS) in the coding sequence of nirK (a pivotal gene in the denitrification pathway), we find convincing evidence for stronger purifying selection on denitrifying bacteria in soils used for agriculture (Fig. 5). Three different methods were used to compare dS/dS - a standard measure of selection pressure between species - for nirK across four land treatments: row crop agriculture (T1), early successional lots (T7), mid-successional forests (SF) and deciduous forest (DF) soils. The results provide clear evidence that nirK sequences from soils used for agriculture are under stronger purifying selection than sequences in deciduous forest soils. Furthermore, the cessation of agriculture led to diminishing levels of purifying selection. These findings are bolstered by analyses of shotgun metagenomes that provide clear evidence that the proportion of the microbial community capable of denitrification is greater in the agricultural site (T1) than any of the unmanaged successional treatments or the deciduous forests.

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**Fig. 4.** Total (top) and net (bottom) greenhouse gas balances of KBS cropping systems if used for biofuel feedstock production. Bars represent different components of the GHG balance from all major sources, 1989 to 2009. From Gelfand et al., in review.
4. Plant Dynamics (K. Gross, lead)

Highlights
- In early successional communities, long-term nitrogen fertilization may not decrease species richness until tall clonal (or other superior growth form) biomass increases.
- Long-term nitrogen addition in our successional communities can cause the destabilization of legume-rhizobium mutualisms, which could have broad implications for nitrogen cycling in terrestrial ecosystems.

In our Plants Dynamics research we continue to focus on three major questions: 1) what are the controls on primary productivity in plant communities in agricultural landscapes; 2) what are the long-term impacts of chronic nitrogen inputs on plant communities; and 3) how does cropping system management impact the crop yields and the weed communities in row-crop agriculture. In this report we focus on key results from syntheses of a long-term experiment on the impacts of N addition on successional dynamics, productivity and diversity (Questions 1 and 2) and a developing new area of research on how long-term N-additions can mediate ecological and evolutionary dynamics between a legume-rhizobium mutualism. The research on legume-rhizobium mutualisms is led by Jen Lau (MSU) and Dylan Weese (former KBS postdoctoral researcher and now faculty at St. Ambrose College, Iowa). It reflects an emerging focus area for our group that integrates the project interest in how cropping systems and plant communities will respond to increasing N-deposition and changes in management (Questions 2 and 3) and the exciting potential to integrate ecological and evolutionary analyses into our research on the sustainability of agricultural systems.

Using data from a continuing cross-site collaboration and synthesis, Gough et al. (2012) analyzed how N addition affected the functional composition of plant communities and how this related to observed changes in species richness (following Suding et al. 2005) and productivity (following Clark et al. 2007). Using data compiled by the Productivity-Diversity Traits Network (PDTNet) they showed that increases in the abundance of species with a ‘tall runner’ growth form in response to fertilization accounted for the observed reductions in species richness in many (but not all) of the sites in this data set. The analysis clarified and expanded results from Suding et al. (2005) which had not detected any effect of clonal growth form or height on probability of extinction in response to fertilization by showing that it was the combination of these traits (growth form and height) that predicted changes in species abundance and composition. This was a novel contribution demonstrating that combinations of traits based on growth form may be better predictors of species responses to nutrient (or other) perturbations than single traits.

We have pursued this approach in more detail in an analysis of the results of a long-term experiment on our early successional MCSE treatment (untilled since 1989; Dickson and Gross, in review). Over the first 14 years of this experiment fertilization significantly increased productivity, but did not affect species richness (Fig. 6a). Using an analysis that focused on responses of species with tall runner vs. other growth forms to fertilization, we found that while there was an initial strong response to fertilization by the tall runner growth form, this was primarily due to the dramatic decrease in Solidago species (in particular S. canadensis and S. graminifolia) in the sixth year of the experiment. The biomass of tall
runner species did not recover until 14 years into the experiment (Fig 6b), which corresponded to the decline in biomass of all other growth forms (Fig. 6c). Over 86% of all species in this community are non-tall runners and non-tall runner biomass is strongly correlated with total species richness in both the fertilized and control plots of this experiment (Fig. 6d). These results provide evidence that fertilization may not decrease species richness until tall runner (or the relevant superior competitor growth form) biomass is consistently increased, and may explain the variation in response to fertilization observed in some experimental studies (Clark et al. 2007) and why species richness is not strongly correlated with productivity at local scales (Adler et al. 2011).

