PASTURE SYSTEMS AND WATERSHED MANAGEMENT RESEARCH UNIT

Improving Productivity, Sustainability, and Profitability of Grassland Agriculture

PROGRESS REPORT
NORTHEAST PASTURE CONSORTIUM
March 4, 2009, Morgantown, WV

For Projects:

Managing Forage and Grazing Lands for Multiple Ecosystem Services
and
Managing Dairy Farms for Environmental Stewardship and Profit

USDA-ARS Rangeland, Pasture, and Forage Research Units.

PROGRESS REPORT – NORTHEAST PASTURE CONSORTIUM
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PROJECT TITLE: Managing Forage and Grazing Lands for Multiple Ecosystem Services

SCIENTISTS: Matt A. Sanderson, Sarah C. Goslee, Kathy J. Soder, Paul R. Adler, R. Howard Skinner, and Curtis Dell

PROGRESS OF WORK AND PRINCIPAL ACCOMPLISHMENTS:

Managing Forage and Grazing Lands for Multiple Ecosystem Services
Matt Sanderson, Paul Adler, Sarah Goslee, Kathy Soder, Howard Skinner, and Curtis Dell.
The goal of the pasture ecology and management research project at University Park is to provide science-based information for establishing, maintaining, and managing diverse forage and grazing lands of the northeastern U.S. to support multiple ecosystem services. The concept of multifunctionality in grassland agriculture recognizes ecosystem services beyond the traditional forage, food, and fiber production to include emerging services such as carbon sequestration, greenhouse gas mitigation, and bioenergy production. Managing multiple plant species in grassland systems is an ecological approach to providing these multiple services. Our objectives are to: 1) develop tools to aid the selection of forage mixtures for pastures and their distribution across a farm; 2) identify new management and supplementation strategies that complement grazing preferences of dairy cattle on mixed-species pastures; 3) identify management practices that minimize net greenhouse gas emissions in forage and energy crop systems; and 4) provide improved management practices that enhance the environment and increase the economic viability of bioenergy cropping systems. This research will generate new tools for pasture management and guidelines for supplementing grazing dairy cows that account for forage selection and preference; new information on grassland systems that minimize net greenhouse gas emissions; and new management practices for bioenergy crops.

Is Pasture "Easier" to Chew in the Evening?
Kathy Soder; Pablo Gregorini, DairyNZ, Hamilton, NZ.
Pasture chemical composition, such as protein, sugar, and fiber content, varies from dawn to dusk. However, it is not known if this variation affects pasture mechanical properties, such as the "toughness" or force need to harvest and chew the pasture. We evaluated changes in pasture toughness in relation to chemical composition throughout the day using a texture analyzer. Experimental meadow fescue micro-pastures were sampled four times daily at sunrise, mid-morning, mid-afternoon, and at sunset. Pasture was analyzed for chemical composition, including dry matter, protein, sugar, fiber, and toughness. Toughness decreased as dry matter and sugars increased throughout the day. Not unexpectedly, as fiber content of the pasture increased, toughness increased. Pasture may be easier to 'chew' in the evening than in the morning. This may partly explain why cattle prefer to graze more during dusk, and why they prefer grass species in the evening.

Supplemental Protein to Pasture-Based Diets May Impair Rumen Fermentation
Kathy Soder; Pablo Gregorini, DairyNZ, Hamilton, NZ.
High-quality pastures in the northeastern United States are typically high in crude protein (CP). Despite this, feeding additional CP in the supplement is not uncommon in grazing dairy cows; however, high supplemental CP may be detrimental to rumen fermentation. We evaluated the effect of increasing levels of CP supplementation (10, 12, 14, or 16% CP) in a pasture-based diet (25.6% CP, 33% neutral detergent fiber) on ruminal fermentation. Increasing supplemental CP decreased pasture digestibility, altered ruminal pH, and increased ruminal ammonia

concentrations. Increases in ruminal ammonia concentration during a grazing session have been proposed as a possible signal for termination of that meal. Therefore, high levels of supplemental CP may decrease pasture intake. Balancing rations in pasture-based diets is crucial in reducing feed costs as well as enhancing grazing behavior to better utilize available forages.

