Dr. Garik Gutman Nov. 30, 1999
Science Division/Code YS
Office of Earth Science
NASA HQ
300 E. St., SW
Washington, DC 20546

Dear Dr. Gutman,

As you have requested, this letter summarizes progress on our project 'Land-cover Change in the Great Plains: Predicting Impacts of Regional Forest Expansion on Biogeochemical Processes' which is funded through the NASA Land-cover and Land-use Change Program.

Eastern Kansas (KS) has the largest expanse of tallgrass prairie remaining in the world and is second only to TX in livestock productivity. However, in the last several decades, forest cover has doubled in KS and may jeopardize future sustainability of these productive grasslands. Our study has begun to quantify land-cover change in eastern KS and its consequences for ecosystem C and N dynamics and fluxes of CO2, energy, and H2O. Although this study is focused in KS, the results will aid in understanding and predicting the consequences of forest expansion occurring throughout the Great Plains and elsewhere.

The ultimate goal of this research is to develop a method that will allow repeated inventories of land-use and land-cover from space and then to evaluate the ecosystem consequences of observed and predicted land-cover changes in the Great Plains. Without an understanding of the biogeochemical consequences of this major land-cover change in the eastern Great Plains, it will not be possible to manage resources to insure their sustainability. To achieve this goal, we are using aerial photos, remote sensing and GIS techniques coupled with in situ process-level biogeochemical and ecosystem flux studies. We will link the biogeochemical studies to land-cover change using the Marine Biological Laboratory-General Ecosystem Model (GEM) and GIS techniques and ultimately predict long-term changes on a regional scale.

Specific objectives of this proposal are to:
… 1. assess the current distribution of land-cover, document the historical change in land-cover (especially forest cover) using aerial photographs and remote sensing (using both historical and present data), linked to a GIS data base which will have important information on the potential forcing factors (socioeconomic vs climatic, ecological),
… 2. quantify the effects of forest expansion on biogeochemical processes controlling the quantity, quality, and distribution of soil organic matter and soil C, and N cycling and availability,
… 3. determine how these life-form shifts alter ecosystem C balance and fluxes of CO2, H2O, and energy, and
… 4. incorporate a spatially-explicit model (GEM) that will link our in situ biogeochemical and ecosystem studies with spatial information on land-cover change to predict ecosystem consequences of the impact of future

forest expansion.

We have made significant progress in meeting our stated goals and objectives. We established three paired forest-grassland study sites in which we are continuing a series of intensive, process-level in situ biogeochemical measurements and C flux studies. These three forests range in age from 40 (Dobson, Carlson sites) to 60 years old (Borg forest) and represent the ecological endpoint of the shift from grassland to forest. Additionally, we have acquired and continue to process the necessary remote sensing imagery and GIS data which will allow us to scale up the ecosystem consequences of forest expansion to the regional level of eastern KS. We have also incorporated a study of biodiversity changes as grasslands convert to juniper forest. While the Konza Prairie LTER has an extensive database on plant biodiversity in tallgrass prairie, no comparable data existed regarding biodiversity in redcedar forests. In closed canopy forests, plant species diversity (based on 10m2 plots) is severely reduced from 30-35 species in prairie to < 5 in forest. Our 1999 progress report is also documented on our web page (http: //climate.konza.ksu.edu /general nasalandcover/landuse.html established in March 1998). Below we provide specific details as to our progress.

1) Assessing current and historical landcover change using remote sensing

a) Data acquisition and GIS construction

In our first funding increment, we acquired several remote sensing data sets. We obtained the Landsat MSS - NALC (North American Land Cover) imagery for all of Kansas which contains images from 1974, 1986, and 1992. In cooperation with the Konza Prairie LTER program and the Departments of Biology and Geography at KSU, we have purchased Landsat TM images for every year from 1983 to 1999, missing only 1994 when no images are available. We also purchased FSA (Farm Service Agency) aerial photos for the 3 intensively studied sites from 1937, 1957, 1969, 1978, 1985, and 1996. Digital Ortho Quadrangle images are available to us from the Department of Geography at KSU for the entire state of Kansas. We have DOQ images for the 3 study sites as well as the surrounding areas. We have other opportunities for data acquisition. During the summer of 1999, Konza Prairie was the site of a NASA-sponsored 'Bigfoot' project. From this project, we now have AVIRIS imagery for our 3 intensively studied sites. We are currently registered with the NASA Scientific Data Buy (SDB) which will provide multiple fine scale remote sensing data sets that will be useful for assessing future landcover change in the Great Plains.

