2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Agricultural Residues

May 20, 2013
Technology Area Review: Feedstock Supply & Logistics

Principal Investigators: Douglas L. Karlen & David J. Muth Jr.
Organization: Sun Grant Regional Partnership/USDA-ARS/INL

Goal Statement

- Implement field trials quantifying short- and long-term effects of harvesting agricultural residues (*i.e.*, corn stover and wheat straw)

- Develop methodologies and collect data on GHG and water quality impact of agricultural residue harvest

- Develop tools to help guide implementation of sustainable agricultural residue harvest for bioenergy production.

Quad Chart Overview – Agricultural Residues

Timeline

- Project start date: 1-15-2007
- Project end date: 9-30-2013
- Percent complete: 95%

Barriers

- Resource Availability and Cost
- Sustainable Production
- Sustainable Harvest Strategies

Budget (including corn sustainability funds)

Funding for FY11

Sun Grant $1,020,493

Cost share- $255,123

Funding for FY12 – $0

Funding for FY13 – $0

Total Funding (6 yr @ $503,464/yr)

Sun Grant – $3,020,784

Cost Share – $ 755,196

ARS – $1,500,000 (base funds)

INL – $1,500,000

Partners

USDA-ARS

University Partners

Monsanto

Idaho National Laboratory

Project Overview

- Conducted field trials evaluating corn stover harvest impacts
  - Crop yield, plant nutrition, nutrient removal, soil carbon, and soil health/quality indicators were quantified
  - Evaluated alternative harvest strategies
  - Implemented additional land management treatments (e.g., crop rotations, cover crops, biochar, compost, etc.) where feasible

- Instrumented selected field sites for sustainability studies
  - Quantified greenhouse gas (GHG) impacts of stover harvest
  - Monitored potential water quality impacts of stover harvest

- Developed a simulation modeling framework (Stover Tool) that was:
  - Used field trial data to guide site specific, sustainable harvest
  - Shared with commercial groups developing sustainable crop residue harvest strategies

1 – Approach: Core Corn Stover Experiment

- Established and leveraged replicated plots on highly productive soils
- Used no tillage or least possible for successful crop production
- Continuous corn if possible or corn – soybean rotation if necessary
- Minimum stover harvest treatments – none, ~50%, and maximum collectable (~90 to 100%)

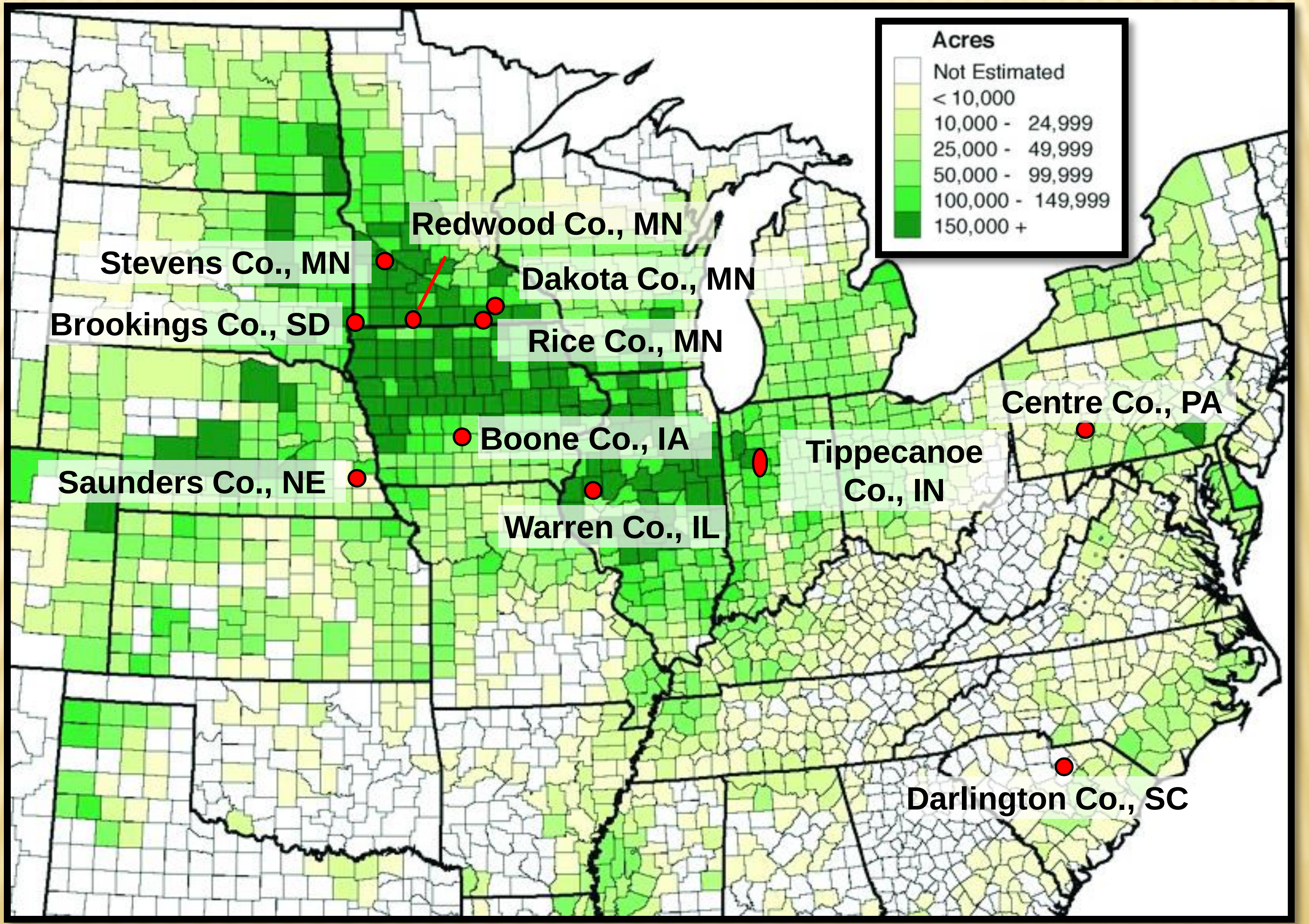
- Baseline and 2012 soil sampling to a depth of 1m
- More frequent near-surface testing at some locations
  - Deep cores divided into increments of 0 to 5 cm, 5 to 15 cm, 15 to 30 cm, 30 to 60 cm, and 60 to 100 cm
  - Total organic C, pH, total N, bulk density, soil-test P & K at a minimum

- Plant sampling
  - Agronomic practices, grain yield, N content, and moisture content
  - Corn stover yields, moisture content, and N-P-K concentrations
  - Dry matter retained in field computed by subtraction

2 – Results

- No additional work on wheat residues
  - Insufficient supply except for irrigated areas
    - Too many competing uses for a viable feedstock supply
- Stover updates since 2011 Platform Review
  - Added data collection sites for yield and soil health monitoring in Illinois by moving university partner funds from UMN – Morris to UIUC
  - ARS GHG and soil carbon data from West Lafayette IN was leveraged with no additional DOE funds

REAP/Regional Partnership Field Sites



USDA National Agricultural Statistics Service ,2010

Harvest Technologies

Ames, Morris & St. Paul

University Park

Lincoln

Florence

Collaborators

Stover Harvest Effects on 4-yr Average Grain Yield

State	Mgmt.	None	Mod.	High	State	Mgmt.	None	Mod.	High
		---------- bu/acre --------					------------ bu/acre ------------		
IA	CP/MM	171	188	188	IA	NT/MM	168	183	195
IL	CP/MM	218	212	215	IL	NT/MM	177	200	205
MN	NT95/MS	143	146	137	MN	NT05/MS	164	160	157
MN	MbP/MM	199	198	199	MN	ST/MM	199	198	196
NE	NTNI/MM	96	---	109	NE	NTIRR/MM	190	209	209
PA	NT/MM	147	153	147	PA	NT/MS	152	152	143
SD	NT/MS	123	126	125	SD	NT/MS+CC	119	126	123
SC	NTIRSS/MM	83	81	84					

Stover Yield Summary

- A variety of harvest methods resulted in similar moderate and high removal rates that averaged 1.8 and 3.1 tons/acre/year, respectively
- Hand samples and harvest index estimates may over-estimate available stover quantities
- Rainfall amounts and wind damage increased seasonal variation in available stover quantities
- Stover harvest may be beneficial for overcoming cool, wet soil conditions that limit early-season Midwestern corn growth in subsequent years