The Effect of Fallowing on Pasture Vegetation and the Seedbank
Sarah Goslee, Jeff Gonet, and Matt Sanderson
Fallowing, the practice of leaving a pasture ungrazed for a growing season, is sometimes used as a tool for improving pasture quality by allowing grasses to reseed naturally. For three years (2004-2006), we sampled the vegetation and seed bank of paddocks on a Maryland farm that had been fallowed 0-6 years previously, or had never been fallowed. Tall fescue and other forage grasses increased in the seed bank in autumn of the fallowing year and in the following spring, but these changes did not persist. Short-term increases in weed abundance and decreases in legume cover were also observed, but again did not last more than two years past fallowing. Pasture fallowing did not lead to measurable improvements of forage species in the seed bank or the vegetation on this farm.

Remote Sensing of Pasture Biomass *Sarah Goslee and Jeff Gonet*
Measuring pasture production requires frequent samples matched to the grazing schedule, or the use of exclosures, The former method is expensive and time-consuming to apply to multiple farms, while excluding grazing animals in latter method can give different results than sampling grazed areas. Remote sensing may provide a third option. Multispectral Landsat satellite images record both infrared and visible light, and can be used to estimate standing-crop biomass. An image is taken of each section of the Earth's surface every eight days, and the image archive goes back decades, making Landsat images the best available for farm monitoring. Two sites with detailed on-farm measurements of production data were selected, and 132 Landsat images covering multiple growing seasons were acquired. The current objective is to identify and the mathematical index that is most accurate at predicting pasture biomass from Landsat images, and to use the methods developed to improve monitoring of biomass production in pastures.

Pasture Species Traits *Sarah Goslee and Jeff Gonet*
Previous studies have shown that pastures contain diverse plant communities, with an average of 31 species in a 0.25-acre area. Each of those species behaves differently in a grazed pasture, and adds to or detracts from biomass production, drought resistance, and other ecosystem functions of interest in pastures. The contribution of each species to a pasture is related to its traits, measurable attributes such as height, growth rate, and leaf size and thickness. Trait information has been collected from previous scientific studies, from greenhouse experiments, and from field samples for over fifty common forage species and pasture weeds found in the northeastern United States. This information will be used to develop a better understanding of how pasture species mixtures perform, how to tailor mixtures to particular management objectives, and how to manage mixtures more effectively.

BMP Placement in Spring Creek Watershed, PA *Sarah Goslee*
The objective of the USDA Conservation Effects Assessment Program (CEAP) is to quantify the economic and environmental effects of agricultural best management practices (BMPs). CEAP funds support a joint project between ARS and Penn State to investigate the watershed-level effects of agricultural land use and BMP placement in the Spring Creek watershed in central Pennsylvania. Aerial remote sensing data will be used to create a detailed elevation

map of the watershed. On-farm sampling and aerial photography will be used to map concentration areas, barnyards, buffer strips, and other land use types and BMPs. The land use and elevation maps will be combined to identify water flow pathways and possible nutrient movements or filtering. This information will be combined with long-term data on water quality in the Spring Creek watershed to help to understand the environmental role of agricultural land use placement.

Experience with the Pasture Condition Score System in On-Farm Research

Matt Sanderson, Sarah Goslee, Jeff Gonet, and Robert Stout

The Pasture Condition Score (PCS) system was developed by the USDA-NRCS as a monitoring and management tool. We have worked with the PCS system for several years. In a survey study, we used the PCS system to assess pastures on 31 farms across the northeast. Results indicated that few pastures fell into the lowest or highest score categories, whereas >80% fell into the score category of "Needs some improvement." Scores for the indicator "percent legume" had the lowest rating of all indicators, which suggests that producers should focus management on establishing and maintaining legumes. Pasture condition score was negatively related to plant species richness. This may indicate that focusing strictly on increasing the number of species in a pasture without regard to the species composition may not be wise. In a second on-farm study, we examined how PCS results vary within and among grazing seasons and within and among farms. We applied the PCS on five farms across the northeast during 3 yr. Our data indicated that a strategy of assessing PCS at the start of the grazing season in spring, during stressful growing conditions (typically mid summer) and near the end of the season (to determine the extent of recovery) would be useful. Grouping pastures managed for different classes of cattle (e.g., heifer, dry cow, or holding pastures) and monitoring representative subsets of these pastures, may reduce the monitoring work load.

