FACTSHEET FOR PARTNERSHIP FIELD VALIDATION TEST

Partnership Name	Big Sky Carbon Sequestration Partnership		
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Principal Investigator	Lee Spangler		
Field Test Information: Field Test Name	Cropland Field Validation (+ remote sensing work)		
Test Location	North central Montana		
Amount and Source of CO_2	Tons Source: atmosphere		
Field Test Partners (Primary Sponsors)	Washington State University, Montana State University, Los Alamos National Lab		

Summary of Field Test Site and Operations:

Cropland Field Validation

The cropland field validation test is being conducted in north central Montana which consists of 2+ million ha of cropland (the most representative cropping region in Montana), and in other select locations in the region. The predominant land use for the region is small grain agriculture (i.e, wheat, barley, peas). The region has been under cultivation since the early 1900's with soil management progressing from intensive moldboard plowing to less intensive cultivation to no-till or direct-seed management. The adoption of direct-seed management in MT is not well documented and as a part of Phase II we are utilizing satellite imagery to better document land management in the region.

Soil carbon sequestration in the region is being researched in 1) controlled sites to develop regional estimates of carbon storage rates as a function of management and 2) measuring, monitoring, and verifying (MMV) carbon change using proximal sensing methods at sites enrolled in a pilot carbon trading mechanism. During the cropland field validation test, existing field trials at six controlled sites (farms, with multiple fields) with a range of management practices (till vs. no till and alternate year fallow vs. continuous cropping) will be extended over the duration of the project. Several MMV techniques (lab-based and "on-the-go" visible and near infrared spectroscopy (VisNIR), laser-induced breakdown spectroscopy (LIBS), and combined VisNIR – LIBS spectroscopy) will be evaluated at eight independent enrolled sites.

Based upon the results of the controlled and enrolled cropland field tests, BSCSP will prepare a Cropland Terrestrial Project Planning Handbook that details cropland sequestration project design and best management practices.

Remote Sensing Validation Group

The project area for the MMV Field Validation Group is located within the Golden Triangle Region in North Central Montana. This region roughly includes land between Havre, Shelby, Conrad, Great Falls, and Fort Benton with the actual project area constrained to land falling within Landsat image scenes 39-26 and 39-27.

Field locations for data collection were determined by applying a random point generator to a Landsat Thematic Mapper (TM) Image set following an image masking process to remove non-agricultural areas. A file containing road spatial reference area was then overlaid onto the imagery and all generated points located away from a road structure were removed, resulting in 500 semi-random field reference locations. These sites were physically visited June 2007. Data collected included cropping status (vegetated or fallow), crop type, and tillage management (tillage vs. no-till). A portion of the sites visited included rangeland, as we were unable to obtain rangeland information for the image masking process. The resulting reference field data included 421 cropland sites and 101 rangeland sites. These locations included 220 fields under no-till management and 201 fields under conventional tillage management. 112 of these sites were fallowed and 309 were vegetated. Data for over 500 conservation reserve sites were provided by the Montana Farm Service Agency.

Research Objectives:

The overall goal of this project is to demonstrate that terrestrial sequestration in cropland is a safe and permanent method to mitigate greenhouse gas emissions. The Partnership's objectives for this project are to quantify and determine cropland management practices that optimize carbon sequestration (controlled site field validation) and develop MMV protocols to evaluate carbon sequestration for enrolled farms (enrolled farm field validation). Remote sensing, using Landsat imagery, will be evaluated as a cost effective verification tool for monitoring enrolled acreages and to provide the areal extent of potential C sequestration for the region.

Remote Sensing Validation

The objective of this component is to determine if remote sensing can be used to accurately identify agricultural practices specified in carbon contract agreements as specified by the National Carbon Offset Coalition. This will include using remote sensing techniques to identify no-till, crop intensity, and conservation reserve lands. Crop intensity is defined as the proportion of years a field includes crop cover as opposed to summer fallow; conservation reserve indicates the use of perennial crop cover as opposed to annual cover. We have hypothesized that these management practices can be classified with > 85% accuracy through the object-oriented (O-O) classification of Landsat satellite imagery. The resulting land use data will also be used to calculate cropland carbon sequestration attributed by current cropland management trends, thereby estimating regional carbon intake contributed by no-till, conservation reserve, and crop intensity. The potential for increased sequestration given universal adoption of these management practices was also assessed.

Summary of Modeling and MMV Activities:

Standard carbon measurement, employing dry combustion and modified pressure calcimeter analysis for total carbon and inorganic carbon, respectively, is a well documented and accepted method. This method relies on efficient sampling designs to measure SOC temporally and spatially. 2008 fall soil sampling will provide critical look at effects of management practices on SOC after 6 years, often regarded as the first checkpoint where delta C can be reliably measured against background TOC. It will likely be 1st quarter 2009 before those results are available.