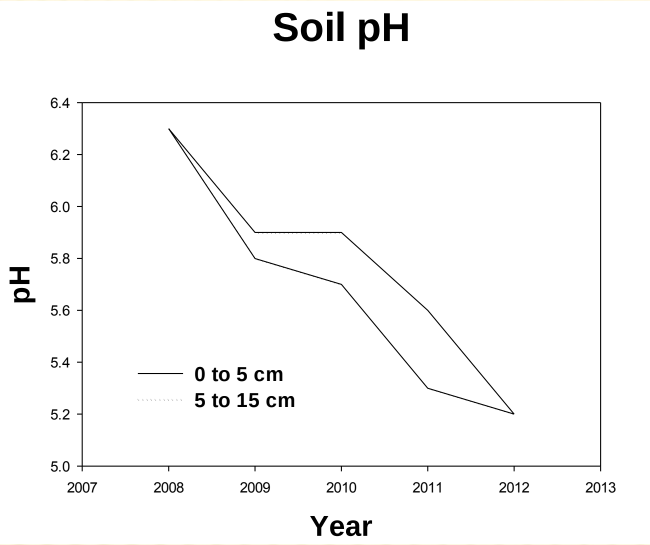
Average Stover Removal of Macronutrients

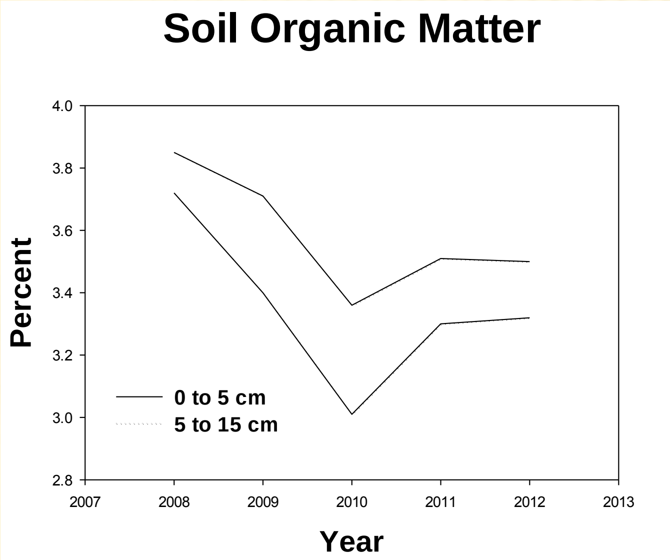
Measurment Method	Moderate Harvest Rate (1.8 t/ac)			High Harvest Rate (3.1 tons/acre)		
	N	P	K	N	P	K
	-- lb/acre --					
Machine	16	2.0	29	28	3.2	49
Hand	25	3.5	41	52	7.4	81

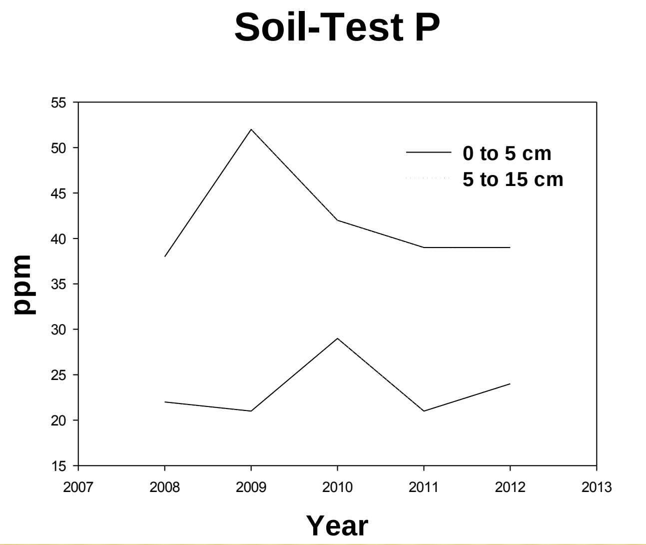
Machine harvest data – single pass harvesting of both grain and stover

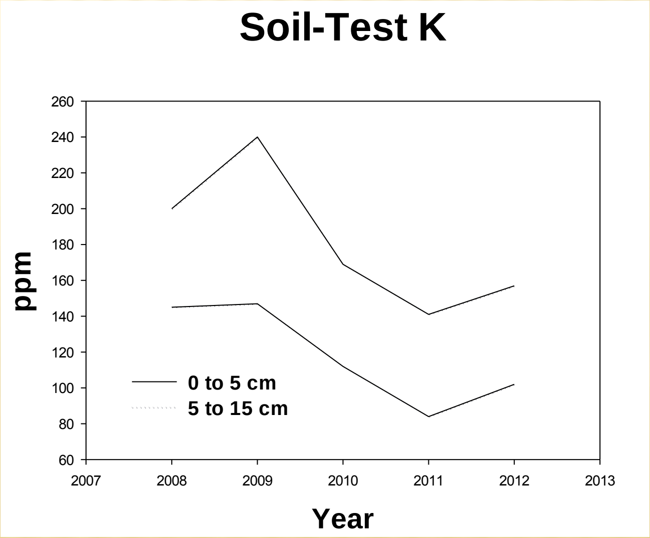
Hand harvest occurred between physiologic maturity and grain harvest. Previous REAP publication shows a very rapid change in mineral concentrations during this period. Must document growth stage at time of sampling.

Ames – Soil Test Response

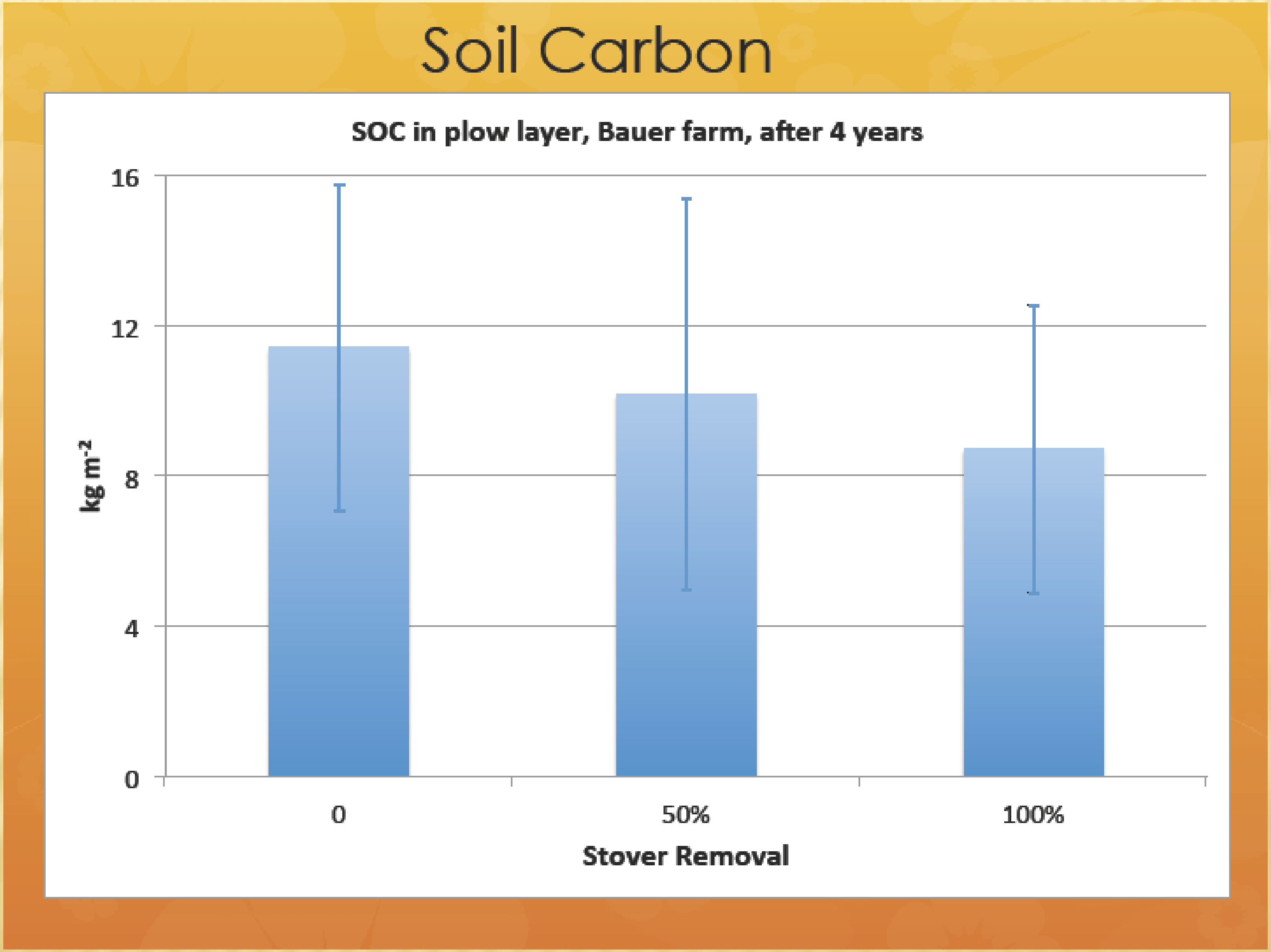








Rice County MN



Stover Treatment		POM	SOC	Total N
		---------------------- kg^{-1} soil ----------------------		
			Chisel	
	Control	7.42	25.9	2.19
Cut	High	7.23	24.1	2.11
	Low	7.18	26.3	2.23
			NT 2005	
	Control	10.42	26.7	2.27
Cut	High	9.60	26.5	2.25
	Low	10.78	26.9	2.27
			NT1995	
	Control	**14.5a**	28.8	2.46
Cut	High	**14.0a**	27.0	2.36
	Low	**11.3b**	26.2	2.27

Morris, MN – Effect of stover treatment on POM measured in 2009, SOC, and total N measured in 2011 in the surface 0-5 cm. Within a column, different letters signify $P \leq 0.05$ signif.