For the GIS data base development, we have obtained the 7.5 minute Digital Elevation Models (DEM) for the three intensive study sites. Detailed digitized soil maps have been incorporated into the data base. Other GIS coverages that we have incorporated into our project include county boundary, state geology, hypsography (topography) at 1:100K and 1:250K scales, and the Statsgo soils GIS coverages. In addition, many of the 34 counties in eastern Kansas have GIS coverages partitioned into as many as 22 land use types. We will be using these data for both ground-truthing and landscape modeling. We are also compiling data on socioeconomic drivers of landcover change e.g., human population by county, housing starts, cattle prices, number of head of cattle produced, acreage in rangeland, etc.

b) Data processing and spectral mixing model development

We began our remote sensing analysis using scanned and digitized historical aerial photos for each of the 3 intensively studied sites. These images were then rectified to the DOQ images. As a first step, we used these images to determine the age and rate of expansion of cedars in these 3 sites. An unsupervised classification was used to measure the percentage of the study area covered by cedars from 1957-1996. From this, we determined that cedars spread at a rate of 4% cover per year at the site level. Therefore, open grassland can be converted to closed canopy forest in as few as 35 years.

Our next step was to use satellite remote sensing to scale up from the site level to the regional level. Our approach was to use a supervised classification of Landsat TM imagery from 1997 to identify closed canopy cedar forests in the 7 northern counties of the Kansas Flint Hills region. We determined that closed canopy forest occupied 4400 ha of the northern 2 counties but only 25 ha of the southern county in the region. Ground-truthing showed these coverages to be greater than 95% accurate. Furthermore, this pattern of forest cover was strongly and positively correlated to population increases at the county scale.

Once we have identified closed canopy forest, our next challenge is to identify areas with a mixture of grassland and cedars. From the supervised classification described above, we identified a 14,000 ha region of Riley County with a relatively high cedar coverage. These grassland-forest mosaics presently occupy 3x as much area as closed canopy forest in eastern KS. If these young trees and open canopy forest continue to mature, then closed canopy forest area could increase by as much as 230% in 14 years according to our preliminary land cover model. We decided to use linear spectral mixing models because the relatively simple procedures such as classifications could not accurately identify these mosaic, open canopy areas. Our approach was to use TM imagery from 1983 and 1997 in combination with linear spectral mixing models to determine cedar canopy at the subpixel level. For each image, we related spectral values to percent cedar cover determined from the photos taken from within 2 years of the satellite imagery. Using the two dates, we were able to determine the rate of change in cedar cover at the pixel level over the 14 year period and then develop a landcover change model.

This analysis indicates that the linear spectral mixing model explained 0.88 and 0.92 percent of the variance in each image. The model was applied to the TM imagery to create a coverage where the pixel value represented the proportion of the pixel occupied by cedar canopy. We then combined these data into 4 land cover classes: open grassland, closed canopy forest, and two intermediate classes. By comparing the 1983 and 1997 images, we were able to determine rates of cedar expansion at the regional level and also to relate the rate of canopy closure for an individual pixel to adjacent pixels. This allows us to determine the probability of a pixel changing from grassland to forest based on the surrounding landscape. We are currently in the process of validating these land cover change models. From our preliminary model results, we determined that in the 14,000 ha study area, grasslands have decreased by 7% and concurrently, cedar forest increased by 190% between 1983 and 1997. The number of cedar forest stands has increased by 38% while the mean size of these stands has increased by 32%. In summary, our spectral mixing model approach has been highly successful as a tool in change detection analysis in these forest-grassland mosaics.

2) Biogeochemical and ecosystem consequences of forest expansion

We have made significant progress on quantifying the biogeochemical and ecosystem consequences of forest expansion. While there is an extensive database on productivity, decomposition and nutrient cycling processes in regional tallgrass prairies, available through the Konza Prairie LTER Program, we had no comparable data regarding these ecosystem characteristics in redcedar forests at the onset of this study. Since the initiation of this project, we have acquired new data on tree biomass and productivity, standing stocks of C and N in tree biomass, aboveground litterfall, leaf and root decomposition rates, and soil N dynamics in redcedar stands. We harvested a series of trees of varying age and size in order to develop allometric growth equations relating trunk diameter (dbh) to tree biomass for both mature closed-canopy stands and young open canopy stands representing the early phase of redcedar expansion. These allometric equations have been applied to our study sites for non-destructive estimates of aboveground tree biomass. Trees at various sites have also been cored to determine age, and the annual growth increments are being used to develop estimates of tree productivity for these forest stands. In addition, detailed measurement of C and N content of various components of the total tree biomass have allowed us to estimate standing stocks of C and N in redcedar trees at these sites. Aboveground tree biomass at our three main study sites averages about 148,000 kg/ha dry mass representing a standing stock of about 78,000 kg C/ha. This pool of C represents a substantial increase in plant biomass C, compared to regional grasslands, and we are continuing to evaluate the consequences of this change (as well as changes in soil C, as indicated below) for regional C storage.

