

**‘Scaling Up the Ecosystem Consequences of Forest Expansion in the Great Plains Region’:
Progress Report Aug 1, 2002-Jul 31, 2003**

Land Cover and Land-Use Change Research Program

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Project Abstract

Our overall goal is to determine rates and patterns of woody encroachment over space and time in the Great Plains, and concomitant rates of change in C and N stocks and fluxes, and to develop a predictive biogeochemical model to forecast future rates of woody encroachment. As highlighted recently, forest encroachment in the Great Plains is poorly known, difficult to quantify, but potentially important as a C sink. Indeed, land use is becoming recognized as an equally important factor, if not more important, in rates of C accumulation in biomass and soils, as compared to growth enhancement by elevated CO₂, N deposition and global change, in general. Woody encroachment is occurring rapidly in the Great Plains: Juniper, in particular, is spreading over more than 7 million ha in five state area in the lower Midwest.

Our previous LCLUC project helped to fill a critical gap in understanding the role of land use and land cover change in the Great Plains. Our research group quantified how woody encroachment in eastern Kansas grasslands has resulted in fundamental changes in ecosystem function as related to this life form shift from C₄ prairie grasses to C₃ evergreen junipers. Our approach has been strongly multi-disciplinary: it has involved in situ biogeochemical approaches at the plot-level linked with multi-temporal Landsat images and historical aerial photos and biogeochemical modeling. Our research has been unique in that we have also quantified changes in C source/sink activity by using eddy flux towers in forest and grassland as a complement to direct measurements of carbon stocks in biomass and soils. From our 1.5 years of net C exchange measurements, of particular note is how conversion to forest changes the phenology of net CO₂ exchange and source/sink activity; the forest site (with trees utilizing C₃ photosynthetic pathway) is a C sink in the cool parts of the growing season while the C₄ grassland site is a strong, but short duration, C sink in mid-summer. We aim to continue these critical measurements of net C exchange, water and energy balance on an interannual basis to determine if the same phenological pattern continues and how year-to-year differences in temperature and precipitation, so characteristic for the Great Plains, affect source/sink activity in forest relative to grasslands.

In this renewal proposal, our overall objective is to 'scale up' our extensive plot-scale data to the regional level of the Great Plains and to continue to calibrate our biogeochemical model (GEM) to allow us to predict the ecosystem consequences if woody encroachment continues in the future. Because the use of remote sensing is so integral to quantifying the rate and extent of forest encroachment, our research group has teamed up with Dr. Kevin Price from the Kansas Applied Remote Sensing Center at the University of Kansas. Price brings to the project a special expertise in the analyses of multi-temporal data and has rapidly moving into the realm of hyperspectral analysis to study land use and land cover patterns.

Our specific objectives are to:

- continue to develop the spectral mixing models necessary to capture the fine-scale dynamics of woody encroachment across the Great Plains region. This will allow us to determine the regional extent and to relate this to regional C storage.
- link our spectral mixing model cover classes to plot-level changes in C and N stocks and fluxes in the same cover classes to predict changes in rates of C and N accumulation in time and space as woody encroachment proceeds,
- continue to parameterize and calibrate our biogeochemical model (GEM) to develop a spatially explicit prediction of the biogeochemical and ecosystem consequences of forest expansion in the Great Plains,

- develop a predictive model based on scenarios of future regional woody encroachment in order to generate hypotheses about future land use/land cover change and concomitant changes in C and N stocks and fluxes and
- explore how interannual variation in temperature/moisture affect C source/sink activity, water and energy balance in forest relative to grassland, and the role of phenological differences between the dominant C4 prairie grasses and C3 juniper forest.

KEYWORDS

- 1) Research Fields: Carbon cycle, nutrients, plant ecology
- 2) Geographic Area/Biome: Grassland, woodland, North America
- 3) Remote Sensing: Landsat, AVHRR, and MODIS
- 4) Methods/scales: Regional scale, mixture modeling

Questions, goals, approaches

Relevant NASA ESE Scientific questions :

Question 1: What are the changes in land cover and or land use over time

(monitoring/mapping activities)? Our research addresses the changes in woody encroachment over time in the Great Plains using remotely sensed data. Dr. Kevin Price, Associate Director of the Kansas Applied Remote Sensing Center leads this effort and supervises one post-doctoral fellow (Fangfang Yu, and recently, xxx KU) on this aspect.

Question 2: What are the causes of LCLUC? The increase in woody encroachment appears to be related to fire suppression (thus favoring tree expansion into grassland) as mediated by socioeconomic drivers such as suburbanization and abandonment of rangeland. In our research, approximately 10% of our effort is allocated to the study of human dimensions and socioeconomic drivers of LCLUC.

Question 3: What are the consequences of LCLUC? Our research focuses on the biogeochemical consequences of forest encroachment especially as related to changes in net ecosystem CO₂ exchange, C storage and net primary productivity. Dr. Jay Ham, a micrometeorologist and collaborator, is responsible for supervising an assistant scientist in the collection, data analysis, and interpretation of annual C budgets in forest and grasslands. We are using a biogeochemical model (GEM-General Ecosystem Model) as a tool to predict the ecosystem consequences of woody encroachment over space and time in the Great Plains. Dr. Bob McKane, a terrestrial ecosystem ecologist and well-respected ecosystem modeler at the EPA lab, is leading this effort. Drs. Loretta Johnson and John Blair are responsible for quantifying and assessing the ecosystem consequences of forest expansion, especially as related to belowground C and N cycling and processes. Dr. Johnson (lead PI) is also responsible for overall project integration and synthesis.

Themes covered in project:

Carbon 25%
 Water 5%
 Nutrients 5%
 GOFC 35%

Other- modeling to predict the ecosystem consequences of continued woody encroachment 25%

Goals and accomplishments for the period

1. Refinement and ‘scaling up’ of the spectral mixing model for estimating geographic distribution and percentage of cover by red cedar (PI: Kevin Price).

- Hired personnel (post-doc Fangfang Yu at the KU Applied Remote Sensing Center) has progressed well in methods development for applying the spectral mixing models.
- Recently, Ph.D. student Jude Kastens was hired for the 2002-2003 academic year

2. Continue to estimate rates of change in C and N stocks and productivity along the grassland-forest continuum: The use of chronosequences (PIs Johnson and Blair)

- Recruited doctoral graduate research assistant (Tracey Crocker). Began spring 2002. Second student (Duncan McKinley) began fall 2002.
- Identified sites and began assessment of C and N stocks along chronosequences from grassland to closed canopy forest. Continue to estimate C and N stocks and rates of C and N acculation in plants and soil along the chronosequence.