Johnson et al., in-press

Brookings Site

- Fine silty mixed hapludols
  - 47% sand, 6% clay, 47% silt;
  - pH 6.3
- ARS leverage site – started in 2004
- Sampled July 2008 and 2012
- 0-5 cm depth
- Soil separated into 6 aggregate size classes dry aggregate stability method
  - <0.4mm, 0.4-0.8mm, 0.8-2 mm, 2-6mm, 6-19mm, >19mm

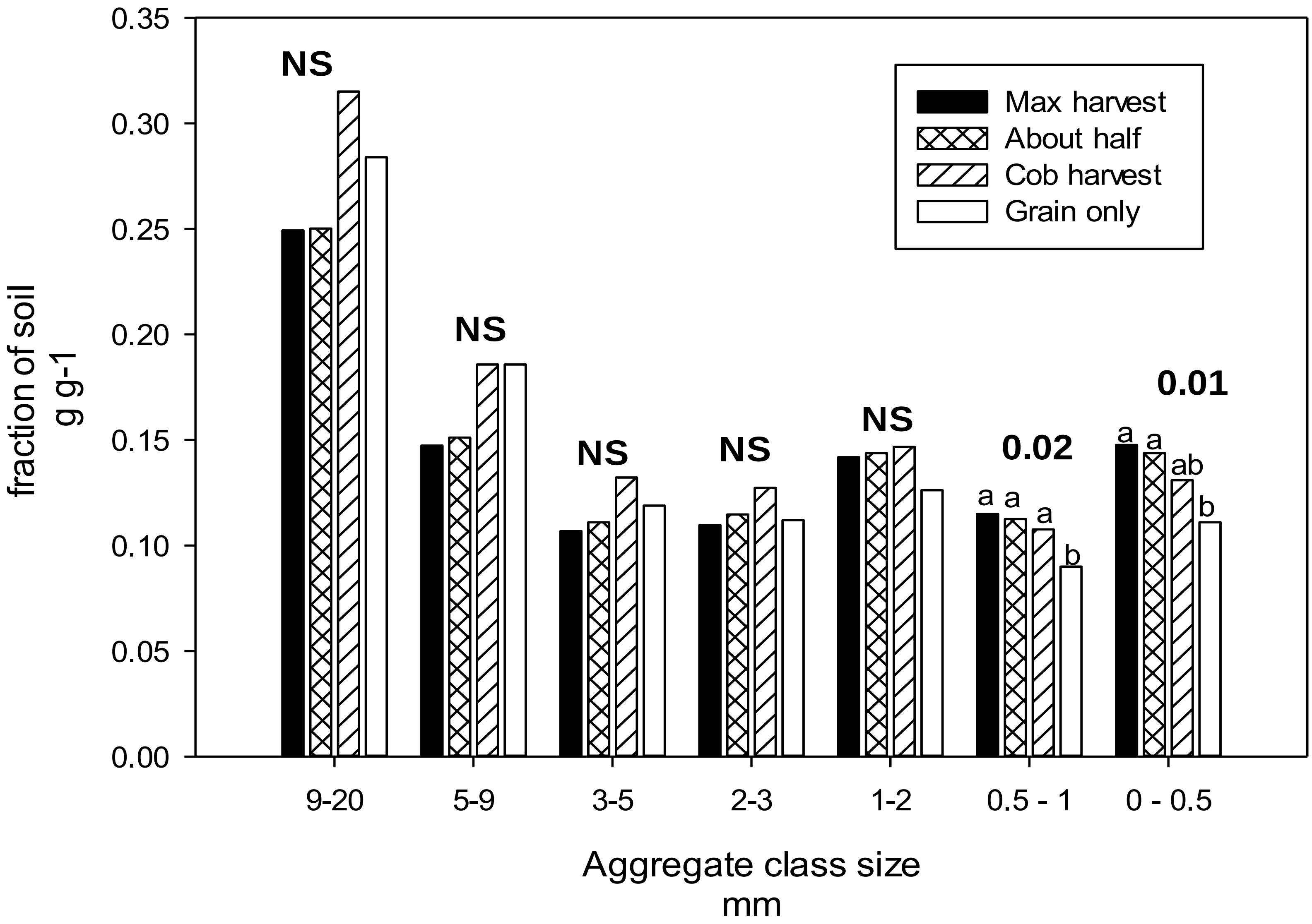
Brookings – residue removal effects on erodible fraction ‡ in top 5 cm with and without the addition of cover crops.

Residue Removal	2008	2012	2012
		No Cover Crop	Cover Crop
LRR	93	85	75
MRR	154	130	150
HRR	184	307	161
Pr > F	0.001	0.001	0.001

‡EF – Erodible fraction is the mass fraction of soil <0.84 mm in diameter.

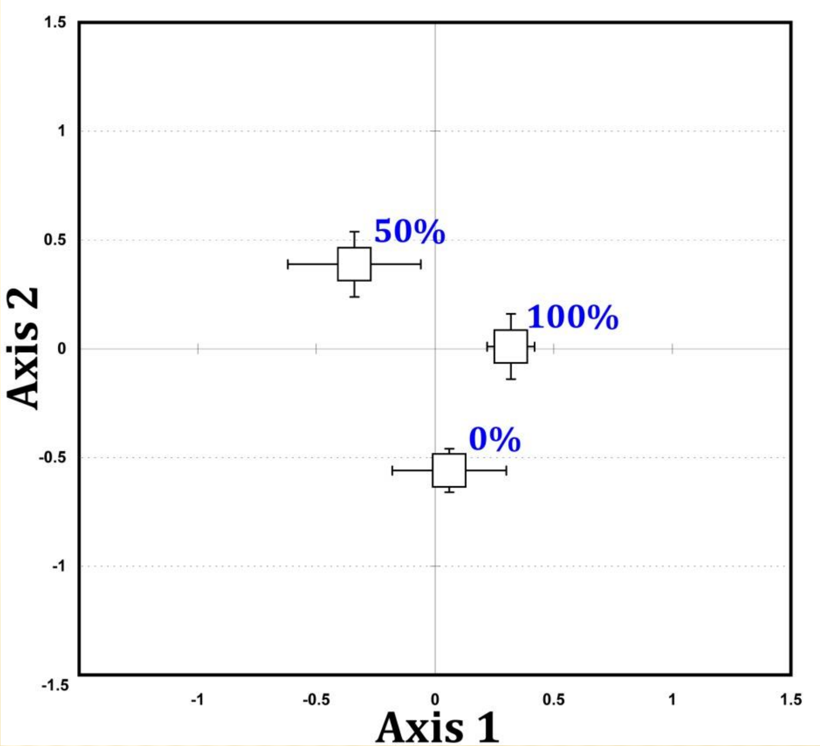
Morris, MN – Dry aggregate size distribution determined in 2012 in the surface (0-5 cm). (NS (not significant). Bars labeled with different letters within a class size differ at P≤0.05. Combined mixed model, replication within field)

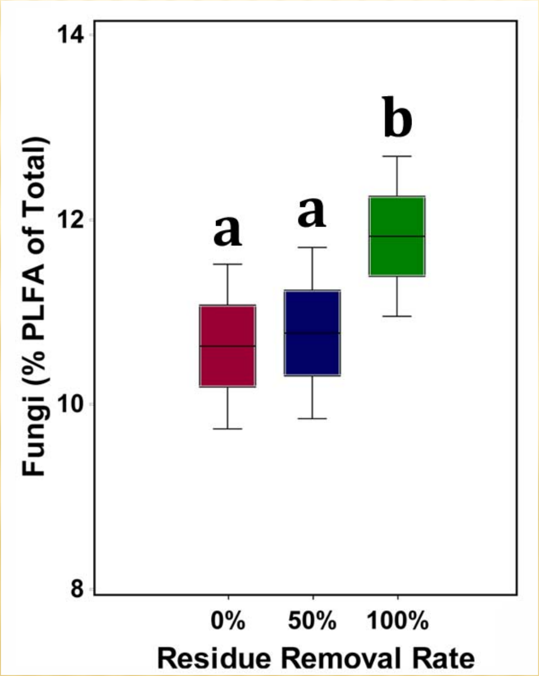
Effect of residue treatment on 2012 erosivity in three fields.