Using data from unfertilized and non-herbicided microplots in the MCSE permanent no-till treatment, we have also been exploring how chronic nitrogen addition can destabilize a legume-rhizobium mutualism. Lau and Weese (in review) have found evidence that this can cause the evolution of less cooperative rhizobia. Rhizobium strains were isolated from plants growing in both fertilized and unfertilized microplots. *Trifolium pratense* (red clover) plants inoculated with rhizobium strains isolated from N-fertilized plots produced 17-30% less biomass and had reduced chlorophyll content compared to plants inoculated with strains from unfertilized control plots. The impact of this destabilization varies among legume species and depends on the trait evaluated. The legume-rhizobium mutualism is the major contributor of naturally-fixed N to terrestrial ecosystems, and so the evolution of less cooperative rhizobia could have significant environmental consequences. Understanding these evolutionary dynamics will help to better mitigate anthropogenic manipulation of the global N cycle. Research to further explore the evolutionary dynamics of this interaction and the consequences for both successional and row-crop systems is being pursued.

5. Insect Dynamics (D. Landis, lead)

**Highlights**

- An investigation of biocontrol in complex agricultural landscapes shows that landscape simplification is associated with increased insecticide use in multiple crops, resulting in application of insecticides to an extra 3.5 million acres in the Midwest annually – i.e., that more complex landscapes provide greater biocontrol services.
In previous studies, we have shown that landscape simplification in the Midwestern U.S. leads to lower natural enemy activity and higher pest abundance. Recent work extends this finding to show that landscape simplification is associated with increased insecticide use in multiple crops, resulting in application of insecticides to an extra 3.5 million acres in the Midwest annually (Meehan et al. 2011).

Understanding the relationship between insect biodiversity and pest suppression in agricultural landscapes is of vital importance. Our work focuses on a better understanding of how dispersal of predatory organisms may influence these relationships at multiple scales. In 2011-12 we conducted investigations in two broad areas: 1) within-field dynamics of predator-prey interactions, and 2) landscape controls on predator-prey interactions and pest suppression.

Coccinellidae (lady beetles) provide an important service by suppressing populations of soybean aphid in soybean. Critical interactions between coccinellids and aphids occur in early summer when aphid densities are too low to support local reproduction of coccinellids. Thus, the ability of coccinellids to suppress aphids likely depends on their rates of immigration to infested patches within fields. To test this, we manipulated coccinellid immigration to aphid patches by covering 1m³ PVC frames with mesh to varying degrees and monitored resulting changes in coccinellid and aphid populations (Fig. 7).

Treatments created a range of coccinellid immigration. As expected, reducing coccinellid arrival to near zero in full exclusion cages resulted in large increases in soybean aphid populations, while naturally occurring levels of immigration (3-5 beetles/m²/week) resulted in extremely low aphid populations. Two-sided barriers that reduced coccinellid arrivals to approximately 2 beetles/m²/week also resulted in low aphid populations, suggesting that very few coccinellid arrivals is sufficient to achieve control. Resident predator densities and coccinellid egg-laying were low, indicating that predation was primarily due to transient predators. We also used video surveillance cameras to continuously monitor individual soybean plants for predator arrival. As expected, the diurnal community was dominated by Coccinellidae and Anthocoridae (pirate bugs). The nocturnal community was dominated by two groups of arachnids, the Opiliones (harvestmen) and Araneae (spiders). We observed araneae foraging at a similar rate (seconds of foraging per hour of video) during night hours as the coccinellidae foraged during day hours. This suggests a need for future research to determine the degree to which nocturnally foraging araneae contribute to soybean aphid biocontrol.