3. Continue net CO₂ exchange measurements in forest and grassland. Determine C source/sink activity in forest relative to grassland using eddy covariance towers. Determine effects of phenological differences and interannual variation in temperature and moisture (PI Jay Ham)

- Continued daily collection of net CO₂ exchange data from towers
- Changed from closed path to open path infrared analyzer in the forest and grassland eddy flux micromet towers
- Recruited assistant scientist (Jamie Dysterhaus) to compile, analyze, and interpret data on effects of land cover change on net CO₂ exchange
- Continued calculations and modeling of annual carbon budgets from the tower data

4. Begin to close critical gaps in our knowledge of C stock and fluxes especially belowground processes and C cycling, root productivity and turnover (PIs Johnson and Blair)

- Recruited graduate research assistants (Crocker and McKinley)
- Establish in situ field study (‘trenching’) experiment at the forest tower site to partition soil C fluxes into soil respiration from roots and heterotrophic respiration,
- Begin taking measurements of soil respiration in trenched (microbial respiration only) and untrenched plots (microbial and root respiration)
- Continue soil incubations of forest and grassland cores; determine isotopic composition of the soil CO₂ evolved to determine the vegetation substrate for microbial respiration

b. Root productivity and turnover.

- Install minirhizotron tubes for characterization of root productivity and turnover in forest and grassland sites
- Began recording images of roots from minirhizotron tubes
- Will sample peak season root biomass in closed canopy forest and grassland sites in 2003.

5. Continued model calibration of the biogeochemical model GEM to predict ecosystem consequences of woody encroachment. Use as a tool for synthesis, integration, and scaling (PI Bob McKane)

- Continued parameterization of GEM for grassland and forest ecosystem types.

-Continued data input, especially of belowground processes, as these data become available from empirical plot-level studies

Brief narrative statement of the progress and future work

1. Linear Spectral Mixing Model Development: Field Level Progress, High Resolution Digital Aerial Photography, and Estimating Canopy Cover of Redcedar from TM images

The goal of this component of the study is to develop a remote sensing method for estimating geographic distribution and percentage of cover by red cedar. Accurate estimates of red cedar encroachment based on satellite observations are necessary to reduce the uncertainty of regional spatial heterogeneity. The test study area for development of the spectral mixing model is Douglas County in eastern Kansas with a total area of about 1228 km².

During the early spring of 2002, 49 red cedar sites of varying cover classes were located in the field in the test study area in Douglas County, KS. The geographic location for each site was located on a map and Landsat satellite image. While in the field, a line transect method was used to estimate red cedar cover for these selected sites. During late spring 2002, a DuncanTech 3100 high resolution (< 1.0 m) multispectral aerial imaging camera was flown over all the red cedar study sites. These data are being used to characterize each red cedar site with respect to cover by life-forms (e.g., grass, deciduous forest, and evergreen forest (red cedar)), and other land cover components such as bare ground and water. Estimates of red cedar cover from the aerial imagery are being evaluated against cover estimates made in the field using the line transects approach.

Remote Sensing Methodology. Optimal time periods for discriminating land cover types are based on the information on land cover characteristics, vegetation phenology and image quality (Yang et al., 2001). Nearly cloud-free Landsat-7 ETM imagery (path 27, row 33) acquired on October 25, 2001 is used for analysis in this study. This imagery was selected because in late October, most the deciduous forest and C₄ grass are at the dormant stage and the conifer trees (redcedar and some C₃ grass) are still undergoing photosynthetic activity when the air temperature above freezing point during the daytime. The different reflectances between green and non-photosynthetic vegetation (NPV) can help to distinguish the C₄ and red cedar from C₃ and deciduous canopy.

After each image was examined for sensor errors (i.e., striping, banding, line dropout), the digital numbers were then converted to radiance using the method described by Markham and Barker (1986). The reflectance values were adjusted for atmospheric scatter using 6S atmospheric correction software. The images were corrected for geometric error by transforming to a Universal Transverse Mercator (UTM) projection. The geometric transformation equation was computed using 70 ground control points that produced a final RMS error of < 0.35 pixels (<10.5 m). The spectral values for each pixel were interpolated using a nearest-neighbor resampling approach and the data were output to a 30 × 30 m pixel size. Since the invasion of Juniper redcedar can only occur in the grassland or woodland, the areas of cultivated land, urban regions, and water bodies were masked with the Kansas GAP product (Egbert et al., 2000).

One-meter airborne digital images were acquired to validate the estimated redcedar canopy abundance. These aerial photographs were obtained using the DuncanTech's multispectral (blue, red, NIR). The digital imaging camera was mounted in a small aircraft and

flew over several abandon fields now being invaded juniper in the fall of 2000. At 1 m resolution, the aerial coverage of each image was 1.3 x1.2 km. This imaging system was owned by Kansas Applied Remote Sensing (KARS) Program at the University of Kansas.

Over 30 sites with red cedar cover ranging from about 20% to 80% were visited in the spring of 2002. The geographic location of each site was determined using Universal Transverse Mercator coordinates estimated with a hand-held Garmin II Plus Global Positioning. These sites were then identified in the air-borne imagery and registered to the corresponding pixels in the TM images. The juniper red cedar covers over the sample sites were estimated using the ARCVIEW system by overlaying a grid layer over the digital images (Figure 1). The red cedar coverage was estimated by counting the number of grid over the red cedar canopy to the total number of grid in this plot (Avery and Burkhart, 1994). On the air-born images, two sites with highly cover juniper area (>80% red cedar cover, at least 100m x 100 m areal extent) were identified. Sixteen sample sites of the closed canopy deciduous forest in the test flight area were also identified and located in the TM images. These sites will be used as end-members for further analysis.

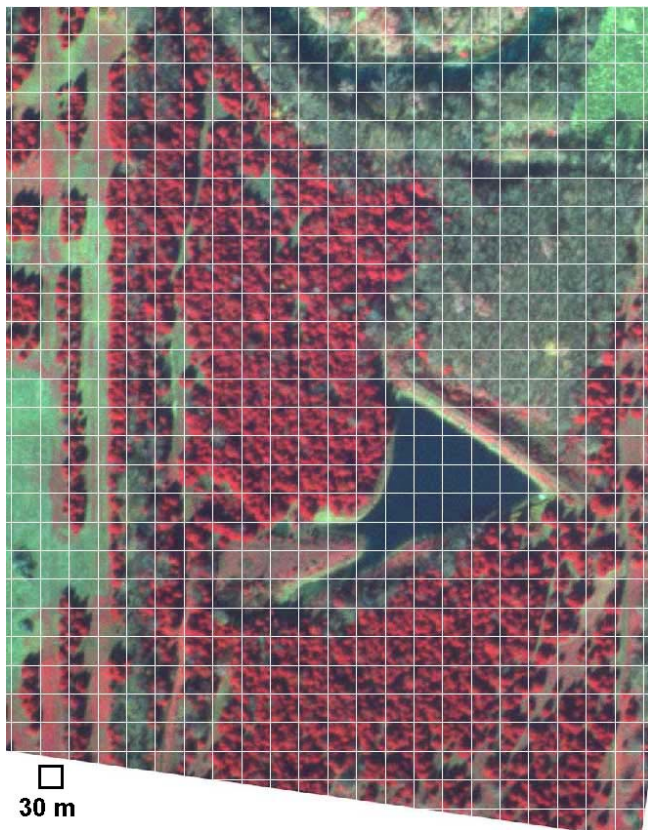


Figure 1. Grids over digital air-born imagery to estimate the redcedar cover.

