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MODELING THE RESPONSE OF PLANTS AND ECOSYSTEMS TO GLOBAL CHANGE

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T7

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1. List of Products

1.1 Publications, submitted manuscripts, and theses (1989-1990):

Cornelius, J. M. and J. F. Reynolds. Determining the significance of discontinuities identified by boundary analysis. (submitted to *Journal of Vegetation Science*)

Dadmehr, S. 1989. Mathematical modeling of water flux through soil during evaporation. M.S. thesis, Department of Mathematics, San Diego State University.

P.C. Harley and T.D. Sharkey. An improved model of C_3 photo-synthesis at high CO_2: Reversed O_2 sensitivity explained by lack of glycerate reentry to the chloroplast. (submitted to *Photosyn. Res.*)

P.C Harley, R.B. Thomas, J.F. Reynolds and B.R. Strain. Modeling the effects of growth in elevated CO_2 on photosynthesis in cotton. (submitted to *Oecologia*)

P.C. Harley and J.D. Tenhunen. 1990. Modeling the photosynthetic response of C_3 leaves to environmental factors. In: Modeling Crop Photosynthesis--From Biochemistry to Canopy, K.J. Boote and R. Loomis (eds). Special Publication, Amer. Soc. Agronomy (in press)

Hilbert, D.W. 1990. Optimization of plant root:shoot ratios and internal nitrogen concentration. *Annals of Botany* (in press)

Hilbert, D.W., and A. Larigauderie. Optimal leaf nitrogen concentration and root:shoot ratio in relation to light, carbon dioxide, and nutrition. (submitted to *Annals of Botany*)

Kemp, P. R., J. M. Cornelius, and J. F. Reynolds. Discontinuities in weather patterns of the North American Prairie during the period of meteorlogical record. (submitted to *Climate Change*)

Kemp, P. R., J. M. Cornelius, and J. F. Reynolds. Interpreting ecosystem response to global climate change in terms of local and regional climate: A case study in the Great Plains. Proceedings of the Symposium on Biometeorology and Global Change, Anaheim, California. (submitted)

Larigauderie, A., and D.W. Hilbert. Influence of CO_2 and nitrogen availability on root activity and nutrient concentrations in *Bromus mollis*. (submitted to *Functional Ecology*)

Tenhunen, J.D., A. Sala Serra, P.C. Harley, R.L. Dougherty, and J.F. Reynolds. 1990. Factors influencing carbon fixation and water use by mediterranean sclerophyll shrubs during summer drought. *Oecologia* 82:381-393.

1.2 Presented Papers (1989-1990)

Cornelius, J.M., P.W. Leadley, J.F. Reynolds and B. Acock. 1989. A test of the generality and transferability of GENMOD: A generic, modular, plant growth model. Annual Crop Simulation Conference, Champagn-Urbana, Illinois, March 1989.

Cornelius, J. M., and J.F. Reynolds. 1989. Determining the significance of discontinuities identified by boundary analysis. Ecological Society of America, Toronto, Ontario, Aug. 1989.

Cornelius, J. M. and J. F. Reynolds. Effects of interactions between water and nitrogen on the growth of creosotebush (*Larrea tridentata*): A simulation analysis comparing geomorphic surfaces on the Jornada and Sevilleta LTER sites. Ecological Society of America, Snowbird, Utah, July 1990.

Hilbert, D.W. Anaysis of optimal leaf nitrogen concentration and root:shoot ratio. Ecological Society of America, Toronto, Ontario, Aug. 1989.

Hilbert, D. W. Optimal leaf nitrogen concentration, specific leaf weight, and root:shoot ratio in response to light and carbon dioxide. Ecological Society of America, Snowbird, Utah, July 1990.

Hilbert, D.W., and J.F. Reynolds. The challenge of ecological modeling at the landscape level. 4th Annual Landscape Ecology Symposium, Fort Collins, Colorado, March 1989.