Seed bank Characterization of Pastures and Hayfields of the University of New Hampshire Organic Dairy

Matt Sanderson and Robert Stout; Kevin Brussell, Charles Schwab Univ. of New Hampshire

Buried seed in pasture soils are often reservoirs of weedy plants. The seed bank was characterized in pastures and hayfields with different management histories at the University of New Hampshire Organic Research Dairy. Three hayfields [two of alfalfa (*Medicago sativa* L.) and one grass] and five pastures were sampled in August 2007. At each site, two soil cores (1.88 cm diameter by 5 cm deep) were taken at 27 georeferenced points within a 20- by 50-m modified Whitaker plot. Soil samples were placed in a greenhouse for 5 months and germinated seedlings counted regularly. Soil from the hay fields had the fewest number of seed (8 to 83 seeds per plot sample) and plant species (2 to 14 per plot sample) compared with pastures. Pastures had 98 to 277 seeds per plot sample and 12 to 25 plant species. Nearly 42% of the soil samples from the hay fields had no germinable seeds, whereas only 7% of soil samples from pastures had no germinable seeds. Grasses (*Agrostis* spp. and *Festuca rubra* L.) were most abundant in the pastures and grass hayfield. Ragweed (*Ambrosia artemisifolia* L.) and slender rush (*Juncus tenuis* L.) predominated in the seed bank from the alfalfa fields.

Virginia Wildrye Persistence and Performance in Riparian Areas

Matt Sanderson, Martin van der Grinten, and Robert Stout, USDA-ARS, University Park, PA.
USDA-NRCS Plant Materials Center, Big Flats, NY.

Virginia wildrye (*Elymus virginicus* L.), a perennial cool-season grass native to the northeastern USA, grows in moist bottomland areas and could be useful in revegetating riparian areas. In this field study, we compared nine populations of Virginia wildrye originally collected from Maryland, New York, and Vermont with a commercial ecotype and a cultivar ('Omaha') on wet

soils at three locations. All entries were transplanted into single-row field plots of 17 plants per plot at Wye, Maryland, Klingerstown, Pennsylvania, and Big Flats, New York in April 2004. Rows were oriented perpendicular to the slope so that each accession was evaluated at the top, middle, and bottom slope positions. Survivorship, tillers per plant, and plant dry weight were assessed in 2007. Survivorship after 3 yr ranged from 46 to 77% for the nine populations and averaged 80% for the ecotype and cultivar. Populations of wildrye from Maryland and Vermont had poorer survival than the commercial ecotype or cultivar. Averaged across locations and wildrye entries, survivorship was nearly 80% at the top slope position and 60% at the bottom slope. Biomass and tillers per plant also decreased from the top to the bottom of the slope; however, the change was much greater at the Maryland site compared with other sites. Significant variation exists among wildrye populations in adaptation to riparian areas, which could be exploited in developing new plant material for conservation programs.

Grass Mixtures for Japanese Knotweed Control *Howard Skinner, Martin van der Grinten (USDA-NRCS), Mark Simonis (US Army Corp of Engineers), and Art Gover (Penn State Univ.)*
Japanese knotweed (Polygonum cuspidatum) is an invasive species that has quickly become a serious problem both in riparian zones and in upland sites throughout the eastern US. It is an herbaceous perennial that can reach heights of 10 ft or more, and is capable of reproducing and quickly spreading by creeping rhizomes and root and stem fragments. Once established, it forms solid colonies that usually choke out all other herbaceous vegetation. This study focuses on planting native species mixtures in plots from which the Japanese knotweed has been suppressed by mowing and herbicide treatments. By 16 months after planting the Japanese knotweed had reestablished itself to some degree in all plots. The following plantings provided the best knotweed suppression, prairie cordgrass-Virginia wildrye, a 27-species commercial riparian buffer mixture, bluejoint-Virginia wildrye, and a native cool-season grass mixture. Hightide and Kanlow switchgrass were not able to compete with the Japanese knotweed and have been nearly eliminated from the plots where they were planted.