Florence – Microbial Community Analysis - PLFA

Clear separation between microbial communities, as measured by PLFA, in the 0%, 50%, and 100% corn stover removal rate plots. →





Higher percentage of fungal PLFAs (3 year average) in 100% removal rate plots.
←

Greenhouse Gas Assessments

- Automated chambers – provide better temporal resolution and thus more accurate cumulative data, but high cost limits replication.
- At both IA and MN sites, N_2O production was generally greater in early spring when stover is removed, but the difference is not large. Emissions were similar during the later growing season.
- Stover removal impact on soil respiration is small relative to the large difference in C input, indicating excessive stover removal is likely to have a measurable impact on soil organic matter.

REAPnet Database

Data entered into standardized Excel template

→

Excel spreadsheets converted to Access data tables

→

Access data tables combined to create one master database for each participating location

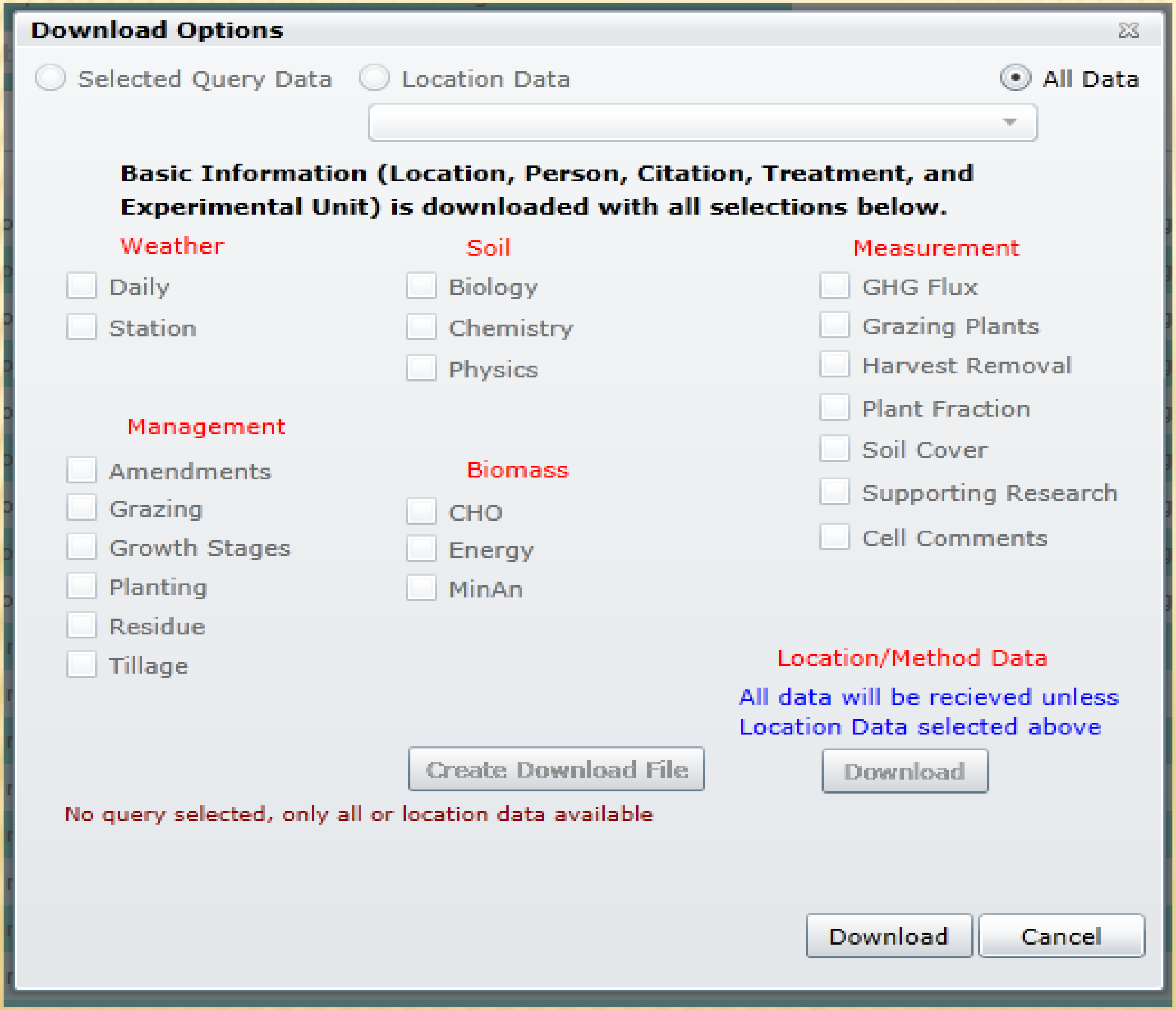
→

Each master database uploaded to SQL to produce data query and download application

Public version released on January 24, 2013

Available at: nrrc.ars.usda.gov/slreap/#/Home

Data Download Template



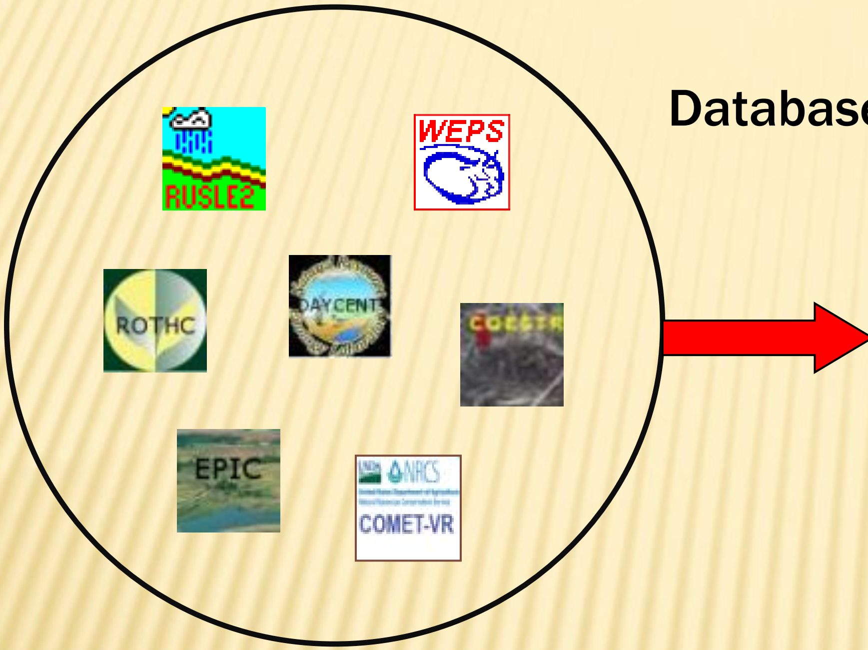
Protocols for downloading data, making unit conversions, and entering it into the KDF are currently being developed using Corn Stover team data.