Kemp, P. R., J. M. Cornelius, J.W. Skiles, and J. F. Reynolds. Discontinuities in Great Plains weather patterns and implications for ecosystem response. Ecol. Soc. Amer. Annual Meeting, Toronto, Canada, 1989.

Kemp, P. R., J. M. Cornelius, and J. F. Reynolds. Interpreting ecosystem response to global climate change in terms of local and regional climate: A case study in the Great Plains. AMS Annual Meeting, Symposium on Biometeorology and global change, Anaheim, California, February 1990.

Reynolds, J. F., R. A. Virginia, and J. M. Cornelius. Resource island formation associated with the desert shrubs, creosotebush (*Larrea tridentata*) and mesquite (*Prosopis glandulosa*) and its role in the stability of desert ecosystems: A simulation analysis. Invited paper, Ecological Society of America, Snowbird, Utah, July 1990.

PROGRESS IN COMPLETING PROJECT GOALS

1° Goals	Specific tasks	Data needs/potential collaborators	Expected products	Progress
Develop GePSI	(1) Parameterize leaf model at ambient and elevated CO_2	(1) Cotton Expt. (Nov. 1989) Harley/Thomas (Strain)	(1) Use of an analytical model to interpret photosynthetic changes in cotton grown under elevated CO_2.	1) Manuscript submitted to Oecologia; second manuscript w/ Dr. Tom Sharkey on modeling Pi limitations to photosynthesis submitted to Photo. Research
	(2) Determine effects of leaf age, leaf N and sink strength on leaf level parameters	(2) Cotton Expt. (Nov. 1989) Harley/Thomas (Strain)	(2) Effects of chilling roots on growth and photosynthesis of cotton	2) Manuscript in preparation (w/ Thomas and Strain)
	(3) Determine leaf level parameters and canopy structure (1) at a single point in time, and (2) over a growing season, and relate to measured whole plant gas exchange	(3) Expt. on annual weed (Spring/Summer 1990) Harley/Bazzaz/Thomas/Hilbert and/or Expt. on Konza grasses either in Kansas or San Diego Sionit/Harley/Kemp/Hilbert possible collaboration with Norby	(3) Parameterization (validation?) of a shoot carbon uptake model for a C3 successional species. Possible other papers	3) Experiments planned at Konza site for 1990 to address question of how leaf model parameters vary over the course of the growing season
	(4) Develop an allocation approach to R:S and leaf protein during Balanced Exponential Growth	(4) Cotton Expt. (Nov. 1989) Harley/Thomas (Strain)	(4) Balanced activity through variable allocation to photosynthetic enzymes and root and shoot biomass.	4) In manuscript; preliminary results to be presented at ESA meetings, Aug. 1990
	(5) Develop simple whole plant model for vegetative growth	(5) Growth and photosynthesis data on successional annual; Hilbert/Bazzaz/Harley/Thomas	(5) A whole-plant vegetative growth model incorporating morphological and physiological plasticity in response to resource availability.	5) In development
	(6) Determine leaf/canopy/whole plant parameters for C_3/C_4 grass system	(6) Expt. on Konza grasses either in Kansas or San Diego Sionit/Harley/Kemp/Hilbert	(6) A whole-plant vegetative growth model of a C3 and a C4 perennial grass in response to resource availability.	6) Existing Bromus model is being modified for use with Konza species as Konza data becomes available.
	(7) Literature review of CO_2 'acclimation' in native spp.	(7) Hilbert/Harley/Reynolds	(7) Morphological and physiological changes with growth at elevated atmospheric carbon dioxide.	7) Analysis of optimal allocation patterns; one publication in press, a second submitted
	(8) Develop 3rd generation Larrea Model	(8) Larrea data of Lajtha, Rundell, LTER; new expt?	(8) Carbon-nitrogen balanced growth model for creosote	8) In development; preliminary results to be presented at ESA meetings, Aug. 1990
	(9) Modify Larrea Model for deciduous trees	(9) possible collaboration with Norby/Harley	(9) Carbon-nitrogen balanced growth model for white oak and yellow poplar	9) To be initiated in 1990
Develop Community Model	(10) Develop mechanistic plant community model	(10) Parameterization and validation data sets available in literature	(10) Resource competition in plants as influenced by resource structure of community	10) First generation plant community model developed
	(11) Modify plant community model to incorporate CO_2 effects	(11) CO_2 effects on growth of C3/C4 grasses and herbaceous annuals; Kemp/Drake/Owensby/Bazzaz	(11) Change in community structure and composition at elevated CO_2	11) To be developed following experiments and collaboration with Bazzaz
Develop GEEM	(12) Develop, parameterize and validate SOWAT point model	(12) Kemp/Cornelius; collaboration with Konza LTER if soil water, Ψ_{soil}, soil physical properties available	(12) Simulation of soil water flux in arid soils.	12) In development; preliminary results to be presented at ESA meetings, Aug. 1990
	(13) Use OOPS to scale up from point model to landscape	(13) none; Cornelius/Whitney	(13) Simulating landscape patterns in rainfall, runoff and soil water flux in the Chihuahuan Desert.	13) In development; preliminary results to be presented at ASA meetings
	(14) Develop and validate decomposition model (?)	(14) collaboration with Konza LTER, depending on data availability (buried bag decomp, climate, soil water)	(14) Response of soil biota to elevated CO_2. Rates of decomposition of litter grown in elevated CO_2.	14) Soil biota and decomposition experiments initiated at Konza (w/ Dr. Solange Silva)
	(15) Boundary analysis techniques for analyzing serial events	(15) available weather data; Kemp/Cornelius	(15) Determining the significance of discontinuities identified by Boundary Analysis.	15) In manuscript; to be submitted to J. Veg. Sci. in May
	(16) Translation of global changes to regional changes, and effects on ecosystems	(16) available weather data; Kemp/Cornelius	(16) Fluctuations in Great Plains weather and ecosystem response to global climate	16) In manuscript; to be submitted to Climate Change Second manuscript submitted to AMS Symposium
	(17) Develop and validate GEEM	(17) CO_2 effects on ecosystem response; Drake/Owensby	(17) Simulation of ecosystem response to elevated CO_2 and associated climate change.	(17) In development