Linear Spectral Mixture Model (LSMM) and Endmember Selections

We used linear mixture modeling to the Landsat TM data to derive the fraction cover of different vegetation types in the study area. Success of the spectral mixture approach rests on the acquisition of endmember reflectance bundles that maximally encompass the actual spectral

variability of the dominant land cover types (Adams et al. 1995) and the spectra of the endmembers should be discriminated from each other (DeFries et al., 1999).

Six image endmembers were used in this study to run the LSMM, including green redcedar trees, photosynthetic C3 grass, dormant C4 grass (NPV grass), deciduous forest (NPV forest), soil, and shadow. While most of the other image endmembers mix with solar illumination illustration, we use shadow endmember to describe the fraction associated with the effect of topography and clouds. The pixel values of the cloud shadow were used to represent the endmember spectra.

To distinguish the different life forms, the normalized difference vegetation index (NDVI) and Tasseled Cap Indices (TCI) derived from the TM data are added to the spectra data to run the LSMM. Calculations of the vegetation indices are as followed.

$$\text{NDVI} = (\text{TM Band 4} - \text{TM band 3}) / (\text{TM band 4} + \text{TM band 3}) \quad (1)$$

TCI values are calculated as the equations provided by Huang et al. (2001)

$$\text{Brightness} = 0.3561 * \text{band 1} + 0.3972 * \text{band 2} + 0.3904 * \text{band 3} + 0.6966 * \text{band 4} + 0.2286 * \text{band 5} + 0.1596 * \text{band 7} \quad (2)$$

$$\text{Greenness} = -0.3344 * \text{band 1} - 0.3544 * \text{band 2} - 0.4556 * \text{band 3} + 0.6966 * \text{band 4} - 0.0242 * \text{band 5} - 0.2630 * \text{band 7} \quad (3)$$

$$\text{Wetness} = 0.2626 * \text{band 1} + 0.2141 * \text{band 2} + 0.0926 * \text{band 3} + 0.656 * \text{band 4} - 0.7629 * \text{band 5} - 0.5388 * \text{band 7} \quad (4)$$

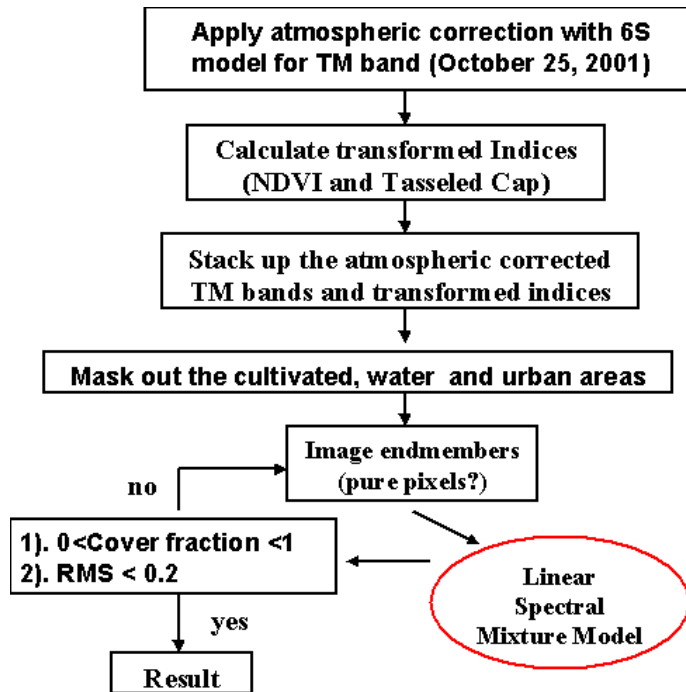


Figure 2. Flow chart of the linear mixture model processing methodology.

In the linear spectral model, each pixel is assumed to be a linear combination of the “pure” or end-member spectra of the materials located in the pixel area, weighted by their fractional abundance. It can be modeled on the relationship:

$$R_i = \sum_{j=1}^N r_{ij}x_j + \varepsilon_i \quad (5)$$

where R_i is the reflectance in band I, r_{ij} is the reflectance of end-member j in band i, x_j is the fractional cover of end-member j, ε_i is the error term and N is the number of end-members. The sum of fractional cover for each pixel should be equal to 1.

$$\sum_{j=1}^N x_j = 1 \quad (6)$$

The model fitness can be also assessed by looking at the root mean squared (RMS) error across all bands.

$$RMS = \text{sqrt}\left(\sum_{i=1}^N (\varepsilon_i)^2\right) / N \quad (7)$$

Since redcedars only encroach into natural terrestrial ecosystems, we masked out the cultivated, urban and water areas using the Kansas Land cover map which was derived as part of GAP project (Egbert et al., 2001). The 10-band data set (6 bands plus 4 indices data) are imported to ENVI software for further analysis.

Image endmembers are chosen from stepwise analysis of the training area pixels (Figure 2). Iterations were used to select the pixel endmembers for the unmixing models until the follow two constraints (in equations (8)-(9)) are met. The spectral reflectance and ancillary indices for the 6 endmembers were illustrated in Figure 3. Two criteria were used to identify the pixel endmembers (Adams et al., 2000).

$$1) \quad 0 < x_i < 1 \quad (8)$$

$$2) \quad RMS < 0.2 \quad (9)$$

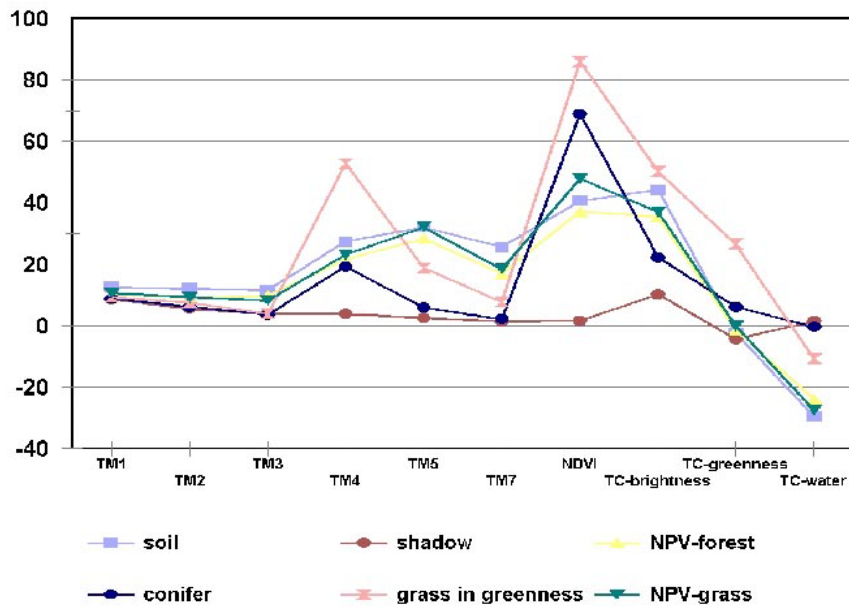


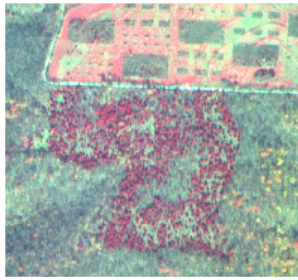
Figure 3. Spectra and vegetation indices of the endmember values.