Warm-Season Grasses for Use in Riparian Zones *Howard Skinner, Matt Sanderson, Martin van der Grinten (USDA-NRCS) and Bill Skaradek (USDA-NRCS)*
Due to periodic flooding of their habitat, plants growing in riparian areas are subjected to a variety of stresses including reduced nutrient uptake and reduced oxygen availability. In response to waterlogged conditions, many plant species develop large air spaces in their roots called aerenchyma. These air spaces allow oxygen from shoots to move into submerged root tissues, thus allowing continued root growth and nutrient uptake. We examined aerenchyma development, root growth, plant survival, and aboveground growth of several native warm-season grass species and cultivars. In a greenhouse study, all cultivars exhibited extensive aerenchyma formation but the presence of aerenchyma did not guarantee good root growth under waterlogged conditions. Suitable plant materials for inclusion in riparian areas were found among four of the six warm-season species examined. Nine cultivars representing a range of tolerance to waterlogged soils were further evaluated at four field locations subjected to flooding. Red River prairie cordgrass provided superior performance at all locations. The worst performing cultivars in the greenhouse study also performed poorly in the field. However, not all cultivars that performed well in the greenhouse also performed well in the field. Osage indiangrass was the third ranked cultivar for flooding tolerance in the greenhouse but had acceptable performance at only one of the four field sites. Conversely, Meadowcrest eastern gamagrass exhibited only moderate flooding tolerance in the pot study but was among the best performing cultivars at three of the four locations. Controlled environment studies were useful for eliminating unacceptable cultivars but field studies were necessary to identify the best cultivars for riparian areas.

Assessing Pasture Grasses, Legumes and Pasture Blends for Varying Soil Conditions in New England and Pennsylvania *Stephen Herbert, University of Massachusetts; Sid Bosworth, University of Vermont; and Matt Sanderson, USDA-ARS University Park, PA*

Many farmers contact Extension and USDA-NRCS seeking information and recommendations on pasture species and varieties. We have established field plots of 25 to 30 commercial pasture mixtures (2 to 7 species) from several seed companies in grazed small-plot trials in Massachusetts, Vermont, and Pennsylvania. All locations were planted in late summer or fall of 2007. Additionally, paddock-scale plantings (1 to 2 acres) of several commercial mixtures were planted in cooperation with several farmers. The objective is to measure herbage yield, persistence, forage quality, and weed invasions during four years. The trial in Pennsylvania was established on a beef cow-calf farm near State College. In 2008, the commercial mixtures were grazed six times and yield measured at each harvest along with botanical composition. Preliminary data analyses indicate that mixtures with 3 to 5 species yielded more forage undergrazing; however, there was a large range in variation among mixtures. Additional years of data are needed to make firm conclusions.

Species Evenness, Productivity, and Invasion Resistance of Grass-Legume Mixtures
Matt Sanderson, Sarah Goslee, USDA-ARS, University Park, PA; Geoff Brink, USDA-ARS, Madison, WI; and Matt Harbur, Alfred State University, NY

This research will provide information on how number and relative abundance of forage species in mixtures affects seasonality of forage production, nutritive value, and resistance to weed invasion on different site types. Our hypothesis is that mixed plant communities with greater species evenness produce more forage and are more resistant to weed invasion than mixtures with lower evenness or monocultures. We expect the advantages to be greater on stressful sites than on productive sites. Plant communities were constructed to include grass and legume species that contrast in establishment rate (slow or rapid), growth habit (erect types such as bunchgrasses and upright legumes or prostrate types with rhizomes or stolons), and environmental adaptation. Two groups of 15 experimental plant communities were planted in a modified simplex design that systematically varies relative abundance of each species with a fixed level of overall initial abundance. In the fall of 2008, the plant communities were planted on two sites in Pennsylvania and two sites in Wisconsin. A fifth site will be established at the Alfred State College in spring 2009. Herbage yield, persistence, and weed invasion will be measured for three years.

Spatial Distribution of Soil nutrients in Pastures as Affected by Animal Impact
Matt Sanderson, Corinna Feldmann, John Schmidt, and Antje Herrmann, USDA-ARS University Park, PA and the University of Kiel, Germany

Grazing animals often congregate at watering points, feeding stations, or shaded places in pastures. Vegetation in these areas can be destroyed by defoliation and trampling and the compaction of soil may increase soil erosion, which eventually leads to a higher amount of runoff water with elevated nutrient levels. There is a lack of knowledge with respect to the gradient of soil nutrient levels around animal concentration areas and the extent and location of transition zones. Our objective was to determine the extent and the spatial distribution of soil nutrients in livestock concentration areas on pastures and to quantify the relationship among the soil nutrient gradients, vegetation cover, and surface runoff. The experiment was conducted on a dairy farm in Northumberland County, Pennsylvania and at the Alfred State College dairy farm in Allegany County, New York. The concentration of soil P and soil K was greater in the animal concentration area than in the less affected area of the pasture. That reflects the impact of grazing animals on the heterogeneous distribution of soil nutrients in the pasture, as the

amount of excretal return is greater in areas around animal concentration areas.