3.0 Co-operative experimental and modeling studies of the response of tallgrass prairie to global change.

3.1 Coordinated studies of tallgrass prarie ecosystrem

We have initiated close collaboration with experimentalists at Kansas State University that will provide data necessary to parameterize and validate plant and ecosystem models of response to global change. This collaboration also includes co-operative experimental work carried out by staff at SERG that expands the range of ecosystem level processes measured in the open top chambers at Manhatan, Kansas.

Several factors suggest that close co-operation between our two groups will be especially advantageous for the realization of the broad goals of the DOE CO_2 consortium: (1) The experimental effort is very extensive at the tallgrass prairie site, both large open top chambers and smaller closed chambers are now in operation. Data collected in these experiments will provide information at the ecosystem, community, whole-plant, and leaf levels. (2) We have been in close contact with the Kansas State group for some time and are begining a major addition to the open chamber studies this summer. Consequently, we will be present at the field site for much of the summer, working directly with the group there. (3) Several members of our group have extensive experience working in grasslands and our ecosystem model is currently well structured to handle grassland simulations.

Several SERG staff members (P. Harley, D. Hilbert, P. Kemp, and N. Sionit) visited Kansas State University on Feb. 27, 1990 and held discussions with Clenton Owensby and Mary Beth Kirkham in order to initiate closer collaboration between our groups. It was agreed that Naser Sionit's work would closely follow the experimental protocol now employed by Dr. Owensby, with the addition that Sionit would carry out some leaf level photosynthesis work in all the open top chambers. This will provide important information for our models as well as dovetail nicely with work being done by Dr. Kirkham in the closed chambers. We have also made plans to add studies of litter quality and decomposition as well as soil microflora and fauna. These studies will be carried out in collaboration with Dr. Ross Virginia from SERG. These studies will be an important addition to current efforts in the open top chambers and are an important expansion of the ecosystem level studies of CO_2 effects.