Figure 4 (below) shows red cedar cover in the study area estimated from our LSMM. It shows while red cedar invasion into the grassland is pervasive, only a very small area (<1%) in the study area is covered with closed canopy red cedar (red cedar fraction > 80%). Most areas have red cedar coverage between 25% - 50%, indicating the relative new encroachment of the woody species. The large area with less than 25% red cedar in this study area strongly implies that we overestimated the red cedar cover at low values. Further work is needed to refine the LSMM model to reduce the uncertainty at low red cedar coverage estimate.



Figure 5 (below) shows the digital aerial photograph, TM data false color composite (2-blue, 3-green, 4-red) and model results for abandoned cultivated land. The estimated abundance pattern of the redcedar corresponds well to the redcedar distribution shown in the digital aerial photograph.

**Digital aerial photograph
in early Oct., 2000**



**TM data (2-blue,3- green, 4-red)
in late Oct., 2001**



**LSM model result of Juniper (redcedar) over
the Kansas Biological Reserve Area**

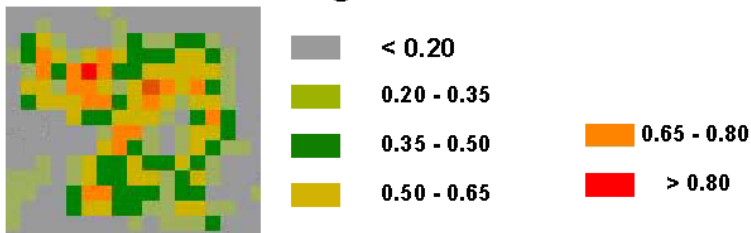


Figure 5. Comparison of the digital aerial photograph, TM data and the LSM model results in the study area near the Kansas Biological Reserve.

Figure 6 displays the relation between LSMM estimated redcedar abundance and the aerial photographs estimate over the registered sample sites. For the sites with over 20% redcedar coverage, the correlation coefficient (r^2) between the two estimates is 0.9. The strong linear relation between two estimated redcedar abundance metrics may indicate the potential application of the LSMM for the TM data in estimating redcedar abundance in the eastern Great Plains.

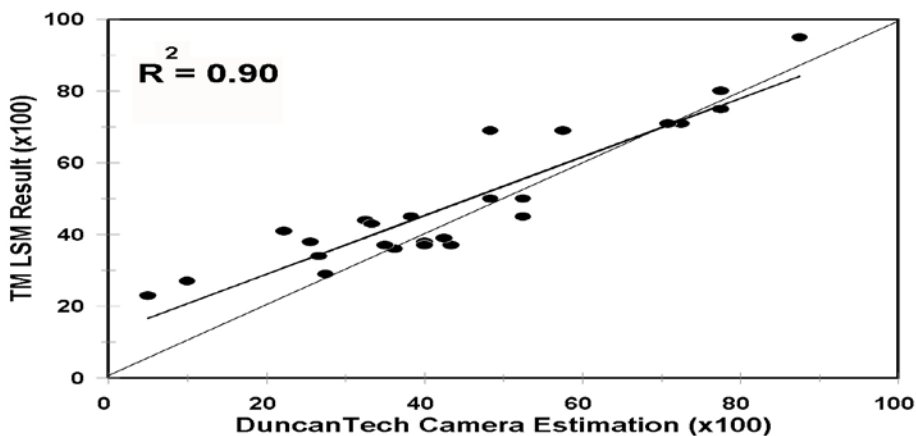


Fig. 6. Relation between TM LSMM estimated cover and DuncanTech camera estimation.

In conclusion, the methodology described can be used to classify the mosaic of redcedar canopy abundance in Landsat-TM images in eastern Great Plain. The vegetation indices, in addition to the TM bands, provide discriminant information to distinguish different life form land cover characteristics for the LSMM. Refinement of the pixel endmember spectra to make such estimates from TM data sets from the early 1980s is currently being pursued to estimate the redcedar encroachment rate in this region.

Future Work: Scaling Up to the Regional Level

After the TM LSMM method has been refined to produce cover classes with an acceptable degree of accuracy (>80%), the classification results will be used in an attempt to calibrate and refine a regional scale cover classification for red cedar. Since we completed the linear spectral mixing model work at the county level using Landsat, we have been investigating various methods for use of remotely sensed data for estimating cover of red cedar at the regional scale. We have investigated the use of time-series Landsat imagery which did not work well due to change sun angle that changed the amount of shadow cast by the red cedar trees over the growing season. We are now investigating the use of time-series using larger pixels like those of AVHRR 1 km and MODIS 250 m pixel resolution. We have been investigating the use of the continuous class method described by Dr. Ruth Defries and others. We have also been downloading MODIS 250 m data to build a multi-temporal dataset for our region. We are now working on a manuscript describing our efforts, successes, and limitations of estimating red cedar cover at the local scale. This manuscript is in advanced stages of preparation.

2.Net CO₂ exchange and C source/sink activity in forest relative to grassland: Effects of phenological differences and interannual variation in temperature and moisture

Using the flux towers, our research group is poised to take advantage of a unique opportunity to measure how common land use activities (grazing, forest encroachment) affect C source/sink activity in the Great Plains. Our preliminary analysis indicates that interannual differences in precipitation, temperature, and length of growing season could greatly impact estimates of net C exchange (Fig. 7) on an annual basis and shift source/sink relationships between forest and grassland. This also gives us an opportunity to compare measurements of net C exchange from tower measurements with measured changes in C stocks in the field. Thus, we plan to continue to make annual C exchange measurements for the next several years. The flux measurements from the tower will be coupled with remotely sensed data to estimate the impact of forest expansion on the water, C and energy balance of the region using the GEM model.

Questions we are addressing include:

- Are forests storing more C than grasslands? Are they a stronger C sink?
- How do source/sink relationships change with year-to-year variation in temperature and moisture?
- Does forest and grassland net C exchange respond in the same manner to increases in temperature and/or precipitation?
- Will grasslands be a stronger sink for C in drought years while forests act as a C sinks in wet years?
- Are these evergreen forests a sink because of difference in phenology and the ability of this life-form evergreen) to take advantage of favorable weather conditions outside of the typical growing season?