Habitats adjacent to crop fields can enhance natural enemy populations by providing food, refuge habitat and overwintering sites. To understand how neighboring habitats influence the carabid community in wheat, we monitored carabid activity-density in wheat with standard pitfall traps and movement across wheat borders with bi-directional pitfall traps. We found that carabids moved more frequently between wheat and corn and between wheat and grassy-roadside vegetation than between wheat and soybean or forest habitats. The preferred habitats were characterized by greater vegetation cover during the course of our sampling, suggesting that carabid preferences might change as vegetation conditions changed in each of these habitats. Additionally, the carabid community composition within wheat fields changed over the course of the summer, with different species being dominant at different times during the growing season. Furthermore, the carabid community composition in the center of wheat fields was significantly different from the community composition of carabids entering wheat fields from any of the four neighboring habitats, suggesting that adjacent habitats are making different contributions to the ultimate community in wheat.
6. Human Dynamics (S. Swinton, lead)

Highlights
- A new breakeven budgeting framework for prioritizing plant breeding innovations needed for profitable perennial grains shows that improving yield and perenniality are the most promising avenues to encourage farmer adoption.

Understanding how people manage working ecosystems like row crop agriculture is central to KBS human dimensions research. In 2011-12 we began to explore conditions for farmers to coordinate management across a landscape and assess the potential appeal to farmers of managing for ecosystem services associated with perennial grains, while continuing research into economic valuation of ecosystem services.

To enable the provision of ecosystem services that emerge at the landscape level, both ecological and socioeconomic conditions need to be met. For surface water quality regulation, vegetative cover matters. For pest regulation services, habitat for natural enemies is essential. But for those ecological conditions to be met, landowners must coordinate their behavior. Their incentives to do so are shaped by human institutions, such as markets and policies (Stallman 2011) as well as learning about rewards to coordination (Parkhurst and Shogren 2007). Graduate student Leah Harris has identified how ecological and socioeconomic conditions contribute to the suitability of coordinated provision of landscape-level ecosystem services (Fig. 8). Her research is contributing to a new allied project with The Nature Conservancy on the design of transactions to induce landowners to adopt (and coordinate) crop management practices that benefit stream and lake ecology.

Perennial grains represent a new class of agricultural technology that has been developed more for environmental benefits to society than for private profitability to farmers. If widely adopted by farmers, perennial grains could offer climate and water quality regulation services. Graduate student Carson Reeling and Anne Weir with the USDA “Practical Perennials” project developed a breakeven budget framework to prioritize the plant breeding innovations that will make adoption of perennial grains attractive to farmers. Working with Snapp and her collaborator Richard Hayes in Australia, they identify grain yield and perenniality as key innovations to motivate farmer adoption, with grain quality and subsidies for environmental services of secondary importance (Reeling et al., in review; Weir 2012).

The economic valuation of ecosystem services from agriculture remains a major feature of human dimensions research at KBS. Shan Ma completed her Ph.D. research that statistically estimated both farmer willingness to adopt and resident willingness to pay for ecosystem services from Michigan agriculture (Ma 2011; Ma et al. 2012). Wei Zhang estimated the economic value of natural enemy pest control services in soybean, based on both yield protection and insecticide savings (Zhang 2012). Finally, a set of bioeconomic optimization modeling analyses has identified the implied cost of maintaining
current levels of ecosystem services while increasing the supply of biofuel biomass from southern Michigan (Egbendewe-Mondzozo et al. 2011a, b, c).

7. References


Harris, Leah M., and Scott M. Swinton. 2012. No fences needed: Coordinating farm management to provide ecosystem services. Michigan State University, East Lansing, MI.


We received supplement funding in 2011 for information management, education (ROA, RET, and RHASS), and equipment, and progress to date on supplement activities is noted here.

A. Information Management. Proposed improvements to the data submission workflow have progressed well, in particular on streamlining data upload and associating variates with columns as well as providing graphical QC output. We are continuing work on providing tools to provide feedback to users on the congruency of the data and metadata (including parsing the output from the NIS congruency checker), as well as amending the uploaded data by linking it with other information already in the database. Progress with sensor NIS has included investigating how to integrate sensor software (such as data turbine, highlighted by the sensor NIS group) into our sensor workflow, but we have not used it in production yet. We are in the processes of testing the GCE toolbox to see how it could fit into the workflow. Progress with management, documentation, and publication of spatial data into the NIS is also proceeding well. We have compiled geographic locations for all LTER features such as plot corners and sampling stations and these are now available on the web at http://lter.kbs.msu.edu/datatables/83. Descriptions of our air photos are available from http://lter.kbs.msu.edu/data/air-photos-and-satellite-imagery/ with some example downloads. In order to make our airphotos useful they need to be orthorectified and we recently received additional funding to have this completed. Links to each airphoto will be made available on the web with full EML metadata by spring 2013.