Greg Wilson is contact person

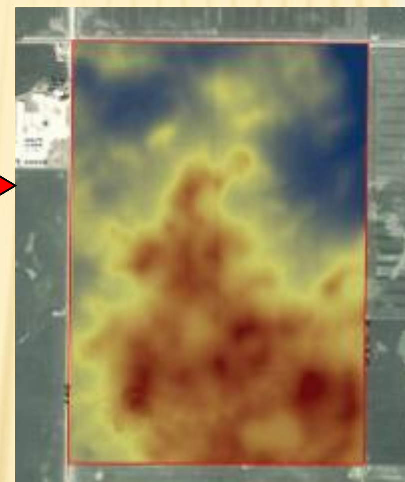
The Residue Management Tool

Approach

Simulation Models



Databases – e.g. SURGO



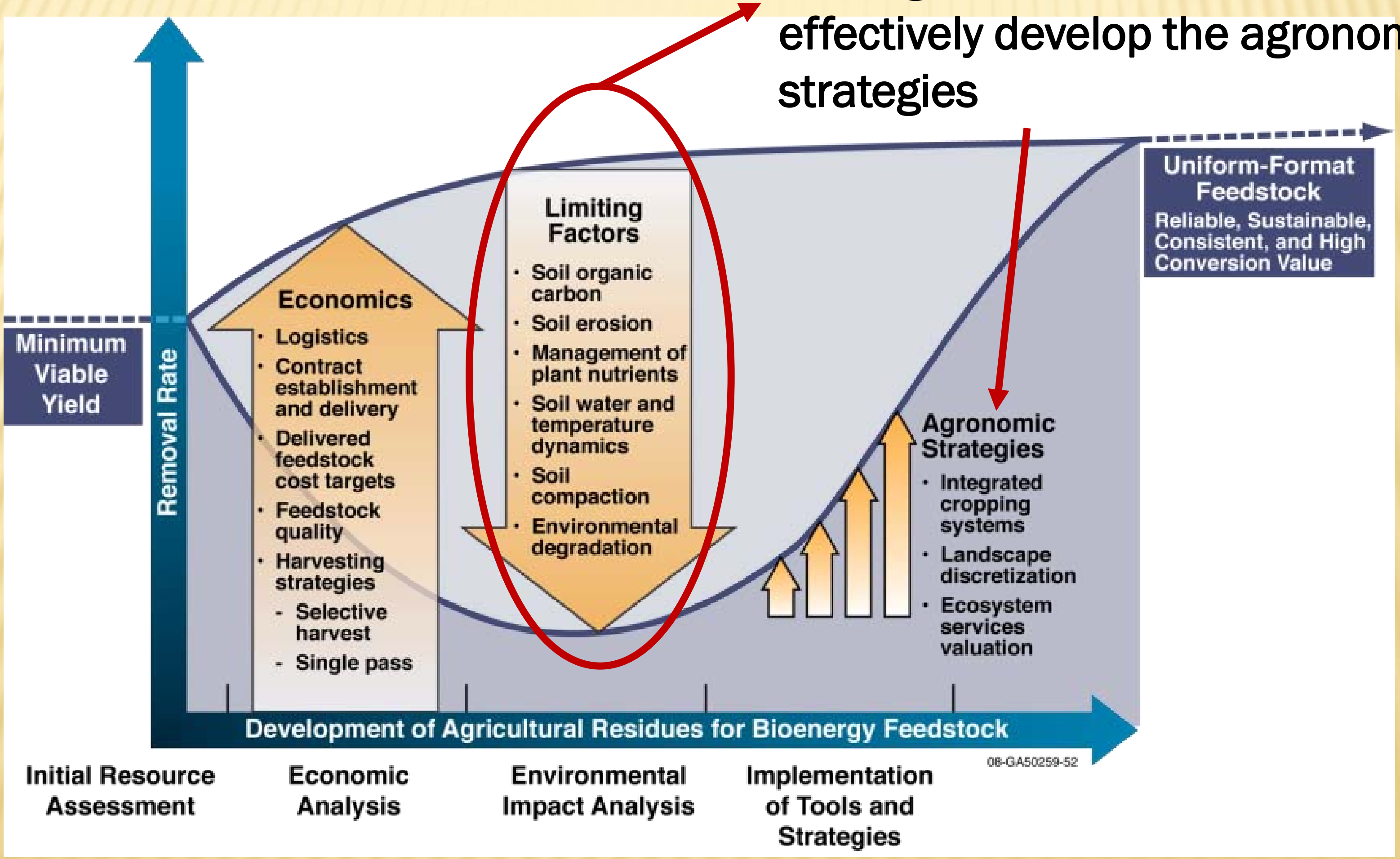
Field Management Decisions

The models and databases exist,

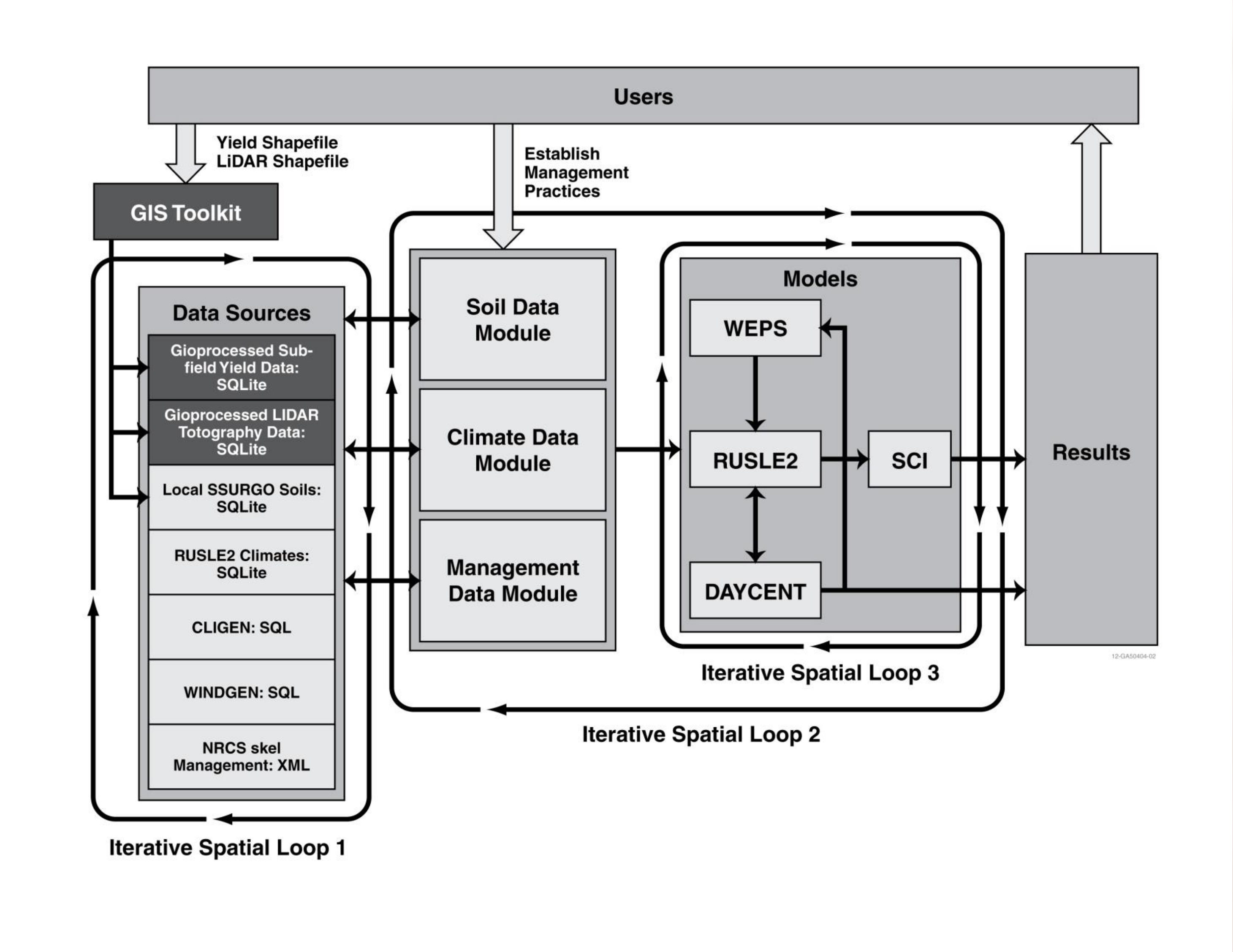
The Residue Management Tool provides a framework where models can plug together to answer questions using available data.

Sustainable Residue Removal

Focused on quantifying the limiting factors, so we can effectively develop the agronomic strategies



Extended Integrated Modeling Framework



3 - Relevance

- Field research data used to develop 1st generation "Stover Tool"
- Stover Tool was tested and evaluated by industry stakeholders (Monsanto/ADM; POET-DSM; DuPont Cellulosic Ethanol; Anterries) for field validation near pre-commercial cellulosic ethanol plant sites in Iowa and Kansas and for enhanced animal feed studies in Illinois, Indiana, and Iowa.
- USDA-NRCS was briefed multiple times to help facilitate Tool approval for guiding commercial agricultural residue harvest operations
- An Apple phone application version of the Stover Tool was released in November 2012 to facilitate real-time evaluations for pre-commercial operations.
- A 2nd generation "Landscape Environmental Assessment Framework" (LEAF) was developed using "Stover Tool" feedback and further research

4 - Critical Success Factors

Success Factors

- Industry/Agency Collaboration
  - This multi-location, multi-agency data collection project has resulted in solid relationships with and use of the information by Monsanto – ADM; POET-DSM; DuPont Cellulosic Ethanol; Virent; Iowa Agricultural BioFibers (IABF); and other industry groups.
  - NRCS/FSA leadership has expressed interest and confidence in the information provided by this project.