Net ecosystem CO₂ exchange (NEE) was measured from tallgrass prairie and cedar forest using open-path eddy covariance. The prairie site (ungrazed, annually-burned) was located in the

Rannells Flint Hills Prairie Preserve approximately 8 km south of Manhattan, KS. Eddy flux instruments, which included a sonic anemometer (CSAT3, Campbell Scientific, Logan, UT) and an open-path gas analyzer (LI-7500, Li-Cor Inc., Lincoln, NE), were positioned 3 m above the soil surface in the grassland. The forest site was a 50-yr-old stand of eastern red cedar (*Juniperus virginiana*) located 32 km north of Manhattan, KS. The average tree height was 9 m and the eddy flux instruments were positioned at 14 m. Measurements of the within-canopy CO₂ concentration profile were used to estimate the rate change in carbon storage in the 0-14 m layer. A detailed description of the instrumentation and data processing methods are provided in Ham and Heilman (2003). Carbon losses from burning the prairie in May 1, 2003 were estimated from sampling the standing dead biomass near the eddy covariance tower and measuring the total carbon content of the clippings (LECO CN-2000, St. Joseph, MI).

Data analysis extended over a 12-month period from May, 2002 through April, 2003. This was the period between controlled burns on the prairie and a logical interval for estimating the annual carbon flux. A severe drought was experienced in 2002 which had a pronounced impact on CO₂ fluxes in mid-summer. From January 1 to July 28, 2002, the prairie and forest sites received 296 mm and 278 mm of precipitation, respectively. The average rainfall for the same period in the previous 10 years was 595 mm for the prairie and 528 mm at the forest. Water stress was alleviated somewhat by 98 mm and 36 mm of rain at the prairie and forest sites; respectively, on July 29, 2002.

Comparison of NEE shows how forestation can have a dramatic effect on the seasonal patterns and magnitudes of carbon fluxes from the landscape (Fig. 7). After the spring burn, the rapidly growing prairie canopy resulted in maximum carbon gains of 13 g CO₂ m⁻² d⁻¹. However, these NEE rates are much lower than those measured during similar growth stages when moisture was not limiting (Ham et al., 1995; Suyker and Verma, 2001). Severe water stress caused NEE on the prairie to decline in late June and the ecosystem became a net source of CO₂ briefly at the height of the drought. After the rain on July 29, the prairie rapidly recovered and became a strong sink for CO₂ until canopy senescence in the fall. The ecosystem was a continuous source of CO₂ after October 10. Ham and Knapp (1998) documented a similar senescence pattern on the nearby Konza Prairie Biological Station. Conversely, the forest site had a seasonal pattern of NEE that was almost opposite the prairie (Fig. 7). The forest lost carbon to the atmosphere during the warm summer months between June and September. The system became a brief sink for CO₂ in the fall, showed almost zero NEE during the December through February, and then became a sink again in the early spring. It is clear that temperature is the critical factor governing NEE from the forest while phenology and water relations are paramount on the prairie.

A plot of cumulative net CO₂ fluxes from the forest is almost the reverse image of that from prairie (Fig. 8). When one ecosystem acted as a carbon sink the other was a source. At the end of 12 months, the prairie showed a net CO₂ gain of 245 g m⁻². However, burning the dead biomass resulted in a -604 gCO₂ m⁻² loss, which resulted in an overall annual loss of -345 gCO₂ m⁻² (-94 gC m⁻²). The forest site showed a net loss of -41 gCO₂ m⁻² (-11.2 gC m⁻²) and was very close to equilibrium in regard to carbon storage. The carbon losses from the prairie were significant and may have been the result of the summer drought that reduced NPP. Other tower studies have shown that annual variations in weather can cause an ecosystem to be a net carbon source one year and a net sink the next. Because of uncertainty in the measurements themselves and the potential annual variation in NEE, it is not possible to conclude if these ecosystems will have a long-term impact on the atmospheric carbon balance. Additional data collection over a

range of weather conditions is needed. Nevertheless, it is clear that forestation of grasslands will cause a diametric change in seasonal patterns of NEE. It is difficult to imagine any change in land management that would cause a more radical shift in surface-atmosphere carbon exchange. For example, the differences observed in Figures 7 and 8 are much more dramatic than any changes in NEE caused by doubling atmospheric CO₂ (Ham et al., 1995), changing burning frequency (Bremer et al., 2003), or modifying grazing intensity (Owensby et al., 2003). Data like those presented here can be used in combination with remote sensing and ecosystem modeling to explore the potential impact of forestation on the carbon balance of the Great Plains region.

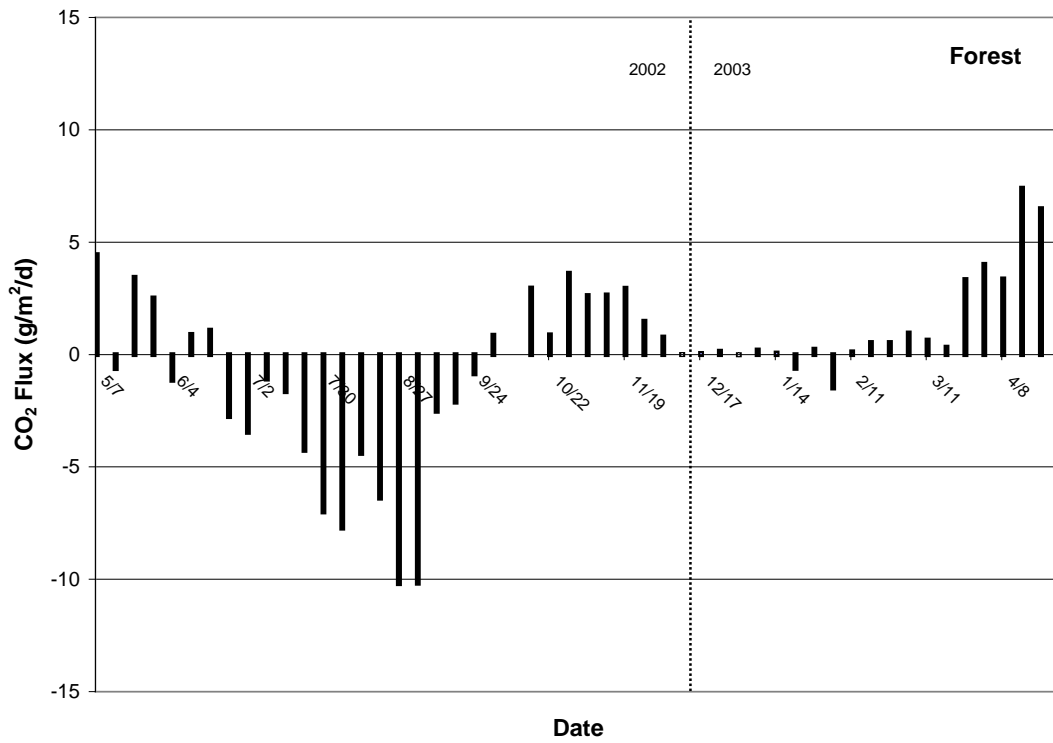
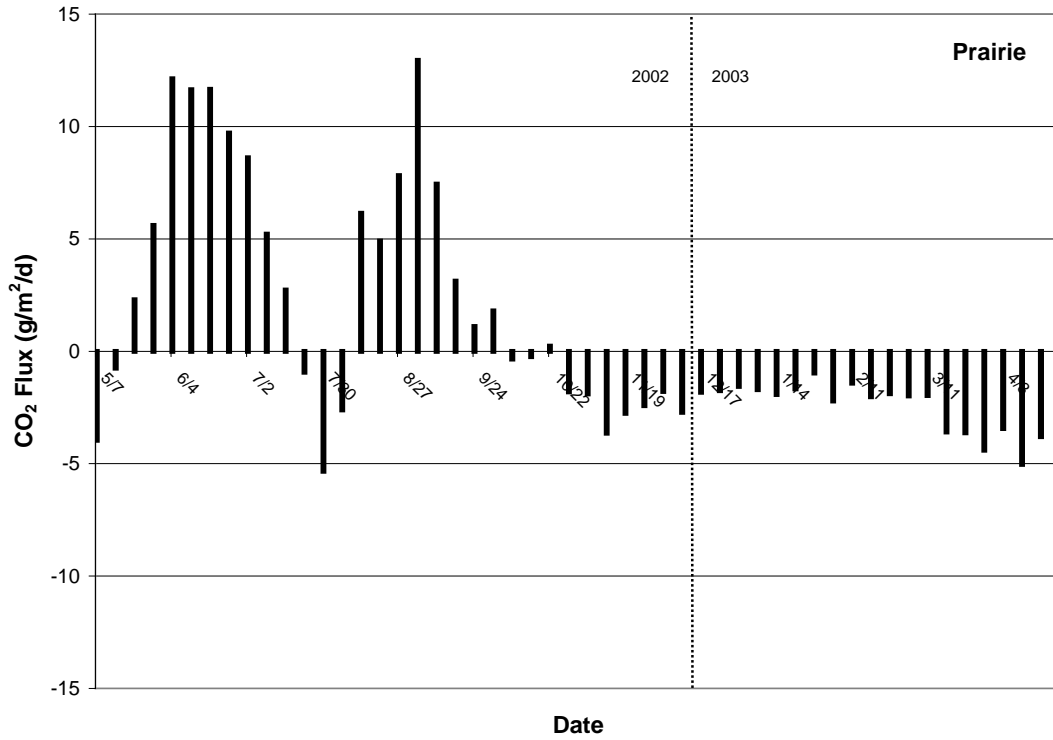