B. ROA Request. Steven Bentivenga of University of Wisconsin – Oshkosh and undergraduate student Jacob Dickman traveled to KBS in August to collect MCSE soil cores for fungal analysis. Cores were collected from plots in T1, T2, T3, T4, T7, and T8 and combined by plot into composite samples. Spores of arbuscular mycorrhizal fungi (AMF) were extracted, enumerated, and identified to species. To date, samples from four of the six replicates from each treatment have been processed. Processing of the remaining samples is ongoing. A preliminary analysis of the spore count data reveals 11 species of AMF: Gigaspora gigantea, Gigaspora margarita, Glomus constrictum, Glomus etunicatum, Glomus intraradices, Glomus mosseae, Glomus rubiforme, Glomus sp. “straw”, Paraglomus occultum, Scutellospora calospora and Scutellospora pellucid. Multivariate analysis of variance of the spore counts reveals significant differences among the species, as influenced by plot treatment (Wilks’ lambda, F = 2.35, p<0.01); sporulation of 5 of the 11 species varied significantly by treatment. For example, Glomus constrictum was abundant in T7 plots (84 spores/100 ml soil), but significantly less abundant in all other treatments (mean=7.8 spores/100 ml soil). Total AMF sporulation was significantly higher in plot T8 than all other treatments, largely due to heavy sporulation of Glomus rubiforme in those plots. Species richness was significantly higher in treatment T7 (mean=7.75 species per plot) than in T2 (mean=5.75 species per plot), but did not vary among other treatments. Data will be re-analyzed when all replicates have been processed. In the next month, plant roots will be extracted for staining and assessment of colonization by AMF.

C. RET Request. By the time we received word that our RET request was to be funded our identified teacher (Lisa Wininger) had committed to another summer position. We have thus delayed our planned 2012 RET activity until summer 2013.

D. RHASS Request. In late 2011 Megan McKenzie, a sophomore high school student, joined co-I Jennifer Lau’s lab to work with graduate student mentors Elizabeth Schultheis and Tomomi Suwa. McKenzie designed and implemented a project addressing the effects of the invasive plant garlic mustard on native plant species in Michigan. Garlic mustard is a prolific invader, outcompeting native species and changing plant communities in the forest understory. Her project addressed one of the ways that garlic mustard may invade - by killing off the mutualist partners of native plants. McKenzie conducted a greenhouse experiment, along with undergraduate collaborators, on garlic mustard-rhizobia interactions. The research was presented at MSU’s Undergraduate Research Symposium in July 2012 in a poster entitled...
Allelopathic effects of Alliaria petiolata on rhizobia and its implications for native legume performance. The poster will also be presented at the Southwestern Regional Meeting of the American Chemical Society in November 2012.

E. Equipment. We bought a computer for work on our sensor network as well as additional disk space for data storage. We also purchased an additional server cabinet to allow us to place servers in the field lab with its halogen fire suppression system.
9. Externally funded projects active in this award period (2010-2016) (* = active during this reporting year)


Recommended for renewal 2012-2018.


Mutch, D. and G.P. Robertson. 2011-2014. Effect of cover crops on N2O emissions, N availability and C accumulation in organic versus conventionally managed systems. USDA AFRI (Organic Transitions Program); $750,000.


Radosevich, M., S. Pfiffner, E. Wommack, and S. Williamson. 2007-2011. Microbial Observatory for phage in soil: Influence of land management practices on virus-host interactions. NSF/USDA Microbial Observatories; $1.35M.


Snapp, S. and S. Swinton. 2009-2013. Practical perennialss: Partnering with farmers to develop a new wheat crop. CSREES USDA-AFRI; $1.05M.