Quantifying the Environmental Outcomes of Pastureland Conservation Practices: The Pastureland Conservation Effects Assessment Project (CEAP). *Matt Sanderson, USDA-ARS University Park, PA; Leonard Jolley, USDA-NRCS Resource Inventory and Assessment Division, Beltsville, MD; Jerry Nelson, University of Missouri, Columbia.*
The pastureland conservation effects assessment project (CEAP) is a multi-agency (USDA-NRCS; CSREES; ARS; NRI; http://www.nrcs.usda.gov/Technical/nri/ceap/grazing.html) effort to quantify the environmental effects of conservation practices used by landowners participating in selected USDA programs. The first step in the CEAP process is to document and summarize the science behind the conservation practices applied to pasture and forage lands. The literature synthesis will not only be a landmark publication the on effects of conservation practices on environmental goods and services derived from pasturelands in the USA, it will also document the gaps in our knowledge that require further research and as such will be useful in developing national research priorities. The American Forage and Grassland Council is an important partner in this effort. The AFGC is facilitating the work of the writing teams and will aid in the publication of the document. In 2008, writing teams of university, ARS, and NRCS scientists were assembled to address the following conservation practices: (1) prescribed grazing, (2) pasture and hayland planting, (3) nutrient management, (4) harvest management and (5) integrated assessments of the socio-economic concerns of implementing these practices. The synthesis will be published in 2010.

Pastureland National Resource Inventory (NRI) *Leonard Jolley, USDA-NRCS Resource Inventory and Assessment Division, Beltsville, MD; Ken Spaeth, USDA-NRCS Grazing Lands Technology Institute, Ft. Worth, TX; Jeff Herrick, USDA-ARS, Las Cruces, NM; Matt Sanderson, USDA-ARS University Park, PA*
The USDA-NRCS is mandated to assess the status, condition, and trends of soil, water, and related resources on the Nation's nonfederal land. As part of that mandate, the USDA-NRCS and Agricultural Research Service (ARS) have conducted pilot projects in 2007 and 2008 to develop an improved sampling protocol to enhance the data collection and pasture assessment when the full NRI sampling effort is implemented. Pilot projects in five states in 2007 and 13 states in 2008 tested new protocols, estimated the cost and time required, and provided a realistic test of implementation within a state. The results were used to streamline field data collection procedures and improve data quality.

Soil Nitrous Oxide Emissions with Crop Production for Biofuel: Implications for Greenhouse Gas Mitigation *Stephen M. Ogle, Stephen J. Del Grosso, Paul R. Adler, and William J. Parton. Natural Resources Ecology Laboratory, Colorado State University, Fort Collins, CO 80523; USDA-ARS, Fort Collins, CO 80526, and USDA-ARS, University Park, PA*
Soil nitrous oxide (N2O) is emitted from soils in croplands directly onsite and also indirectly offsite from volatilization, leaching and runoff of N. Recent research has questioned whether soil N2O emissions have been well quantified in biofuel life cycle analyses for greenhouse gas emissions, particularly the indirect emissions occurring offsite. Thus our objective was to estimate emissions of N2O from soils throughout the US for two common biofuel commodity crops, soybeans and corn, accounting for both the direct and indirect emissions. The implications of N2O emissions for greenhouse gas mitigation was further evaluated using a life cycle analysis for ethanol production from corn grain in the Midwest, under a scenario of converting land enrolled in the Conservation Reserve Program (CRP) to crop production. In general, we found that N2O emissions were lower in Southeast, mid-Atlantic and Northeast, largely due to the lower N mineral fertilization rates. Emission rates were also lower for

soybeans than corn in many of the regions. According to the life cycle analysis, there is a marginal reduction in greenhouse gas emissions with displacement of fossil fuel associated with ethanol production from corn-grain in the Midwest, ranging from 1-23%, which partly depends on the length of time since conversion of CRP land into crop production. Further research is needed to reduce the uncertainties associated with indirect N2O emissions.