Figure 7. Comparison of daily CO₂ fluxes from tallgrass prairie and cedar forest for a 12-month period starting in May, 2002. Positive numbers indicate a net flow of CO₂ into the ecosystem (sink) where negative numbers represent losses to the atmosphere (source).

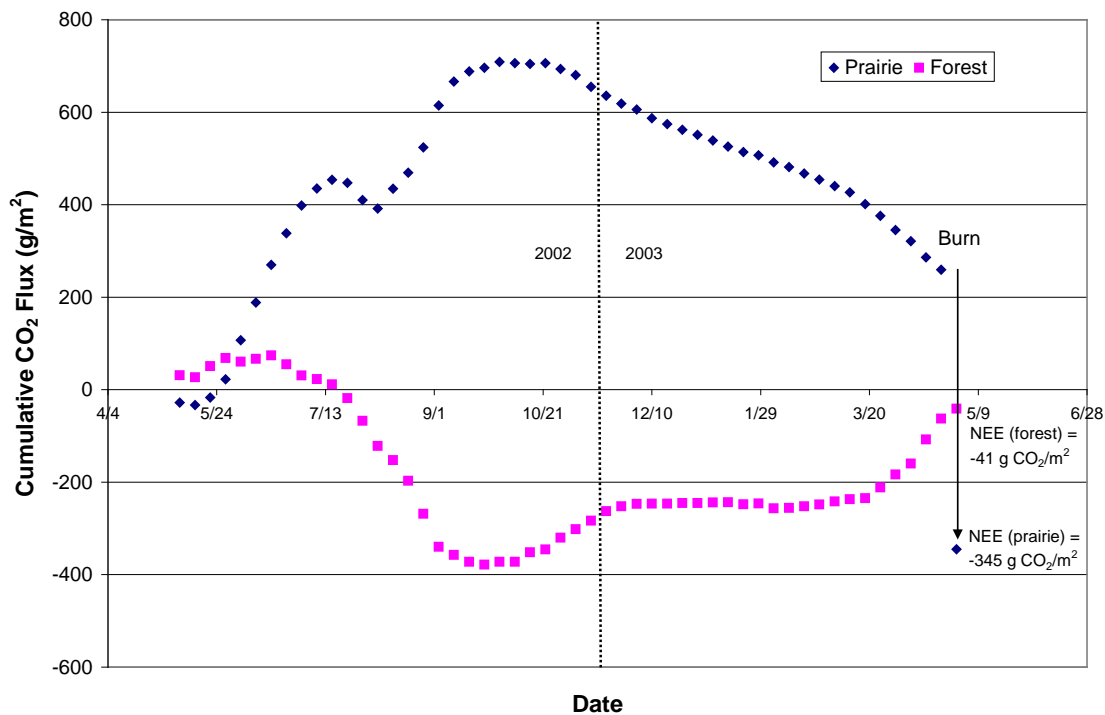


Figure 8. Cumulative annual CO₂ flux (NEE) from tallgrass prairie and cedar forest near Manhattan, Kansas. Negative values represent a net loss to the atmosphere.

Future Work: We have hired an assistant scientist to assist Jay Ham in the collection, analysis, and interpretation of the large volumes of tower flux data. The ultimate goal in the next year is to continue to calculate annual C budgets based on flux measurements and compare that with NPP from harvest measurements (Fig. 9).

3. Belowground C cycling: Refinement of ecosystem C and N budgets in forest and grassland.

Our LCLUC project allowed us to construct preliminary ecosystem C budgets (Fig.9). However, a better understanding of belowground processes is essential for a comprehensive picture of terrestrial C cycles. Thus, more information on belowground processes is necessary to be able to constrain our C flux estimates. Furthermore, the relative sensitivity of belowground processes to vegetation shifts associated with land cover change is also poorly known.