Challenges

- Funding & Longevity
  - Available data is good but funds are needed to sustain multi-location monitoring for at least another five years
  - Climatic variability which helps generated valuable experience and data, but complicates baseline development on and across sites

Impact

- Release of 2nd Generation "Stover Tool" – LEAF (www.inl.gov/LEAF)
  - The U.S. Secretary of Agriculture and CEO of DuPont Cellulosic Ethanol recently signed an MOU stating all feedstock would be collected in a certifiable sustainable manner using our tool set as the decision support engine

5 – Future Plans

- Currently the ARS-REAP (Resilient Economic Agricultural Practices) team does not anticipate additional DOE funding even though these long-term field studies must be continued
- ARS is developing a public-private-partnership through the Agricultural Technology Innovation Partnership (ATIP) to continue the work
  - DOE and NGOs are also being invited to participate
- Emphasis on landscape diversity, sub-field variation, site-specific management, multiple feedstock sources and soil health will be increased

6 – Project Summary

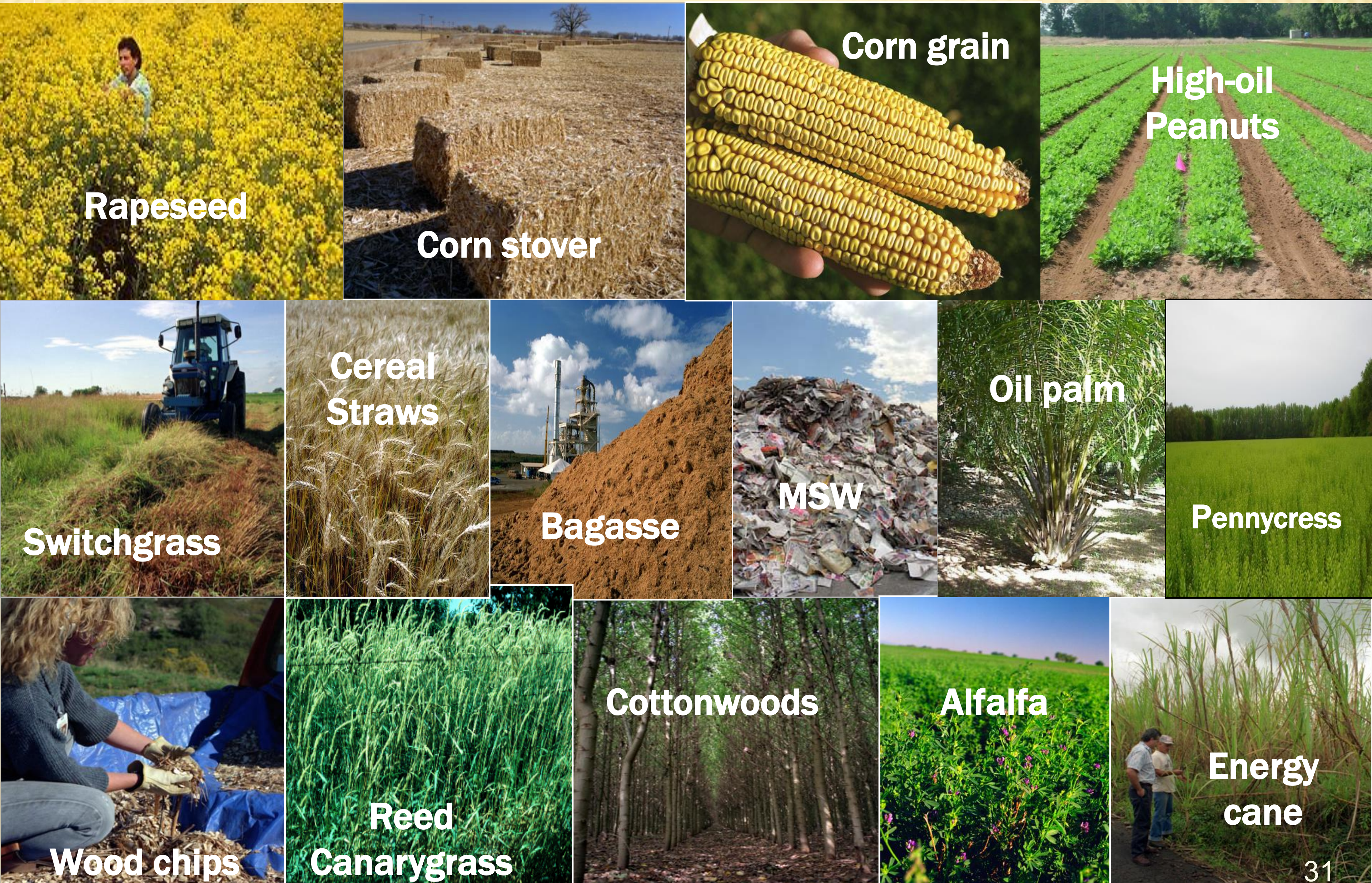
- Overall corn or soybean yield response to stover harvest was minimal
- Sustainable stover harvest rates are determined by grain yield and must be site specific
- Limited residue harvest may help growers adopt no-till corn production in the upper Midwest
- Plant growth stage significantly influences nutrient removal
- Ten years of stover harvest, even with no-tillage, reduced POM accumulation suggesting SOM maybe declining
- Insufficient rates of crop residue return shifts dry aggregate size distribution toward smaller soil aggregates
- Biological parameters suggest insufficient crop residue returns may cause undesirable shifts in the microbial community.
- Sustainable supplies of corn stover may be lower than initially projected because of weather-induced yield variability
- Long-term crop and soil monitoring must be continued

Developing Sustainable Stover Harvest Strategies is Simply the First Step Toward Solving Multiple Ecosystem Challenges

Any Questions?

Additional Slides

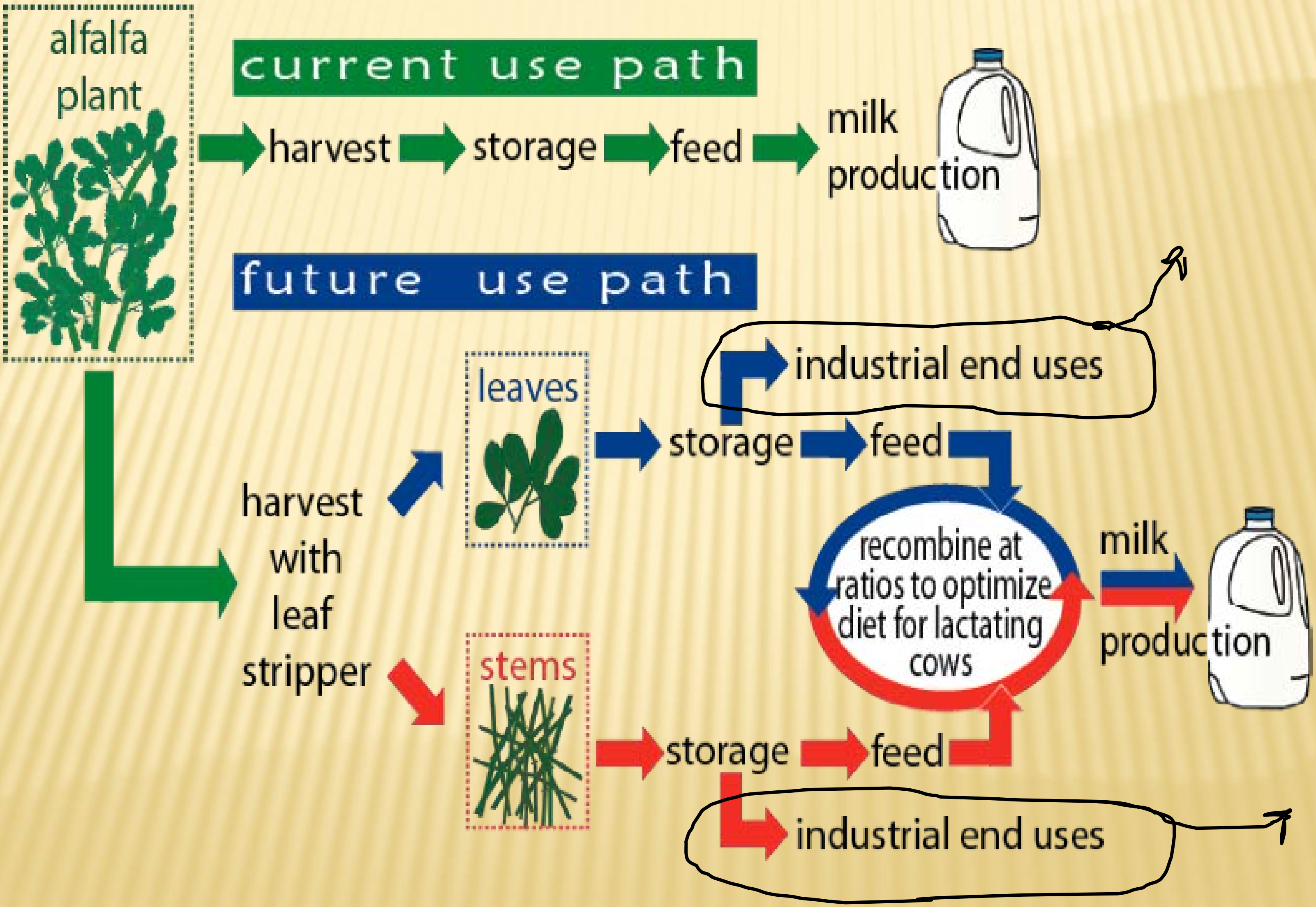
Future REAP/RP Activities – A Diverse Landscape



A Diverse Landscape Provides –

- Multiple ecosystem services
  - Feedstock for bioenergy & bio-products
  - Enhanced nutrient cycling
  - Multiple pathways for sequestering C
  - Food, feed & fiber resources
  - Filtering and buffering processes
  - Wildlife food & habitat
  - Soil protection & enhancement
  - Economic opportunities for humankind

Incorporating Alfalfa Into Bio-Energy/Bio-Product Feedstock Production Systems



Corn in living mulch
Rosemount, MN

What Limits Achieving a Diverse Landscape?