The following outline lists the experimental programs which begin this summer, personnel involved, experimental objectives and inputs to the models developed at San Diego State University. In all cases, SERG scientists will be involved directly with data collection and the modeling team will be in close communication with all the investigators to ensure that both modeling and experimental goals will be met. The experimental program relies on a combination of related studies in the field (measuring ecosystem and plant level responses), greenhouse studies (emphasizing whole-plant responses as well as leaf level information), and phytotron experiments (emphasizing leaf physiological responses).

The data are organized as to their role in modeling: 1) validation data which will be used primarily to test the accuracy and robustness of our models, 2) process information which will provide rate information necessary to develop and modify existing models, and 3) parameter information which describes the characteristics of specific system components in the tallgrass prairie. The primary models for which these data are necessary are also identified: Global Change Ecosystem Model (GEEM), General Plant Simulator (GePSI), and leaf level physiological models.

Kansas State University

I. Open top chambers

A. Principal Investigators: Clenton Owensby (KSU), Nasser Sionit (SDSU)

B. Additional Investigators: Solange Silva (SDSU)

C. Experimental Design: 2 CO_2 levels (ambient, 2 X ambient), 2 Nitrogen levels (natural, fertilized)

D. Species Studied: Natural tallgrass prairie community

E. Primary Objectives: Determine ecosystem level responses to elevated CO_2 and interactions with soil nitrogen. Determine the effects of growth at elevated CO_2 on rangeland forage quality.

F. Specific Objectives:

1. Determine aboveground net ecosystem productivity and LAI of tallgrass prairie as influenced by atmospheric CO_2 and nitrogen fertilization.

2. Analyze the seasonal growth and phenology of important plant species representing the diversity of functional types present in the community:

3. Determine shifts in dominance of major species and functional groups.

4. Determine the effects of elevated CO_2 on forage digestibility.

5. Determine the influence of CO_2 and nitrogen nutrition on photosynthetic characteristics and water utilization efficiency of 2 or 3 major species in the field and relate these to leaf nitrogen concentration.

6. Determine rates of litter decomposition as well as changes is soil microflora and fauna. (Dr. Silva SDSU)

G. Inputs to Modeling:

1. Validation data:

a. aboveground net primary productivity and biomass production through time. (GEEM)

b. seasonal growth dynamics of dominant species (GEEM and GePSI)

2. Process Rates:

a. Carbon assimilation rates of *A. gerardii* and *Poa pretensis* (GePSI and Leaf Model)

b. Soil respiration rates (GEEM)

c. Rates of litter and root decomposition (GEEM)

d. Growth rates in the field of several dominant species (GEEM and GePSI)

e. Longer term changes in species dominance (GEEM)

3. Parameters and driving variables:

a. Microclimatic data (GEEM and GePSI)

b. Leaf Area Index and canopy structure (GEEM)

c. light penetration through the canopy (GEEM)

d. Chemical composition and digestibility of forage (GEEM and GePSI)

e. Chemical composition of litter (GEEM)

f. Basal cover of dominant species (GEEM)

II. Closed chambers

A. Principal Investigator: Mary Beth Kirkham (KSU)

B. Additional Investigators: E.T. Kanamasu (consultant)

C. Experimental Design: 2 CO_2 levels (360ml/l, 720 ml/l), 2 levels of soil water (field capacity, 1/2 field capacity)

D. Species Studied: Natural tallgrass prairie community

E. Primary Objectives: Determine the response of tallgrass prairie plants to elevated CO_2 and interactions with water availability.

F. Specific Objectives:

1. Determine the effect of elevated CO_2 on soil water content.

2. Determine the effect of elevated CO_2 on the photosynthetic rate, transpiration, stomatal resistance, and intercellular CO_2 concentration of *A. gerardii* and *Poa pretensis*.