Swinton, S.M., F. Lupi, and G.P. Robertson. 2005-2010. HSD-AOC: Ecosystem services from low-input cropping systems: Incentive to produce them and value of consuming them. NSF(Agents of Change Program); $400,000.


Tripplett, E., N. Fierer, D. Arp, R. Knight. 2008-2012. How are archaeal diversity, abundance, and function regulated in soil? USDA-CSREES; $1.5 M.

Total number and overall value of awards associated with KBS LTER
   Active since 2010 renewal: 38 ($48,953,566**)
   Active in 2011-2012: 26 ($42,195,112**)

**total does not include $26M of sustainability research in the DOE GLBRC $135M award (Donohue et al., above)
Training and Development:

Since December 2010, the project has supported in part or in whole the research training of 26 graduate students, 18 undergraduate students (including 3 LTER-supported REU awards), 24 postdoctoral scholars, 9 high school teachers (including 1 LTER-supported RET award), and during this period KBS LTER graduate students have completed 4 PhD dissertations and 3 MSc theses, listed in the publication section.

Outreach Activities:

Outreach and Education

Highlights

- We formed new partnerships to host a climate change communication workshop for journalists and scientists from across the Great Lakes region. Workshop participants toured LTER research, worked together to create story ideas, and identified problems of and solutions to climate change communication for the general public.
- Our K-12 Partnership program continues its schoolyard research network: 300 biofuel research plots at 22 different schools in SW Michigan. Serving not only as a citizen science project, this effort also introduces students and teachers to the collaborative power of a research network.
- Partnering with the Electrical Power Research Institute, we developed a way for farmers to participate in carbon markets and be financially compensated for reducing nitrogen fertilizer use. Based on LTER data, the *MSU-EPRI Carbon Offset Methodology for Emission Reductions from Agricultural Nitrous Oxide* was approved by the American Carbon Registry in July 2012.

We place a high value on outreach activities and actively seek opportunities to educate the public, policymakers, students, teachers, and agronomic professionals about the ecology of row-crop landscapes and the importance of taking a systems approach to their understanding. Our outreach programming is centered on our primary research theme, *Farming for Services in a Changing Environment*. Since August 2011 (our last report), we have hosted 24 formal tours and on-site presentations to a variety of these groups as outlined below, resulting in 1,253 visitors to the site.

The *KBS-K12 Partnership for Science Literacy* ([www.kbs.msu.edu/education/k-12-partnership](http://www.kbs.msu.edu/education/k-12-partnership)), supported since 1996 with sLTER funds, has grown to now provide over 100 science teachers from 15 districts around KBS in-depth exposure to ecological science topics based on LTER research areas. The Partnership supports four 1-day school-year workshops for teachers plus a week-long summer science institute in partnership with three externally funded programs developed by LTER scientists and educators. Since August 2011 these have included:

1. An NSF Targeted Math and Science Partnership (MSP) grant with three other LTER sites (SGS, SBC, and BES): *Culturally relevant ecology, learning progressions and environmental literacy* (2008–2013) with the goal of developing learning progressions leading toward environmental science literacy.

2. An NSF GK-12 award: “BEST” *BioEnergy SusTainability Schoolyard Research Network* (2009–2014) with a goal of professional development (graduate student fellows, teachers) and curriculum development grounded in inquiry-based science methods. This project has established 300 biofuel research plots at 22 schools in 11 of our Partnership districts and supports 9 GK-12 Graduate Fellows per year based at KBS.

3. An NSF DRK-12 award: *A learning progression-based system for promoting understanding of carbon-transforming processes* (2010–2015). The goal of this project is the development of tools
for middle and high school teachers to teach about carbon cycling in human and environmental systems, research on learning progression of students, and development of assessment tools, in partnership with the University of Wisconsin.

Additionally six Partnership teachers (M. Green, L. Ratashak, M. Angle, D. Kilmartin, C. Hach, and B. Drayton) worked on RET-type LTER-associated projects, five with MSP funding and one with support from the GLBRC. The MSP project also supported a Teacher in Residence (TIR) during the 2011–2012 (M. Angle) school year, and three teachers are participating in an LTER research trip to Toolik, Alaska (M. Buehler, L. Winniger, and M. Grintals). On the main campus in East Lansing, co-PI Schmidt hosted a middle school science teacher for the 2011 and 2012 summers to help with LTER research.