Comparison of DAYCENT-Simulated and Measured Nitrous Oxide Emissions from Bioenergy Cropping Systems *Paul R. Adler, Curtis J. Dell, Tameria L. Veith, Stephen J. Del Grosso, and William J. Parton. USDA-ARS, Pasture Systems and Watershed Management Research Unit, University Park, PA; USDA-ARS, Soil Plant Nutrient Research Unit, Fort Collins, CO; Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO*

The land use impacts, such as nitrous oxide (N2O) emissions and soil carbon sequestration, are associated with the largest changes in life cycle greenhouse gases from growing bioenergy crops. The biogeochemical model DAYCENT simulates fluxes of carbon (C) and nitrogen (N) between the atmosphere, vegetation, and soil. From weather, soil-texture class, and land-use inputs, DAYCENT simulates crop production, soil organic-matter changes, and trace-gas fluxes. The objective of this study was to evaluate the ability of DAYCENT to simulate measured N2O emissions, the largest greenhouse gas source, from 3 bioenergy cropping systems. Switchgrass, reed canarygrass, and a corn rotation with soybeans and alfalfa were grown in central Pennsylvania. Nitrous oxide emissions were measured weekly during the growing seasons (biweekly during extended dry periods) and periodically at other times of the year. Daily simulated N2O flux overlapped with observed interquartile and max-min ranges 40% and 80% of the time on average, respectively. Given the high variability of N2O fluxes in natural systems, DAYCENT captured the observed daily variability in N2O emissions and simulated the observed seasonal patterns within bioenergy crops and differences in annual mean emissions among systems reasonably well.

Seasonal Time and Frequency of Switchgrass Harvest Affects Biomass Yield and Feedstock Quality *Paul Adler and Matt. Sanderson, USDA-ARS, University Park, PA; H. M. El-Nashaar, S. M. Griffith, and G. M. Banowetz, USDA-ARS, Corvallis, OR.*

Seasonal time of switchgrass (*Panicum virgatum* L.) harvest affects both yield and feedstock quality. There is interest in reducing harvest frequency to improve wildlife habitat value when using Conservation Reserve Program (CRP) land for biomass production; however that would reduce the potential yield and economic viability of these lands for biomass production. A field study in central Pennsylvania compared three seasonal harvest management treatments (i) summer at peak biomass (mid August), (ii) fall after frost, and (iii) in the spring after over wintering in the field, harvested either annually, every 2 yr, or every 3 yr. Biomass yield, residue remaining in the field after harvest, and element concentration of the harvested biomass were measured at each harvest season and frequency, Annual summer and spring harvested yields were similar but 30% lower than fall yields. Biennial and triennial yields showed a different relationship; summer and fall harvested yields were similar, while spring yields were about 35% lower. Only 15 to 25% of the standing harvestable biomass was from previous year's growth in the biennial and triennial harvest, however, residue remaining after harvest accounted for 35 to 55% of the total biomass produced. If management practices could be developed to capture this residue, the economic viability of reduced harvest frequencies could improve. Multifunctional benefits of wildlife habitat, feedstock quality, greenhouse gas benefits, maximized yield stability, reduced farm equipment needs, and year round supply may best be met by harvesting fields over a range of seasons and frequencies.

CO_2 Sequestration Potential of Switchgrass Managed for Bioenergy Production

Howard Skinner and Paul Adler

Switchgrass is an important bioenergy crop with the potential to provide a reliable supply of renewable energy while also removing CO_2 from the atmosphere and sequestering it in the soil. We conducted a four-year study to quantify CO_2 sequestration during the establishment and early production years of a young switchgrass stand in southwestern Pennsylvania. Carbon dioxide uptake was low during the first growing season (2005) due to the immaturity of the crop and to moderate drought conditions which existed that summer. Net CO_2 uptake was restricted to a four-month period each year from May through August, whereas the rest of the year experienced a net loss of CO_2 to the atmosphere. The amount of CO_2 taken up during the summer and the amount lost during the winter were all much greater during the last three years of the study compared with 2004-2005. The amount of harvested biomass increased each year as the stand matured, from 837 lbs dry matter $acre^{-1}$ for the spring 2006 harvest to 3446 lbs $acre^{-1}$ in 2007 and 5333 lbs $acre^{-1}$ in 2008. The amount of CO_2 sequestered increased each year for the first three years as the amount of CO_2 taken up in the summer increased more than the increase in losses due to wintertime respiration and spring biomass removal. However, a small decrease in summer uptake in the fourth year compared with the previous year (-7%), combined with a small increase in wintertime loss (+9%) and a large increase in harvested yield (+55%) caused the field to experience a net loss of CO_2. Averaged over four-years, this field sequestered 0.6 ton CO_2 $acre^{-1}$ yr^{-1}. Switchgrass bioenergy crops in the northeastern USA can function as sinks for atmospheric CO_2 for at least the first few years following establishment, in addition to their primary function as a source of renewable energy.