3. Determine the effect of elevated CO_2 on plant growth at two levels of water availability.

G. Inputs to Modeling:

1. Validation data:

a. Seasonal soil water content (GEEM)

b. Seasonal growth dynamics of major species as influenced by water availability (GEEM and GePSI)

2. Process Rates:

a. Transpiration rates of *A. gerardii* and *Poa pretensis* (GePSI and GEEM)

b. Diurnal photosynthesis as influenced by water status and CO_2 (leaf model, GePSI, and GEEM)

c. Net ecosystem carbon exchange rates (GEEM)

3. Parameters:

a. Stomatal conductance of *A. gerardii* as influenced by CO_2 and plant water status (leaf model and GePSI)

b. Photosynthetic parameters related to plant water status (leaf model and GePSI)

North Carolina State and Duke University

III. Greenhouse Studies

A. Collaborators: Mary Peet (N C State), Boyd Strain (Duke)

B. Experimental Design: 2 CO_2 levels (ambient, 2 X ambient), 2 Nitrogen levels (ambient, 3X ambient)

C. Species Studied: *A. gerardii* (C4),*P. pratensis* (C3)

D. Primary Objectives: Determine the leaf level responses (C assimilation, respiration, stomatal conductance, etc.) of C4 and C3 prairie species to elevated CO_2 under controlled conditions.

E. Specific Objectives:

1. Develop and parameterize models of C4 and C3 photosynthesis for the dominant graminoids occurring in the ecosystem study at Kansas State.

2. Determine the relationship between leaf nitrogen concentration and photosynthetic parameters for *Andropogon* and *Poa*.

3. Determine the influence of short term water stress on photosynthetic parameters.

F. Inputs to Modeling:

1. Validation data: Patterns of carbon assimilation as influenced by CO_2, water, and nitrogen.

2. Process Rates: Photosynthetic rates as functions of internal CO_2, light, and temperature. Stomatal conductance and transpiration rates.

3. Parameters: Vcmax, Jmax, Rd, CO_2 compensation points, and other photosynthetic model parameters for C4 and C3 grasses.

3.2 Soil biota, decomposition and nutrient cycling in the Konza Prairie: *Joint study between KSU and SERG*

The exact response of whole ecosystems to elevated CO_2 is anticipated to be complex due to interactions between primary, secondary and tertiary effects upon plants, and complex feedbacks (positive and negative) between various components of the ecosystem. For example, evidence suggests that elevated CO_2 will have several direct affects on plants, including: 1) Increased rates of photosynthesis, and therefore, production. This will increase amounts of above- and below-ground litter and soil organic matter, which should lead to increased pool sizes of soil nutrients, but if immobilization is favored, levels of available soil nutrients will decrease, (especially nitrogen), 2) Decreased transpiration rates, which could cause increased levels of soil moisture, 3) Increased internal labile carbohydrate pool size, which should increase the amount of root exudates in soil, and 4) Increased C:N ratio of plant tissues, both from CO_2 fertilization and low soil nitrogen, which combined will cause a decreased in the quality of plant litter. These anticipated changes in the soil environment should cause increases in the pool sizes of soil microflora, nematodes, microarthropods and macroinvertebrates, all of which should interact to cause increased decomposition and mineralization rates. Thus, even though the available level of soil nutrients may be lower in a high CO_2 environment, the overall pool size and turnover rate of soil nutrients may be greater.

Experimental Design

On the tallgrass prairie ten ecosystem chambers have been set up with the following combination of treatments:

1. ambient CO_2, ambient soil nitrogen (3 chambers);

2. ambient CO_2, elevated soil nitrogen (2 chambers);

3. elevated CO_2, ambient soil nitrogen (3 chambers);

4. elevated CO_2, elevated soil nitrogen (2 chambers)

Half of each chamber is grazed, the other half is left ungrazed. We propose to conduct this study using the grazed side of two replicate chambers from each treatment (8 chambers). We propose conducting two types of studies to examine elevated atmospheric CO_2 and increased soil nitrogen effects on soil biota and foliage decomposition.