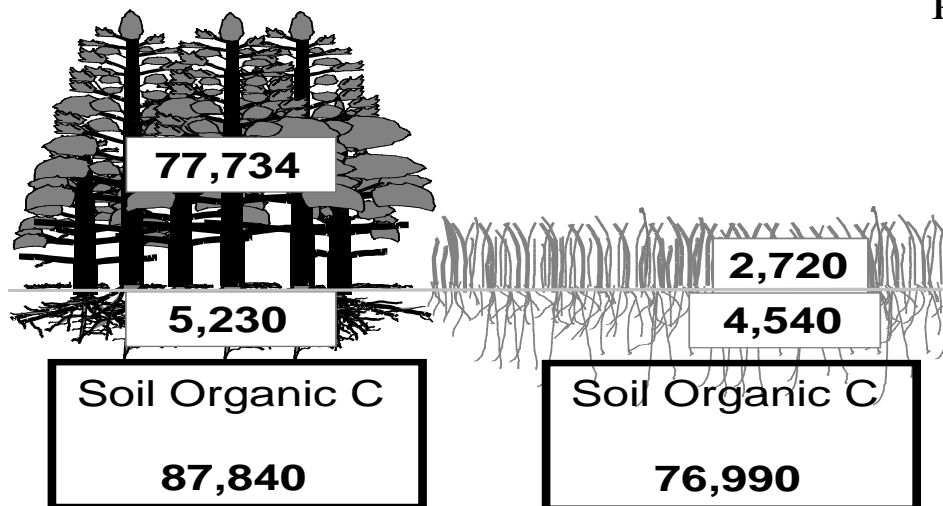
The critical role of soil respiration as a component of whole system C exchange has recently been highlighted considering the global soil respiration flux to the atmosphere is 6x that of fossil fuel CO₂ emissions to the atmosphere. For two years, we have been estimating soil respiration in paired grasslands and forests as an index of in situ belowground C cycling. To date, we are detecting fundamental differences in the rates of soil respiration between forest and grassland (Smith and Johnson, submitted). On an annual basis and for two consecutive years, soil respiration was nearly 30% less in forest compared to grassland. This indicates that belowground cycling is fundamentally different between forest and grassland.

Afforestation has resulted in substantial accumulations C in plant biomass and surface litter pools and ~30% lower soil C fluxes

Soil
Respiration
9,380

6,660

Litterfall
2,529



Summary of measured C stocks (C kg/ha) and fluxes (C kg/ha/yr)

A new question addressed in this proposal includes: What are the mechanisms for the reduction in soil respiration and belowground C cycling in forest? Thus, further investigation is be directed toward determining 1) the mechanism(s) to account for the sharp reduction in forest soil respiration relative to grasslands, and 2) the origin of the C effluxed from soils by analyzing the $^{13}\text{CO}_2$ of the respired C. The main questions addressed here are:

- Can greater belowground (root) allocation in forests relative to grassland result in the observed reduction in respiration rates in the forest?
- Can decreased microbial respiration in forests relative to grassland account for the reduction in respiration rates?
- How labile is soil C in forest relative to prairie? How much of the C respired from soils is new forest C vs old, recalcitrant prairie C? Do forest and grassland soils have differing sensitivities to temperature?
- Can microclimate changes, as forest encroaches prairie (cooler temperatures in forest), account for the reduction in soil respiration in the forest?

To address these questions, our approach included long-term (>1 yr) laboratory soil core incubations to determine potentially mineralizable C and N pools in forest and grassland soils. We also determined the isotopic signature and plant origin of the respired CO_2 using mass spectrometry. We expected that pools of potentially mineralizable soil C and N will differ between Juniperus forest and prairie because of fundamental differences in the quality and quantity of their litter. Gas samples were also collected for $^{13}\text{CO}_2$ analysis. Data (Smith et al. 2003) indicate that respired CO_2 coming from forest is predominantly of C_3 tree origin while that of the recalcitrant C_4 prairie C is minimal. A manuscript describing isotopic approaches to studying effects of woody encroachment on C cycling is in preparation (Johnson, Smith, and Fagan)

Future work will include an in situ field study to attempt to partition the fluxes of C in soil respiration from roots and from heterotrophic microbial respiration. Basically, this involves a 'trenching' experiment in which an area of forest is trenched (1m deep) to sever tree roots on the perimeter and flashing installed as a barrier to exclude roots from growing into the plot. Soil respiration measurements will be carried out using the established soil respiration protocol. Thus,

flux in the trenched plots should result from microbial respiration (roots excluded) and in untrenched controls from both microbial and root respiration. A comparison of the two fluxes will provide data on the magnitude of the root respiration component of the soil respiration flux in forests. The trenching experiment will commence as soon as possible at our three closed canopy forest sites so as to provide at least one year between the time of trenching and the time of measurement (to minimize disturbance effects). We predict that the reduction in soil respiration observed in forests will be a result of lower root respiration, rather than lower microbial respiration.

Future work: Root productivity and turnover. During the previous funding period, we were able to demonstrate substantial increases in aboveground plant productivity (ANPP) as grasslands underwent conversion to Juniper forests. However, we lack critical data on changes in belowground biomass and root productivity but clearly have important implications for the net storage of ecosystem C belowground. Thus, our future work will address the question of how a change from tallgrass prairie to juniper forest alters belowground plant productivity and biomass by quantifying (a) changes in both fine and coarse root biomass, and (b) changes in fine root productivity and turnover. Four minirhizotron tubes have been installed in paired grassland and juniper plots at each study site. Images are collected monthly, and digitized using the MSU ROOTs program. Measured or calculated parameters will include fine root density and depth distribution, fine root productivity, fine root disappearance, and fine root turnover. This work is still in progress.

4. Estimating rates of change in C and N stocks and productivity along the grassland-forest continuum: The use of chronosequences. Future work: While our earlier research focused on closed canopy forest, much of the change in land cover lies in the potential for the woody-grassland mosaic to completely convert to closed canopy forest. Therefore, in our future research, we must quantify the spatial and temporal rates of woody encroachment and the transition from one juniper cover class to the next and, ultimately, to closed canopy forest. Thus, we need to focus our efforts on detailed measurements of C and N stocks and NPP in a chronosequence representing several intermediate age and juniper cover classes in the grassland-juniper continuum. We will conduct these measurements in the midpoint of the following cover classes: 0-20% (if possible to detect this spectrally), 20-40%, 40-60%, and 60-80%. We anticipate four replicate sites for each of these cover classes. Importantly, we will use the same cover classes as those in our LSMM. We have identified preliminary sites for carrying out the chronosequence studies and have begun making measurements and collecting data. Development of the allometric relationships describing forest biomass in the intermediate cover classes is still ongoing. We are using similar methods used in our earlier work in the closed canopy forests (Norris et al. 2001).

5. Continued Modeling Activities

We will use the Marine Biological Laboratory's General Ecosystem Model (MBL-GEM), a process-based model of ecosystem biogeochemistry, to integrate the *in situ* data and predict long-term changes in ecosystem processes on a regional scale. Processes in the model include photosynthesis and N uptake by plants, allocation of C and N to foliage, stems, and fine roots, respiration in these tissues, turn-over of biomass through litterfall, and soil C and N dynamics. We will specifically use our modeling approach to address ecological questions that can not be answered with short-term experiments and that need long time scales in order to play out. We will address such questions as: How will shifts in vegetation type affect NPP and ecosystem-scale fluxes of CO₂ in eastern KS both now and in the future as the young cohort of junipers matures? How much of the C flux is derived from old prairie C? As the young cohorts of juniper mature, will ecosystem C flux be dominated by forest C?