A continued focus on individual problems!

Bioenergy, air quality, water quality, soil quality, wildlife, carbon sequestration, rural development, waste streams & other issues must be addressed as an integrated system

Tools exist (SWAPA, Stover Tool, LEAF), use them

Erosion

Water Quality

Corn Grain

Waste paper

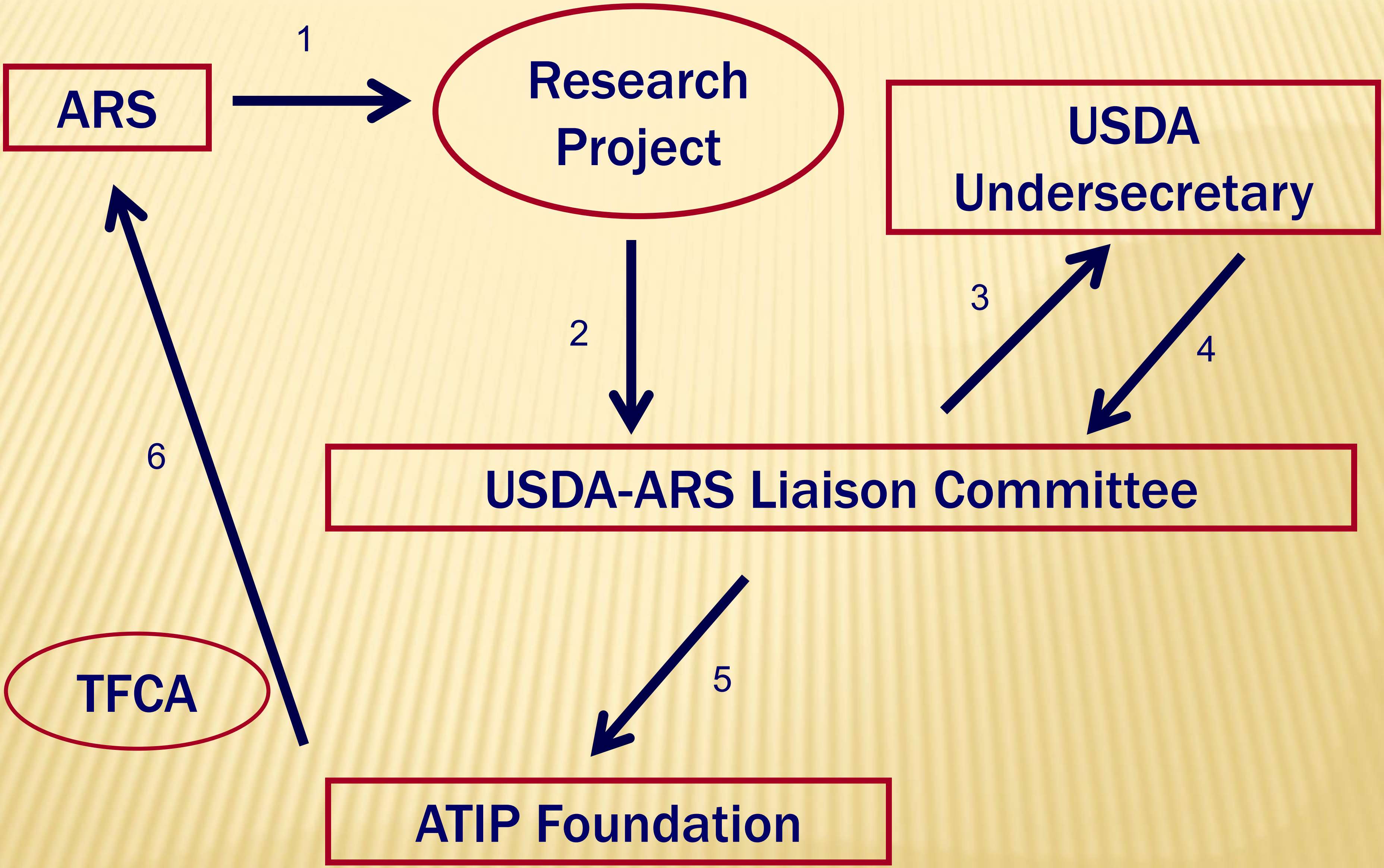
Switchgrass

Crop Residues

ATiP FOUNDATION

(Potential Funding Entity)

To provide both a unifying entity for the members external to ARS, as well as flexibility to engage other organizations that have a vested interest in seeing USDA research outcomes adopted by the private sector to create goods and services for public benefit.


ARS
1
Research Project
USDA Undersecretary
2
3
4
6
USDA-ARS Liaison Committee
5
TFCA
ATIP Foundation

Responses to 2011 Reviewers' Comments

- How important is logistics to this project?
  - Logistics within the feedstock supply chain has always been an integral part of ARS-REAP discussions and information sharing but actual studies addressing harvest, storage, and transportation are beyond the scope of resources provided through the Sun Grant and therefore are primarily being addressed by team members through other collaborations
- Have they established a "maximum" % stover removal?
  - The key message is that specifying any specific percentage or quantity of stover removal per unit area is absolutely the wrong approach. Stover harvest must be site-specific and to be sustainable must account for within-field variability. The Stover Tool is designed to help identify when, where, and how much stover can be sustainably harvested for any use.

2011 Review Comment Responses – Continued

- Much of the eastern, more humid region of the corn belt is not represented in this project.
  - A change in university partners was made for the 2011 and 2012 harvest seasons by moving Sun Grant resources from the University of Minnesota – Morris to the University of Illinois. In response, Dr. Emerson Nafziger (UIUC) has leveraged stover harvest and soil response data from four locations in that state. This is data is being added to the final database.

  - The ARS-REAP team leveraged a West Lafayette, IN study led by Dr. Diane Stott and is in the process of incorporating data from that location into the ARS GRACEnet/REAPnet database. This site has also increased the amount of information being gathered relative to GHG emissions.

2011 Review Comment Responses – Continued

- Need greater intensity on GHG measurements
  - Sun Grant sustainability resources were used to significantly increase GHG assessment efforts at the St. Paul and Ames locations. Although static chambers were initially used because of their lower cost, a key outcome of this cross-location study is that continuous monitoring of GHG provides much better data

- What is the management model for the array of partners?
  - As coordinator for both the ARS REAP and Sun Grant Regional Partnership teams, Dr. Karlen strives to stay in communication with all team members and to be sure information is compiled into meaningful quarterly reports. He also coordinates the yearly face-to-face meeting and is the liaison between team members, Sun Grant administration, and several industry partners.

2011 Review Comment Responses – Continued

- What criteria will ultimately be used to bound sustainable production?
  - Soil erosion, organic matter, nutrient cycling, GHG emissions, and logistics will all be considered
- Has a tool actually been produced?
  - The 1st generation "Stover Tool" served primarily as a prototype for a 2nd generation known as the Landscape Environmental Assessment Framework (LEAF). Core software libraries for LEAF were made available through the leaf-tools Google code project at https://code.google.com/p/leaf-tools/ on July 25th, 2012. Several specific application-based implementations of the LEAF core libraries have been released since then. The mobile stover removal assessment tool, SustainR2, was available for iOS systems via the Apple App Stover on Dec. 8, 2012.

2011 Review Comment Responses – Continued

- How is information going to be transferred?
  - The multi-agency/institution relationships that have been developed as a result of this Regional Partnership provide the key for information transfer. Partnerships with Monsanto, ADM, John Deere, DuPont Cellulosic Ethanol, and POET-DSM also help transfer information and guidelines to stakeholders.
- Is it economical to harvest 1-2 tons/acre – much less than for switchgrass and/or miscanthus?
  - Low quantities per acre are a concern, but vast areas of corn production make stover a viable feedstock for the Midwest. It appears that about 1-1.25 ton/acre will cover harvest costs and after grain yields exceed approximately 175 bu/acre most of the additional stover can be safely harvested and doing so will provide improved residue management. This is especially true if producers will also reduce tillage intensities.