Year 1: Study soil biota inside each of the 8 chambers

Year 2: Study decomposition outside the chambers, but using the litter from each of the 8 chambers.

Soil Biota Study: First Year

Hypothesis: Soil biota densities will increase with elevated atmospheric CO_2 and with increased soil N from fertilization.

Experimental Design

The experiment will be conducted over two years with 3 sampling times per year (beginning, middle, and end of growing season) as follows:

1. on May 15, when the site is dominated by C_3 grasses (primarily *Poa pratensis)*

2. end of July, when the site is dominated by C_4 perennial grasses (primarily *Andropogon gerardii*)

3. November, after senescence of most biomass

During each sampling time three soil cores (5 cm dia, 15 cm depth) will be taken from each of 8 chambers (4 treatments, 2 replicates). A total of 24 soil samples per sampling time will be used to estimate:

1. Microbial biomass using the fumigation procedure

2. Microarthropods will be extracted using a high gradient technique, counted, identified, and assigned to trophic groups

3. Nematodes will be extracted using a sieving flotation technique, counted, and assigned to trophic groups

4. Amonium and nitrate concentration of soil, KCl extraction

5. Total nitrogen content of the soil

6. Nitrogen mineralization potential by batch incubation method

Impact on other chamber studies

Each chamber is 5 m in diameter (area =19.6 m^2). Half of the chamber will be grazed and the other half will remain ungrazed. The soil biota study will be conducted on the grazed side of each chamber. Each soil core is 5 cm diameter, and has a cross-sectional area of 0.00196 m^2. Eighteen soil cores will be collected over two years, resulting in a total disturbed area of 0.0353 m^2, or 0.44 5% of the grazed side of the chamber.

Litter Quality Study: Year Two

Hypotheses:

1) Litter from plants growing in elevated atmospheric CO_2 will have a lower litter quality (e.g., greater C:N ratio), and therefore lower decomposition rates than litter from plants growing at ambient CO_2.

2) The addition of soil nitrogen by fertilization will eliminate differences between ambient and elevated CO_2 treatment in litter quality and decomposition rate.

Experimental Design

Litter quality study will be done outsisde the chambers. Foliage will be collected from each of the 8 chambers (4 treatments, 2 replicates), at the end of the first year. Litter bags (10 x 10 cm) made of polypropylene with mesh size of 1 mm^2 will be filled with approximately 3 g of air dried litter. A total of 640 litter bags will be made, and taken to the field on October 01, 1990 (time 0). A set of 40 litter bags will be retrieved at that time to provide a regression equation to convert masses to an oven-dry basis and for measurements of initial nitrogen and phosphorus content, and carbon fractions of the foliage. A total of 120 litter bags will be collected at each sampling time. Litter bags will be placed in plastic bags, stored in a portable cooler and transported to the laboratory at San Diego State University for analyses. Fifteen litter bags per treatment (with 2 replicates per treatment) will be collected each sampling time and the following will be estimated:

1. Mass of ash-free organic matter remaining (using 10 bags)

2. Litter nitrogen and phosphorus (composite sample of 5 bags)

3. Litter chemistry at the end of year 1 and 2 (using plant litter remaining from step 2 above), which include: amounts and C:N ratios of the following carbon compartments :

a) solubles,

b) cellulose and hemicellulose, and

c) lignin

The experiment will be conducted over two years with a total of 5 sampling times (6, 9, 12, 18, and 24 months).

Sampling schedule

Litter bags will be placed in the field on November 1, 1990.

Litter bag retrieval dates will be:

1. end of April, 1991 (after 6 month)

2. end of July, 1991 (after 9 months)

3. October, 1991 (after 12 months)

4. end of April, 1992 (after 18 months)

5. October, 1993 (after 24 months)

Summary of Experimental Design

. Experimental design: full factorial

. 5 sampling times

. 4 treatment combinations

. 2 replicates within each treatment

. total of 120 litter bags retrieved per sampling time (15 litter bags x 4 treatments x 2 replicates)