Our objective is to use MBL-GEM and GIS techniques to derive a process-based understanding of long-term (decades to centuries) changes in ecosystem processes over for the land cover mosaic. We will continue to use the experimental data from our prairie-forest gradient to calibrate MBL-GEM for 1) tallgrass prairie, and 2) the successional replacement of prairie by forest. Thus we will run the model for our endmembers (grassland, closed canopy forest) and for the cover classes of juniper. The calibrated model will be evaluated by comparing simulated C and N stocks and fluxes to measured data not used for the calibration; these data will include the eddy-flux measurements of the net exchange of CO₂ between the ecosystem and atmosphere at prairie and Juniper sites. We will then link the calibrated MBL-GEM to a GIS (ARC/INFO) so that changes in ecosystem processes within our study area can be simulated for individual pixels, as defined by vegetation and soil type. With our Landsat analysis of historical changes in land cover; the GIS will also enable us to project the transitional probability for a change in vegetation state (i.e., prairie to forest) within each pixel. By driving the MBL-GEM/GIS system with predicted changes in land use, climate, and CO₂, we can predict biogeochemical consequences over the landscape. This work is still ongoing.

Timeline for Dissemination of Research and Synthesis Activities

1. Semi-annual workshop scheduled for Oct, 2003 to assemble the interdisciplinary group, integrate data sets, provide input for calibrating the GEM, plan for manuscript preparation and dissemination of results

2. Continued dissemination of results. Abstracts describing the remote sensing results will be submitted for oral presentations at the annual meetings of the Association of American Geographers (AAG) and the American Society of Photogrammetry and Remote Sensing (ASPRS). A proceedings paper will be prepared for the ASPRS meetings and further refined for submission to the journal, Remote Sensing of Environment. Process-level belowground process work will be submitted to Ecology, Ecosystems, and Soil Biology and Biochemistry. The net C exchange studies will be submitted to journals such as Global Change Biology and Ecological Applications. Loretta Johnson plans to present a paper dealing woody encroachment and regional carbon balance at the Dec. 2003 AGU meeting.

3. Develop plans for synthesis and review article on patterns, causes, and consequences of woody encroachment in the Great Plains and Lower Midwest. This initiative began with the NASA Land Use Land Cover Change book chapter (Wessman-lead author).

New findings, potential, products

1. Synergism with Dr. Jay Ham, micromet expert, to quantify how net ecosystem CO₂ exchange varies with land use and land cover change (forest expansion, grazing, burning, agricultural conversion and agricultural practices). Use of multiple tower sites including those at the Konza Prairie LTER site and the Rannels ranch. Johnson will try to secure funds from NIGEC for this multiple tower site comparison.

2. Uses of oxygen and hydrogen isotopes to determine sources of water for grasses and junipers. The isotope data combined with evapotranspiration data from micrometeorological towers will allow us to assess changes in water balance with forest encroachment. Jesse Nippert (grad student, KSU Biology) has been pursuing this project as part of his Ph.D dissertation. Nippert will take advantage of our mass spec facility at KSU (www.ksu.edu/siml) that allows quick and inexpensive sample analysis of stable isotopes of C, H, N, and O.

Conclusions

This research will assess the current distribution of woody encroachment and the changes that have taken place in the last several decades, identify the impacts of those changes on biogeochemical cycling, biophysical processes and trace gas fluxes, and, through modeling efforts, predict the likely impacts of future land cover change. The effects of woody encroachment on C storage are poorly known, difficult to quantify, but potentially important as a C sink. Although this case study is focused in Kansas, the results will help predict consequences of forest expansion presently occurring in other parts of the Great Plains. This study may also be useful in predicting juniper expansion in semi-arid areas where juniper coverage has increased dramatically in the last 50 years.

Accomplishments and productivity

We have made excellent progress in meeting the goals and objectives of our proposal. Two doctoral students (Biology at KSU), 1 post-doc (Applied Remote Sensing Center at KU), and one assistant scientist (Micrometeorology at KSU) are now supported on this project. Four papers have been published in 2002, several additional manuscripts have been submitted or are in preparation. Seven oral presentations or posters have been/will be presented at national meetings in 2002-2003.

List of publications during the period 2002-2003

Ham, J.M. and J.L. Heilman. 2003. Experimental test of density and energy-balance corrections on CO₂ flux as measured using open-path eddy covariance. *Agron. J.* (in press).

Hoch, G. A., Briggs, Johns M., and L. C Johnson. 2002. Assessing the rate, mechanisms, and consequences of the conversion of tallgrass prairie to *Juniperus virginiana* forest. *Ecosystems*.5:578-586.

Smith, DL and Loretta C. Johnson. 2003. Expansion of *Juniperus virginiana* in the Great Plains: Changes in Soil Organic Carbon Dynamics. *Global Biogeochemical Cycles*. In press.

Smith, DL and Loretta C. Johnson. Changes in Soil carbon cycling as forests expand into grassland: Vegetation-mediated changes in microclimate reduces soil respiration. Submitted to *Ecological Applications*.

Wessman, Carol, Steve Archer, Loretta Johnson, and Gregory Asner. Woodland Expansion in US Grasslands: Assessing Land-Cover Change and Biogeochemical Impacts. *NASA Land Use and Land Cover Change-book chapter*. In Press.

Oral or Poster presentations in year 2002-2003:

J.L. Duesterhaus, J.M. Ham, L.C. Johnson, and C.E. Owensby. 2003. Effect of Forest Expansion on the Energy Balance: Comparison of Cedar Forest and Tallgrass Prairie. Poster to be presented at the American Agronomy Society Meetings, Denver, CO, Oct 2003.

Roxane Fagan, Dixie Smith, Loretta Johnson. Changes in Soil Organic Carbon Cycling as Juniper Forests Invade Tallgrass Prairie: A ¹³C Stable Isotope Approach. Poster presented at the 9th Annual CF-IRMS workshop, St Johns, Newfoundland. Oct 2002.

Kevin Price. Participation in the National Science Foundation Conference on North American Carbon Program, Arlington, Virginia, May 12-14, 2003.

Kevin Price. Invited participant in the NASA/USDA joint workshop on Agricultural Decision Support Systems. Dr. Price participated in the carbon management and invasive species sections of the workshop that was held in Denver, Colorado, March 4-5, 2003.

Kevin Price. Linking Remote Sensing, Land Use, and Carbon Sequestration: Insight from Leaf to Landscape Scales in America's Heartland (Invited speaker at the Conference on Carbon Management Applications Program, of NASA's Earth Science Enterprise, Arlington, Virginia, March 27-28, 2003 (A significant component of this presentation focused on the use of remote sensing for estimating cover by red cedar.

Smith, Dixie, Roxane Fagan , and Loretta Johnson. Changes in Soil Organic Carbon Cycling as Juniper Forests Invade Tallgrass Prairie: A ^{13}C Stable Isotope Approach. Poster presentation at Ecological Society of America, Aug. 2003.

Smith, Dixie, Roxane Fagan , and Loretta Johnson. Changes in Soil Organic Carbon Cycling as Juniper Forests Invade Tallgrass Prairie: A ^{13}C Stable Isotope Approach. Poster to be presented at the National Science Foundation's Long Term Ecological Research Program (LTER) All Scientists Meeting, Seattle, Sept. 2003.