2011 Review Comment Responses – Continued

- The team should consider opportunities for using double-crops.
  - Cover crops are being used at several sites. At Ames, rye and triticale were harvested, providing 1.5 and 4.25 tons/acre of dry biomass in 2011 and 2012, respectively, prior to planting soybean. This system could provide feedstock during both years of a corn/soybean rotation if ash content of the small grain isn't too high. Seasonal water balance is also a key factor that needs to be accounted for in such evaluations.
- What are your conclusions regarding local processing versus regional biorefineries, especially regarding wheat straw?
  - Wheat straw will provide less biomass feedstock than originally projected and would be best managed through local processing.

Publications, Presentations, & Commercialization

- As of April 2013, ARS-REAP has produced:
  - 28 peer-reviewed publications
  - 4 publications in trade journals, extension, or popular press
  - 4 book chapters
  - 20 conference proceedings
  - 36 conference abstracts at regional/national/international meetings
- 15 manuscript titles approved for a special Issue of Bioenergy Research with a target publication date of March 2014
- Pre-commercialization testing of Stover Tool and release of the mobile application in November 2012
- LEAF nominated for a 2013 R&D 100 Award
  - Please see: (www.inl.gov/LEAF)

Peer Reviewed Publications
(Associated with the REAP/Regional Partnership)

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

- Johnson, J.M., Coleman, M.D., Gesch, R.W., Jaradat, A.A., Mitchell, R., Reicosky, D.C., Wilhelm, W.W. 2007. Biomass-bioenergy crops in the United States: a changing paradigm. The Americas Journal of Plant Science and Biotechnology. 1(1):1-28.

- Karlen, D.L., Andrews, S.S., Zobeck, T.M., Wienhold, B.J. 2008. Soil quality assessment: past, present, and future. Electronic Journal of Integrative Biosciences. 6(1):3-14.

- Wilhelm, W.W., Johnson, J.M., Karlen, D.L., Lightle, D. 2007. Corn stover to sustain organic carbon further constrains biomass supply. Agronomy Journal. 99:1665-1667.

Peer Reviewed Publications (continued)

- Liang, Y., Gollany, H.T., Rickman, R.R., Albrecht, S.L., Follett, R.F., Wilhelm, W.W., Novak, J.M., Douglas Jr, C.L. 2008. CQESTR simulation of management practice effects on long-term soil organic carbon. Soil Sci. Soc.Am. J. 72:1486-1492

- Wilhelm, W.W. 2008. My biomass, your biomass, our Solution. Biofuels, Bioproducts, & Biorefining. 2:8-11.

- Varvel, G.E., Wilhelm, W.W. 2008. Soil carbon levels in irrigated Western Corn Belt rotations. Agronomy Journal. 100:1180-1184.

- Baker, J.M., and T.J. Griffis. 2009. Evaluating the potential of winter cover crops in corn-soybean systems for sustainable co-production of food and fuel. Agric. Forest Meteorol. 149:2120-2132.

Peer Reviewed Publications (continued)

- Liang, Y., Gollany, H.T., Rickman, R.W., Albrecht, S.L., Follett, R.F., Wilhelm, W.W., Novak, J.M., Douglas, C.L. 2009. Simulating soil organic matter with CQESTR (v.2.0): model description and validation against long-term experiments across North America. Ecological Modelling. 220(4): 568-581.

- Gollany, H.T., Rickman, R.W., Liang, Y., Albrecht, S., Machado, S., Kang, S. 2010. Predicting agricultural management influence on long-term soil organic carbon dynamics: implications for biofuel production. Agron. J. 103:234-246. doi:10.2134/agronj2010.0203s

- Johnson, J.M.,W. W. Wilhelm, D. L Karlen, D. W. Archer, B. Wienhold, D. T. Lightle, D. Laird, J. M. Baker, T. E. Ochsner, J. M. Novak, A. D. Halvorson, F. Arriaga, N. W. Barbour. 2010. Nutrient removal as a function of corn stover cutting height and cob harvest. BioEnergy Research 7:342-352.

- Karlen, D.L. 2010. Corn stover feedstock trials to support predictive modeling. Global Change Biology-Bioenergy. 2:235-247.

Peer Reviewed Publications (continued)

- Karlen, D.L., Varvel, G.E., Johnson, J.M., Baker, J.M., Osborne, S.L., Novak, J.M., Adler, P.R., Roth, G., Birrell, S. 2010. Monitoring soil quality to assess the sustainability of harvesting corn stover. Agronomy Journal. 103:288–295.

- Ochsner, T.E., J.M. Baker, K. Albrecht, and T. Schumacher. 2010. Water balance and nitrate leaching for corn in kura clover living mulch. Agron. J. 102:1169-1178.

- Wienhold, B.J. and J.E. Gilley. 2010. Cob removal effect on sediment and runoff nutrient loss from a silt loam soil. Agronomy Journal 102:1448-1452.

- Wienhold, B.J., G.E. Varvel, and V.L. Jin. 2011. Corn cob residue carbon and nutrient dynamics during decomposition. Agronomy Journal 103:1192-1197.

Peer Reviewed Publications (continued)

- Wilhelm, W.W., J. R. Hess, D.L. Karlen, J. M. F. Johnson, D.J. Muth, J. M. Baker, H. T. Gollany, J. M. Novak, D. E. Stott, and G. E. Varvel. 2011. Balancing limiting factors and economic drivers for sustainable midwest agricultural residue feedstock supplies. Industrial Biotechnol. 6: 271-287.
- Wilhelm, W.W., Johnson, J.M., Lightle, D., Karlen, D.L., Novak, J.M., Barbour, N.W., Laird, D.A., Baker, J.M., Ochsner, T.E., Halvorson, A.D., Archer, D.W., Arriaga, F.J. 2011. Vertical distribution of corn stover dry mass grown at several U.S. locations. BioEnergy Research. 4(1):11-21.
- Baker, J.M. 2012. Vegetative propagation of kura clover: a field-scale test. Can. J. Plant Sci. 92(7): 1245-1251.
- Hammerbeck, A.L., S.J. Stetson, S.L. Osborne, T.E. Schumacher, and J.L. Pikul Jr. 2012. Corn residue removal impact on soil aggregates in a no-till corn/soybean rotation. Soil Sci. Soc. Am. J. 76:1390-1398.

Peer Reviewed Publications (continued)

- Krueger, E., T.E. Ochsner, P.Porter, and J.M. Baker. 2012. Rye-corn silage double-cropping reduces corn yield but improves environmental impacts. Agron. J. 104:888-896.

- Muth, D.J., McCorkle, D.S., Koch, J.B., Bryden, K.M. 2012. Modeling sustainable agricultural residue removal at the subfield scale. Agron J. 104:970-81.

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- Wilhelm, W.W. 2006. Book review of agriculture as a producer and consumer of energy. Crop Science 46:1838-1839.
- Johnson, J.M., Karlen, D.L., Andrews, S.S. 2010. Conservation Considerations for Sustainable Bioenergy Feedstock Production: If, What, Where, and How Much? Journal of Soil and Water Conservation Society. 65(4):88A-91A.
- Karlen, D.L. 2011. Crop stubble needs and opportunities. Western Australia No-Till Farmers Association Newsletter (WANTFA). New Frontiers in Agriculture. 19(3):112-115.
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Approved Titles for Bioenergy Research

- Yield Response

- Corn grain, stover yield and nutrient removal validations at regional partnership sites
- Sustainable corn stover harvest for cellulosic ethanol
- A multi-factor analysis of sustainable agricultural residue removal potential
- Site-Specific Trade-offs of Harvesting Cereal Residues as Biofuel Feedstocks

- Soil Response

- Regional partnership corn stover management effects on soil aggregation and physical properties
- Corn stover management effects on soil organic carbon contents from several U.S. locations
- Influence of corn stover harvest on soil quality assessments at multiple locations across the U.S.
- Using DAYCENT to model soil impacts of harvesting corn stover for bioenergy

Bioenergy Research Titles (continued)

- GHG Response
- Greenhouse gas fluxes in response to corn stover harvest
- Corn stover removal impacts on N_2O emission and soil respiration: Lessons from automated chamber measurements

- Feedstock Energy Evaluations
- Distribution of energy content in corn plants as influenced by corn residue management
- Distribution of structural carbohydrates in corn plants as influenced by corn residue management

- Economics & Related Crops
- Economics of residue harvest: Regional partnership evaluation
- Green-cane harvest of sugarcane effects on biomass and energy yields and nutrient removal