Accompanying this shift in vegetation is an increased flux of C and nutrients in the form of aboveground litterfall. Annual litterfall in the closed canopy redcedar stands has been measured for two years and averages about 500 g/m2, which is substantially greater than in either grasslands or other regional forest types (i.e., riparian gallery forests). Because of this increase in the relative importance of litterfall, we have also focused on quantifying decomposition rates, and associated nutrient fluxes, of redcedar litter. We are completing a two-year reciprocal litter transplant study comparing the decay rates of redcedar root and leaf litter with that of a locally dominant grass species (Andropogon gerardii). Results from the first year indicate a slower decay of redcedar root litter, compared to grass litter, which appears to be driven by differences in resource quality (% lignin and C:N ratio), as opposed to microclimatic effects of forest expansion. The slower decay rates and greater N immobilization potential of redcedar root litter may contribute to observed differences in soil N mineralization rates. We have been documenting changes in N cycling associated with forest expansion by monthly sampling of extractable soil N, and in situ incubations to determine net mineralization and nitrification rates. The greatest differences between grassland and forest sites occur in the early part of the growing season, when immobilization appears to be greater in the forest soils. We are also evaluating potential changes in the depth distribution of soil N and net N mineralization, by conducting N mineralization assays at varying depths in both the grassland and forest sites. The soil N cycling results will be compared to data from similar studies done at the Konza LTER site, and simultaneous measurements in paired forest and grassland sites will allow us to more fully evaluate the effects of forest expansion of soil N dynamics.

The increased amount and poor tissue quality of litterfall in juniper forests led us to hypothesize that expansion of juniper forest will alter the quality, quantity and distribution of soil organic carbon (SOC). We have used a stable isotope approach to estimate changes in SOC due to Juniper expansion into prairie. Due to differences in discrimination against 13C in C3 and C4 photosynthesis, SOC developed under native C4 tallgrasses has a 13C near -13.0 per mil, while that derived from C3 junipers is about -27 per mil. A comparison of 13C of bulk soils and soil particle size fractions in forest and tallgrass prairie allowed us to estimate the impact of changing landcover on the quality and vegetation origin of the soil organic carbon in cedar forest. Using this approach, 13C of SOC in three juniper forest study sites indicates that at shallow soil depths (0-7.5 cm), as much as 38% of the SOC of the bulk soil is juniper in origin and is contained primarily in coarse size fractions. Prairie-derived C dominates at greater depth especially in the fine size fractions. In spite of the significant changes in the quality and origin of the new plant C inputs as juniper invades tallgrass prairie, these closed canopy forests show relatively minor increases in the total amount of C stored in the soils (8594gC/m-2 in forest vs 7698 in grassland). The increase in soil C is primarily restricted to the litter layer of these Juniper forests with a trend for a slight increase in the top 2.5 cm in the mineral soil. Using this 13C isotope approach, we have determined that fundamental vegetation shifts are altering the quality and distribution of SOC in Kansas soils in as few as 40 years (Smith and Johnson, 1997). As much as 20% of the soil organic carbon (to a depth of 25 cm) in these forests is now of Juniper origin, but so far, the vegetation shifts have only slightly increased the total amount of C stored in these soils.

Last summer, we began measurements of soil respiration (efflux of C from roots and soil microbes) in grasslands and forests as an index of in situ soil C cycling. These studies are strongly complementary to the isotope approach to estimate soil C turnover as well an important component of our net CO2 exchange tower measurements (described below). Soil respiration was measured weekly using a Li-Cor 6200 in our three intensively studied juniper forests and paired grassland sites. To date, we are detecting fundamental differences in the rates and phenological patterns soil of respiration between forest and grassland. In May and June, soil respiration was not significantly different between forest and grassland. However, by early July, grassland soil respiration rates averaged 30 - 50% more than paired forest sites. This could be attributed to 1) greater belowground (root) allocation in prairie grasses, resulting in greater respiration rates and/or 2) increased heterotrophic microbial respiration in grasslands relative to forests. To differentiate between these two causes, we have begun to estimate root biomass in forest and grassland as well as conducting laboratory studies of soil microbial biomass and activity. Further investigation will be directed toward determining the mechanism(s) to account for the sharp reduction in forest soil respiration relative to grasslands.

3) Changes in ecosystem fluxes of $CO_2$, $H_2O$, and energy

We expect forest expansion to have a profound impact on carbon, water, and energy exchange between the surface and the atmospheric boundary layer. Over time, these fundamental changes in life form will have regional and perhaps global implications for land-atmosphere interactions. We proposed to examine the effect of forest expansion on these processes by making simultaneous measurements of boundary-layer fluxes over a Juniper woodland and grassland site near Konza Prairie. These studies will complement on-going studies in which Jay Ham (one of the co-PI's on the NASA project) is using micrometeorological towers to obtain continuous flux measurements at Konza Prairie and in other land-use types (rangeland, row-crops). In the second increment of funding, we have successfully constructed, installed, and hired a post-doc to conduct boundary-layer flux measurements at these micrometeorological towers.