University Students. A number of educational programs affiliated with KBS, MSU, and nearby colleges and universities continue to use the LTER site for formal learning activities, including classes from MSU (both KBS and campus-based courses). We have also supported four REU and other undergraduate interns to gain hands-on research and science communication experience with support from NSF, DOE, and others; this includes one international student from the University of Purpan, France. Additionally we hosted a high school intern with RHASS funding. In the summer of 2012, KBS LTER faculty were involved in MSU’s SpartaNature program, a science initiation workshop for incoming freshmen. There are currently 19 graduate students affiliated with the KBS LTER program. Graduate students are actively encouraged to participate in all aspects of LTER research and outreach activities, including the 2012 All Scientist Meetings at KBS and in Estes Park. Since August 2011, seven students received their degrees working on site.

Agricultural Professionals and Land Managers. In July 2012, the MSU-EPRI Carbon Offset Methodology for Emission Reductions from Agricultural Nitrous Oxide was approved by the American Carbon Registry (ACR). Based on LTER data, this methodology provides a way for farmers to participate in carbon markets and be financially compensated for reducing nitrogen fertilizer use. The approval received print and radio press from numerous sources, including NSF (http://www.nsf.gov/news/news_summ.jsp?cntn_id=123848&WT.mc_id=USNSF_51&WT.mc_ev=click), ACR (http://americancarbonregistry.org/acr-approves-msu-epri-methodology-for-emissions-reductions-from-agricultural-n2o), ScienceDaily.com, and Michigan Farm Radio Network. Since 1995 we have annually hosted part of an international Agricultural Ecology course sponsored by USAID, USDA-FAS, the CGIAR system, and the World Bank; an additional annual International Biofuels course started in 2009. In 2010 we initiated climate change programming to help fill an important information need of Michigan growers. This effort, led by Outreach Coordinator Julie Doll and funded with EPA and MSU awards, continued into 2011 and 2012. Results of these efforts were published in the Journal of Extension (Layman et al., in press). In October of 2011, Doll helped organize a climate, water, and agriculture in-service training for 100 MSU Extension educators. At this meeting MSU educators expressed that they were struggling with how to talk about this contentious issue in their communities. In response, Doll and MSU Extension colleague Claire Layman hosted a Climate Change Communication Workshop for 18 Extension educators at KBS in April 2012. In 2012, Doll, with co-I’s Justin Kunkle and Brian Petersen, conducted four more farmer focus groups to research how farmers perceive climate change adaptation. In spring 2012, Doll was awarded USDA-SARE funding ($75K) to conduct climate change education programming across the North Central Region of the US. Fact sheets continue to be added to the series of Extension bulletins on climate change and agriculture. In April 2012, two fact sheets were translated into Spanish in order to reach more audiences. These, and co-PI authored fact sheets on soil management and native species, are available online at MSU and KBS LTER websites. In addition, co-PI Snapp has published on the national e-Extension website (www.extension.org). In the summer of 2012 co-PI Snapp led a workshop on perennial wheat for farmers, graduate students, and other scientists. Co-PI Swinton is part of this research team, whose results are available via an active perennial grains website (http://pwheat.anr.msu.edu/).
Public. We have expanded our efforts to reach citizens by sponsoring educational booths at local and state venues—e.g., county fairs, agricultural expos, and school science fairs—where LTER staff and scientists share our research with audiences of varied backgrounds and ages. 429 visitors, mainly family groups, toured hands-on exhibits at the LTER field lab during the Station’s Share-the-Harvest field day in October 2011. In addition, we made LTER research results more accessible to the public via our redesigned website (lter.kbs.msu.edu), starting a Facebook page, blogging on our website, and using Twitter. The self-guided walking tour of our signature Main Cropping System Experiment continues to attract visitors and opens our research site to the general public. After piloting an activity guide with 60 3rd graders and two groups of teachers, an RET teacher is currently updating the walking tour curriculum and developing a companion teacher’s guide. In addition, the KBS LTER now has two volunteers, a retired journalist from the Kalamazoo Gazette and a science education teacher who are involved in taking professional photos, writing articles about KBS LTER research and events, and helping with the KBS LTER walking tour.