Soil Carbon Sequestration and Nitrous Oxide Emissions from Pasture, Bioenergy Crops and Forage Rotations

Curtis Dell, Paul Adler, and Howard Skinner

Eliminating tillage and establishing pasture or other permanent, perennial vegetation can increase carbon sequestration in soil, which can decrease atmospheric carbon dioxide levels and help to mitigate climate change. These changes in land management, and associated additions of fertilizer or livestock waste, can also impact emissions of the greenhouse gas nitrous oxide either complimenting or offsetting benefits of soil carbon sequestration. A field experiment comparing soil carbon sequestration and nitrous oxide emissions among grazed pasture (orchard grass/white clover or 6-species mix), bioenergy crops (reed canarygrasss and switchgrass), and a dairy forage rotation (corn/soybean/alfalfa) was established in 2004. Sampling in spring 2008 showed that the upper 5 cm of soil under reed canarygrass and pasture had significantly more carbon than under either switch grass or the crop rotation (20.5 and 17.7 vs. 15.1 and 15.8 g C/kg soil). However, land use had no impact on soil carbon content below 5 cm. Overall, nitrous oxide emissions have been low. Despite nitrogen fertilizer applications to reed canarygrass and switchgrass, the biofuel crops had the lowest observed nitrous oxide emissions (probably due to rapid uptake of nitrogen by the plants). Nitrous oxide emissions from corn plots and pasture were similar. Although no nitrogen fertilizer has been applied to the pasture, large emissions from soil receiving cattle urine contributed a large portion of nitrous oxide from pasture. These data indicate that establishment of pasture or perennial grasses, as bioenergy crops, has a positive impact on the balance of greenhouse gases, but more time will be required to determine the full impact of these land uses on soil carbon sequestration.

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PROJECT TITLE: Managing Dairy Farms for Environmental Stewardship and Profit

SCIENTISTS: C. Alan Rotz, Tamie L. Veith, R. Howard Skinner and Ray B. Bryant

PROGRESS OF WORK AND PRINCIPAL ACCOMPLISHMENTS:

High Biomass Removal Limits Carbon Sequestration Potential of Mature Pastures
Howard Skinner USDA-ARS, University Park, PA
Proper management of agricultural lands has the potential to increase soil carbon sequestration and help reduce the rate that carbon dioxide concentration is increasing in the atmosphere. Converting plowed, annual cropland to perennial pasture is one potential practice that could be beneficial in this regard. However, the ability to sequester carbon decreases when land has been in pasture for several years. This research examined how much carbon dioxide was being gained or lost over a four year period from two central Pennsylvania fields that had been managed as perennial pastures for at least 35 years. A complete carbon budget must include gains and losses from physiological processes such as photosynthesis and respiration, and from management processes such as removal of harvested forage and return of manure. The pastures examined in this study were small carbon dioxide sinks when only physiological processes were considered. However, when a complete carbon budget was calculated, they became net carbon dioxide sources to the atmosphere. Heavy utilization of the forage that was produced on the pastures prevented them from sequestering additional soil carbon. This suggests that mature pastures in the northeastern USA probably cannot help slow the increase in atmospheric carbon dioxide and may actually contribute to the increase.

Ammonia Emissions Model *Alan Rotz and Felipe Montes* USDA-ARS, University Park, PA
Ammonia emissions from animal feeding operations are an important concern due to their potential adverse effects on animal and human health and the environment. Emissions occur from manure surfaces on the barn floor, during storage, and following field or pasture application. Based upon theoretical principles and associated published information on ammonia emission, relationships were refined for modeling the dissociation constant, Henry's law constant and mass transfer coefficient to better predict ammonia loss from manure surfaces. Theoretical inconsistencies in widely used expressions for the dissociation constant and mass transfer coefficient were found. Refined expressions were developed that relate these parameters to the temperature, pH, and ionic strength of the ammonium containing material, and the velocity of air flowing over the material. These expressions were tested by comparing predicted ammonia emission rates against values measured in controlled laboratory experiments for buffered ammonium-water solutions and dairy cattle manure. Experimental results compared well to values predicted using these theoretical expressions derived from ammonia volatilization literature. These process-level relationships provide a basis for developing predictive tools that quantify management effects on ammonia emissions from farms and thus assist in the development and evaluation of strategies for reducing emissions.