A flux-monitoring tower has been in operation at one of the closed-canopy cedar sites since the spring of 1999 and a post-doc (Dale Bremer) has been overseeing tower construction, operation and data analysis. This tower records continuous measurements of carbon, water, and energy fluxes from the cedar forest. Similar measurements are being conducted at nearby grazed and ungrazed tallgrass prairie to determine the effect of cedar encroachment on ecosystem fluxes. Preliminary results suggest strong phenological differences in C dynamics between C4 warm season grasses dominating the prairie with C3 cedar forests. In the summer, the cedar forest was a source for $CO_2$ (net C exchange-11.1 gC/m-2 in June to hovering around 0 in Aug), while the tallgrass prairie was a sink ( as high as +20.3 g/m-2 in June) on an ungrazed tallgrass prairie. In the Fall, plant senescence brought about a decline in NCE at the prairie site. At the same time, the forest site became a sink. Seasonal dynamics between climate and canopy phenology will undoubtedly vary fluxes during and between years. However, these data indicate that cedar encroachment is indeed having a significant impact on $CO_2$ fluxes in the Great Plains.

In the next increment of funding, we will continue our flux measurements over the annual cycle. Data quality will be checked in the Spring of 2000 by mounting an eddy co-variance system on the tower and comparing it to results from the relaxed eddy accumulation technique (Bremer and Ham, 1999). This third increment of funding will allow us to continue these important flux measurements over annual cycles to predict how cedar expansion will change regional C balances.

5) Spatial and temporal scaling of ecosystem processes using GEM (General

Ecosystem Model)

While our in situ studies will be extremely valuable in understanding how components of the ecosystem response to changes in land cover, an important goal is to integrate these data so that the biogeochemical dynamics of the land surface and its interactions with the atmosphere can be extrapolated over space and time. We will use the General Ecosystem Model (MBL-GEM), a process-based model of ecosystem biogeochemistry and GIS techniques, to integrate the in situ data, to predict long-term changes in ecosystem processes on a regional scale, and to derive a process-based understanding of long-term (decades to centuries) changes in ecosystem processes over for the land-cover mosaic in eastern KS. We will use the experimental data from our paired prairie-forest sites to calibrate MBL-GEM for 1) tallgrass prairie and 2) the successional replacement of prairie by forest. 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 Juniperus 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.

We are in monthly contact with our collaborator (Bob McKane-Terrestrial Ecosystem Ecologist, U.S. EPA) responsible for modeling. We are presently parameterizing the model to meet our stated goals and objectives. A network web site has been established to easily input empirical data needed for McKane's modeling efforts. So far, we have parameterized the model for prairie and, as we continue to obtain empirical data from our process-level field studies in forests, we will continue to input these data to parameterize GEM for conversion to forest. We envision the modeling effort to be a major component of our activities in the third increment of funding as we use GEM as a tool for synthesis and integration.

Moreover, GEM is being further developed as a tool for synthesis and integration. Bob McKane was recently invited in last month to a Workshop for Modeling Ecosystem Processes at Regional Scales sponsored by NSF and the San Diego Supercomputer Center (SDSC) to promote regional extrapolation of research conducted at LTER sites and our associated regional NASA study. The SDSC facility may be potentially very useful for modeling regional effects of land cover change, a task that will be computationally intensive and generate large amounts of model output. The SDSC can address these issues and also provide valuable data visualization techniques. We are taking steps to take advantage of these resources, including modifying GEM's soil water submodel to facilitate it's incorporation into a regional modeling framework that can be run on the supercomputer.

In summary, we believe we are making excellent progress in meeting our stated goals and objectives. Our progress is due in large part to the three motivated graduate students hired to assist on the project (Greg Hoch, remote sensing; Dixie Smith, soil C dynamics, Mark Norris; productivity and decomposition and N cycling). Additionally, a post-doctoral associate to assist with the eddy accumulation studies was hired in March 1999 and continues to play a critical role in the carbon flux studies. Thus far, all three students have made significant progress; two of the three students have presented papers or posters at the 1998 and 1999 ESA and SES meetings. One paper has been published to date, and we envision 6 more will be submitted during the final increment of the grant and as data becomes. Another highlight is the symposium (Land use/land cover change in the last century and prospects for the next millennium) that Pam Matson and I are organizing for the 2000 ESA meeting. Several participants of the NASA Land Cover/Land Use Change Program are scheduled to take part in this symposium on the ecological consequences of land use/land cover change.

Please feel free to contact me if additional information is required.

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