Media. In 2012 we expanded our efforts to reach the media by partnering with MSU’s Knight Center for Environmental Journalism and the Society for Environmental Journalists to host a climate change communication workshop at KBS. Participants included 11 journalists and 11 scientists from around the Great Lakes region; they toured KBS LTER research and explored news ways of connecting climate science to the general public. In August of 2011 the KBS LTER received recognition in the local (Kalamazoo) paper and several articles about LTER research were highlighted in regional farm journals, including Michigan Farmer, GreenStone Farm Credit Services, and USAGNET. In addition, several KBS publications received national media attention, including Gelfand et al. 2012 (PNAS) and Woltz et al. 2012 (Agriculture, Ecosystems and Environment). We place significant value on efforts to educate and inform national and state decision makers.
Journal Publications (from Dec 2010)


**Books or Other One-time Publications (from Dec 2010)**


Web/Internet Site

URL(s): http://lter.kbs.msu.edu

Description: In the past year, we launched a redesigned website that has a new layout, an improved navigation system and enhanced functionality. This site explains the purpose of the research funded by the award, describes the research, and is the principal data repository. This site consists of over 2,500 html and database files managed by a professional information manager.
Other Specific Products

Product type: Data or databases

Product Description: In the past year we have added significantly to the data sets produced and managed by the KBS LTER project and available on-line via the KBS server (http://lter.kbs.msu.edu). Recent additions include enhancements to databases for weather, net primary production, agronomic yields, soil properties (chemical, physical, and biological), biodiversity (plants and insects in particular), and trace gas fluxes.

Sharing Information: This data is available (with some restrictions) to all researchers. The standard use policy is described at http://lter.kbs.msu.edu/data/TermsOfUse.php.

Product type: Physical collection (samples, etc.)

Product Description: Plant species new to KBS that have been collected in the past year have been placed in the KBS herbarium. New insects collected have been placed in MSU collections. Soil and plant tissue samples have been archived at KBS. Microbial samples have been archived at MSU.

Sharing Information: Collections are available (with restrictions) through standard use policy described at http://lter.kbs.msu.edu/data/TermsOfUse.php.

Contributions

Contributions within Discipline: Contributions of KBS LTER research to the discipline of environmental biology (including the ecology and evolutionary biology of plants, microbes, and insects and other invertebrates) are described in the Research Activities and Findings sections of this report.

Contributions to Other Disciplines: Contributions of this research to other disciplines can be inferred from the Research Activities and Findings sections of this report as well as from the publications list. Disciplines other than environmental biology include geology, hydrology, sociology, genetics, plant and insect physiology, agronomy, soil physics and chemistry, economics, and geography.

Contributions to Human Resource Development: The project has supported in whole or in part the training of 26 graduate students, 18 undergraduate students (including 3 LTER-supported REU interns), 24 postdoctoral scholars, and 9 high school teachers (including 1 LTER-supported RET award) since December 2010. The LTER site was also visited by a number of other educators and professionals, and educational tours provided to the lay public and K-12 students served to further educate the public informally. Our KBS-K12 Partnership for Science Literacy is providing in-depth professional development training >80 K-12 science teachers from around KBS. These contributions are described further in the Outreach Activities section, above.

Contributions to Resources for Research and Education: Major contributions to resources for science and technology include a substantive publication base about various aspects of agricultural ecology, additions to a permanent database of archived information about the LTER site (including a biocollections database), and archived plant, microbial, and soil samples. Additionally the project participates in the development of new methodologies for science and technology, including molecular, chemical, and computational methods. Additionally we have contributed to the development of K-12 curriculum materials as detailed in the Outreach section of this report.

Contributions Beyond Science and Engineering: Contributions of this project to society as a whole (beyond science and engineering) are embodied in its aim to help provide the U.S. with a healthy, economical, and environmentally safe food supply. Economists have consistently estimated the annual
rate of return for research related to food production at 30-40%; this implies a substantial economic impact for this research.