Greenhouse Gas Emissions Model *Dawn S. Chianes* ENVIRON International, Los Angeles, CA and *Alan Rotz* USDA-ARS, University Park, PA, Concern over greenhouse gas emissions and their potential impact on global climate has grown rapidly in the US over the past couple years. Livestock agriculture is recognized as an important emitter of these gases, but little quantitative data exist on emission rates and the effect of management on these emissions. Simple process-level relationships were integrated in a comprehensive model for predicting all important sinks and emission sources to determine a whole-farm carbon balance and an estimate of the net farm emission of greenhouse gas. Relationships were used to track carbon dioxide, methane, and

nitrous oxide flows during crop production, from the animals, and from manure on the barn floor, during storage and following land application. These relationships were added to the Integrated Farm System Model to predict net greenhouse gas emissions along with nitrogen and phosphorus losses and the overall performance and economics of farm production systems.

Dairy Greenhouse Gas Model *Alan Rotz and Felipe Montes* USDA-ARS, University Park, PA; *Dawn S. Chianese*, ENVIRON International, Los Angeles, CA The Dairy Greenhouse Gas Model (DairyGHG) was developed to provide an easy to use software tool that estimates total net greenhouse gas emissions and the carbon footprint of a dairy production system. DairyGHG uses a relatively simple process-based model to predict the primary GHG emissions from the production system, which include the net emission of carbon dioxide plus all emissions of methane and nitrous oxide. Emissions are predicted through a daily simulation of feed use and manure handling where daily values of each gas are summed to obtain annual values. A carbon footprint is then calculated as the sum of both primary and secondary emissions in CO_2 equivalent units divided by the milk produced. Secondary emissions are those occurring during the production of resources used including machinery, fuel, electricity, fertilizer, pesticides, and plastic. DairyGHG is available for download from our Internet site (http://ars.usda.gov/naa/pswmru). The model includes a fully integrated help system with a reference manual that documents the relationships used to predict emissions.

Precision Feed Management and Phosphorus *Tamie Veith and Al Rotz,* USDA-ARS, University Park, PA; Lula Ghebremichael, University of Vermont, Burlington, VT; Paul Cerosaletti, Cornell Cooperative Extension of Delaware County, Hamden, NY; Jim Hamlett, PSU, University Park, PA. Phosphorus (P) accumulates in the soil when farm P imports (as feed and fertilizer) exceed P exports (in milk, manure, and other products) and this buildup leads to greater runoff loss. Using detailed farm data, P losses before and after the implementation of farm-level precision feed management (PFM) strategies were simulated using a watershed water quality model (Soil and Water Assessment Tool, SWAT) on a single-farm watershed located within the Cannonsville Reservoir Watershed in New York. Use of the PFM strategies more precisely balanced dairy cattle dietary P and improved on-farm forage production and use, which together reduced the importation of feed nutrients, lowered manure P concentration, and reduced soil-P build-up and loss while maintaining farm profitability. Such model-based representations and evaluations of farm plans at a watershed level help integrate farm management plans (the smallest management unit) into a watershed plan. These tools have proven helpful in assessing comprehensive and economically viable solutions to the permanent reduction of P losses from dairy agriculture to the Cannonsville Reservoir.

Stream Bank Fencing and Phosphorus Loads. *Pete Kleinman and Tamie Veith,* USDA-ARS, University Park, PA; *Erin James*, Virginia Tech, Blackburg, VA; *Richard Stedman*, Cornell University, Ithaca, NY. Movement of phosphorus from agricultural lands to water is a major concern because this leads to the eutrophication of lakes and reservoirs. The Conservation Reserve Enhancement Program (CREP) is a management practice that reduces cattle access to streams through stream bank fencing and replanting, thus reducing phosphorus loading to the stream and downstream water bodies. This study sought to quantify the phosphorus loading from pastured dairy cattle fecal deposits to streams in the Cannonsville Watershed of New York. Based on field observations and spatial modeling, deposition of manure into streams by pastured dairy cattle was estimated to contribute about 12% of the total phosphorus load attributed to agriculture in the watershed. As of 2007, implementation of CREP was estimated to have reduced in-stream deposition of manure phosphorus by 32%. This study highlights the importance of stream bank fencing programs in controlling phosphorus loadings from pastured cattle.

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