Visible and near-infrared diffuse reflectance spectroscopy (VisNIR) spectral signatures of materials are defined by their reflectance, or absorbance, as a function of wavelength. These signatures are due to electronic transitions of atoms and vibrational stretching and bending of structural groups of atoms that form molecules and crystals. SOC and SIC are both molecular components of soil and VisNIR has been shown to semi-quantitatively estimate SOC and SIC in soils. "On-the-go" VisNIR has the advantage of quickly collecting large amounts of spatial VisNIR data to map soil variability within fields.

Laser-induced breakdown spectroscopy (LIBS) is fundamentally an elemental analysis technique. LIBS involves directing a focused Nd:YAG onto the surface of the target material. The focused laser ablates a small amount of surface material producing a supersonically expanding plasma of electronically excited ions, atoms, and small molecules. These excited species emit light as they relax back to lower electronic states at wavelengths indicative of the identity of the elements present in the sample. Some of this emission is directed into a dispersive spectrometer and the resulting spectrum is detected with a charge-coupled device (CCD) detector. Combining VisNIR and LIBS sensors should theoretically provide quantitative determination of SOC and SIC.

The collaborative MMV Washington State University-LANL group will shortly be submitting a peer-reviewed manuscript to Geoderma regarding using the LIBS method for simulated in situ carbon measurements. The group concluded that to the best of their knowledge, this study represents the first rigorous validation of LIBS calibrations using a significant number (78) of intact soil cores. Using LIBS with a spectral range of 200-300 nm and employing partial least squares regression (PLSR) modeling, they achieved semi-quantitative validation accuracies for total carbon (TC) ($R2 = 0.68$, $RPD = 1.6$, $SEP = 5.8$ g kg-1, $SEL = 0.9$ g kg-1) and inorganic carbon (IC) ($R2 = 0.60$, $RPD=1.5$, $SEP = 5.8$ g kg-1, $SEL = 1.03$ g kg-1). Soil organic carbon (SOC) predictions appeared unacceptable ($R2=0.19$, $RPD=1.0$, $SEP = 3.4$ g kg-1); however the low validation R2 and RPD values were due, in part, to low SOC variability ($\sigma = 3.47$) with laboratory reference measurement error (SEL) estimated at 1.37 g kg-1 or 40% of σsoc.

Regression coefficients from PLSR models suggested that calibrations utilized stoichiometric relationships between C and elements related to C in the soil matrix. Emissions from carbon (247.8 nm), Mg (279.55-280.4 nm, 285.26 nm), and Si (288.1 nm) were important predictors for estimating total and inorganic carbon. The relatively narrow spectral range (200 – 300 nm) of the LIBS spectrum recorded in this study; however, omitted emissions from elements related to soil carbon, including Ca, O, H, and N. Increasing the spectral range to the full LIBS spectrum (200 – 900 nm) could increase predictive accuracies for in situ measurement of both inorganic and organic C.

In addition to expanding the spectral range, they identified three key strategies for improved LIBS in situ soil measurements. First, uneven soil surfaces associated with in situ interrogations caused fluctuations in laser focus and the efficiency of plasma emissions captured with a fiber optic cable. Extending the focal length of the laser and repositioning the fiber optics should ameliorate this problem. Second, evaluating the ability of LIBS to capture SOC variability will require the acquisition of calibration soil cores with greater SOC variability. Finally, we need to acquire soil cores from a more diverse set of locations to evaluate the potential of developing regional LIBS calibrations. Continued LIBS development and evaluation will assist in realizing the full potential of this emerging spectroscopic technique for in situ soil characterization.

Remote Sensing Validation

The Remote Sensing Validation Group has completed their research pertaining to Phase II. Extensive literature review validated that the randomForest model remains the best option for image classification in the context of this study due to its robustness in handling unbalance data sets, a tendency to not overfit, and an ability to provide a within-model estimate of classification accuracy.

The highest classification accuracies for tillage type included information from 113 NT-cropped, 61 NT-fallow, 70 tilled-cropped, and 22 tilled-fallow field locations. Total model accuracy was 70%, with low user's and producer's accuracies (31%, 67%) in the tillage class.

The greatest classification accuracies pertaining to the discrimination of Conservation Reserve (CR) land from small-grains crop utilized 304 cropland (95 till and 209 NT) and 127 CR sites. Total model accuracy was 99%, with 100% producer's accuracy in the cropland class (96% user's) and 90% in the CR class (100% user's). Classification error primarily resulted from the misclassification of CR as NT-cropped and tilled-crop.

RandomForest modeling was able to distinguish senesced crop from fallow with greater than 82% accuracy. Data from 188 cropped and 67 fallow sites were used in building the model. Misclassification errors within the fallow category were attributed to objects located within landscapes characterized by narrow (< 100-m wide) crop and fallow strip management. This was likely due to within-pixel mixing of crop and fallow spectral signatures. The object-based classification tended to favor the "cropped" class, resulting in a classification bias under these conditions.

The group concluded that adequate separation of no-till (NT) from conservation tillage management through spectral and textural-based satellite mapping is unlikely given the current technology. Specifically, they saw difficulty in discovering a contracted farmer who has agreed to follow NT practices, but is in fact practicing a less extreme form of conservation tillage. Some level of 'on-site' tillage management validation within carbon contract sites will likely be necessary, complimented by satellite-based classifications to detect heavy tillage disturbances.

Land-use data for this portion of north central Montana indicated potential for increasing conversion to NT tillage management and higher degrees of crop intensity. This study estimated 56% of the cropland in north central Montana evaluated within this study was under NT and 44% was under some form of tillage management in 2007. Currently only 5% of the evaluated cropland had incorporated continuous cropping. Results suggest that while NT has quickly become the new "convention" replacing traditional tillage systems, increasing cropping intensity beyond crop-fallow rotations has been slow to adopt in the study area.

An estimated 24% of the evaluated region was under a grassland-based Conservation Reserve (CR) management in 2007, 22% greater than the area shown to be under CRP contract with the Montana Farm Service Agency (MFSA). This percentage reflects observations noted during field data collection, where 16% of lands designated as cropland appeared to be in some form of "unmanaged" grassland state.

It was estimated that the evaluated portion of north central Montana might sequester approximately 59,497 t C yr^{-1} through the universal adoption of NT practices and eliminating the fallow practice. This analysis represents a rough estimate with sequestration rates based on a review of regional literature. Further research efforts are needed to quantify the extent that cropland management changes can increase C sequestration rates across variable physical and biological conditions, and will be essential to the refinement of regional C storage potential estimates. Technological advances in SOC monitoring equipment are needed to allow for the efficient and cost effective monitoring of C gains on land under C contracts.

Field Accomplishments to Date:

- Initial measurements using standard methods and "on-the-go" VisNIR have been completed.

- "On-the-go" VisNIR has shown spectral patterning within enrolled fields. Those patterns are currently not correlated with SOC and are somewhat correlated to soil clay content.

- Initial results from simulated *in situ* SOC measurements using VisNIR and LIBS have been very encouraging with low bias (1.8 and 0.7% of MSEP, respectively), and R^2 values of 0.62 and 0.64, respectively).

- Using LIBS with a spectral range of 200-300 nm and employing partial least squares regression (PLSR) modeling, semi-quantitative validation accuracies were achieved for total carbon (TC) (R^2 = 0.68, RPD = 1.6, SEP = 5.8 g kg^{-1}, SEL = 0.9 g kg^{-1}) and inorganic carbon (IC) (R^2 = 0.60, RPD=1.5, SEP = 5.8 g kg^{-1}, SEL = 1.03 g kg^{-1}).

- The remote sensing MMV component has been completed.
  - Adequate separation of no-till (NT) from conservation tillage management through spectral and textural-based satellite mapping is unlikely given the current technology.
  - In 2007, 56% of the cropland in north central Montana evaluated within this study was under NT and 44% was managed with some form of tillage.
  - The evaluated portion of north central Montana might sequester approximately 59,497 t C yr^{-1} through the universal adoption of NT practices and eliminating fallow.

Summarize Target Sink Storage Opportunities and Benefits to the Region:

- Results from standard and proximal sensing SOC measurements are applicable to within the defined study area.
- All methods are applicable to terrestrial sequestration projects globally.

Cost:

Total Field Project Cost: $1,635,089

DOE Share:	**$1,388,226**	**84.9%**
Non-Doe Share:	**$246,863**	**15.1%**

Field Project Key Dates:

Baseline Completed: 6/30/08

Drilling Operations Begin: NA

Injection Operations Begin: NA

MMV Events: NA

Field Test Schedule and Milestones (Gantt Chart):

Task 7.0 -	Q1-06	Q2	Q3	Q4	Q1-07	Q2	Q3	Q4	Q1-08	Q2	Q3	Q4	Q1-09	Q2	Q3	Q4	Q1-10	Q2
Task 7.1 - Planning																		
Task 7.2 - Controlled Test Soil Carbon Sampling and Calibration																		
							Tm4				Tm8						Tm13	
Task 7.3 - MMV on Enrolled Sites/Farms																		
									Tm6			Tm11						Tm15,16
Task 7.4 - Cropland terrestrial Project Planning Handbook																		

Additional Information