ESSM 622

BIOGEOCHEMISTRY OF TERRESTRIAL ECOSYSTEMS

SPRING SEMESTER - 2020
T-TH 8:00-9:15 AM

INSTRUCTOR:

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BACKGROUND AND PURPOSE:

The biogeochemical cycles of carbon, nitrogen, sulfur, and phosphorus have tremendous contemporary significance due to their critical roles in determining the structure and function of ecosystems, and their influence on atmospheric chemistry and the climate system. Human impacts on these nutrient cycles are now responsible for a multitude of global changes that threaten the sustainability of ecosystem services essential to mankind.

This course provides a framework for understanding the major biogeochemical cycles, their significance at levels of organization ranging from the molecular scale to the globe, and their contemporary relevance to ecosystem science and management. The cycles of carbon, nitrogen, sulfur, and phosphorus are emphasized due to their significance in the earth-atmosphere-biosphere system. Ecosystem-level processes are studied in forest, grassland, and agricultural ecosystems. Because many of our most pressing environmental problems are manifestations of disturbed biogeochemical cycles, this course is fundamental to understanding environmental issues such as global climate change, changes in atmospheric composition, land cover/land use changes, carbon sequestration, nitrogen saturation, acid precipitation, nonpoint-source pollution, and water quality.

This course is relevant to graduate students in ecology, soil science, geosciences, hydrology, atmospheric sciences, agricultural sciences, and environmental engineering. There are no prerequisites other than graduate standing in one of these disciplines.

LEARNING OUTCOMES AND OBJECTIVES:

1) Be able to define the fundamental characteristics and properties shared by all biogeochemical cycles, and establish the relevance of energy flow and the hydrologic cycle to all other nutrient cycles.

2) Be able to document the major properties and processes that characterize the biogeochemical cycles of carbon, nitrogen, sulfur, and phosphorus at ecosystem to global scales.

3) Develop an in-depth knowledge of the key biogeochemical processes that occur at the ecosystem level of organization, and be able to evaluate the role of soil structure, soil biology, and soil biochemistry in those processes.

4) Be able to document how land cover/land use changes in grassland, forest, agricultural, and urban ecosystems alter and interact with major biogeochemical processes.

5) Develop an understanding of the strong interactions between biogeochemical cycles and global changes.

EVALUATION PROCEDURES:

Two exams (100 points each) will be given during the course of the semester. In addition, each student will give approximately brief (10-15 min) oral presentations (50 points each) that summarize and interpret an assigned reading Class participation in discussions of the assigned readings is expected of all students throughout the semester.

COURSE MATERIALS:

Assigned reading:	available on e-Campus (http://ecampus.tamu.edu/)
Class notes:	available on e-Campus (http://ecampus.tamu.edu/)

AMERICANS WITH DISABILITIES ACT (ADA) POLICY STATEMENT:

The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation, please contact Disability Services, currently located in the Disability Services building at the Student Services at White Creek complex on west campus or call 979-845-1637. For additional information visit http://disability.tamu.edu

ACADEMIC INTEGRITY STATEMENT:

"An Aggie does not lie, cheat, or steal or tolerate those who do."

For more information see the Honor Council Rules and Procedures on the web at: http://aggiehonor.tamu.edu

ESSM 622 – BIOGEOCHEMISTRY OF TERRESTRIAL ECOSYSTEMS

SPRING 2020

Jan 14	Tue	Course introduction

A) The Major Biogeochemical Cycles

Jan 16	Thu	Energy flow and the hydrologic cycle in biogeochemistry
Jan 21	Tue	Carbon cycle
Jan 23	Thu	Carbon cycle
Jan 28	Tue	Carbon cycle
Jan 30	Thu	Nitrogen cycle
Feb 4	Tue	Nitrogen cycle
Feb 6	Thu	Sulfur cycle
Feb 11	Tue	Phosphorus cycle
Feb 13	Thu	*Test I*

B) Key Biogeochemical Processes in Ecosystems

Feb 18	Tue	Soil respiration
Feb 20	Thu	Root turnover
Feb 25	Tue	Organic matter decay
Feb 27	Thu	Nitrogen fixation
Mar 3	Tue	Nitrogen transformations
Mar 5	Thu	Phosphorus loss and retention
Mar 10	Tue	*Spring Break*
Mar 12	Thu	*Spring Break*

C) Soil Structure, Biology, and Biochemistry

Mar 17	Tue	Soil physical structure
Mar 19	Thu	Organic matter chemistry
Mar 24	Tue	Dissolved organic matter
Mar 26	Thu	Soil microbial diversity and function
Mar 31	Tue	Mycorrhizae
Apr 2	Thu	Soil enzymes
Apr 7	Tue	Soil animals

D) Land Uses and Biogeochemistry

Apr 9	Thu	Plant species effects, invasive species, vegetation change
Apr 14	Tue	Agricultural lands – tillage and rotation effects
Apr 16	Thu	Rangelands – grazing effects
Apr 21	Tue	Forestlands – management effects

E) Global Changes and Biogeochemistry

Apr 23	Thu	Atmospheric deposition
Apr 28	Tue	Redefined as a Friday – No Class
Apr 29	Wed	Reading Day – No Class
May 1	Fri	*Final Exam, 1-3 PM*

REQUIRED READING
ESSM 622 – BIOGEOCHEMISTRY OF TERRESTRIAL ECOSYSTEMS

(A) THE MAJOR BIOGEOCHEMICAL CYCLES

(1) Thur Jan 16 - Role of Energy Flow and Hydrologic Cycle in Biogeochemistry

a) L'Ecuyer TS, Beaudoing HK, Rodell M, Olson W, Lin B, Kato S, Clayson CA, Wood E, Sheffield J, Adler R, Huffman G, Bosilovich M, Gu G, Robertson F, Houser PR, Chambers D, Famiglietti JS, Fetzer E, Liu WT, Gao X, Schlosser CA, Clark E, Lettenmaier DP, Hilburn K. 2015 The observed state of the energy budget in the early twenty-first century. ***Journal of Climate*** 28: 8319-8346.

b) Lindsey R. 2009. Climate and earth's energy budget. ***NASA Earth Observatory***. http://earthobservatory.nasa.gov/Features/EnergyBalance/

c) Oki T, Kanae S. 2006. Global hydrologic cycles and world water resources. ***Science*** 313: 1068-1072.

d) Abbott BW, Bishop K, Zarnetske JP, Minaudo C, Chapin FS, Krause S, Hannah DM, Conner L, Ellison D, Godsey SE, Plont S, Marcais J, Kolbe T, Huebner A, Frei RJ, Hampton T, Gu S, Buhman M, Sayedi SS, Ursache O, Chapin M, Henderson KD, Pinay G. 2019. Human domination of the global water cycle absent from depictions and perceptions. ***Nature Geoscience*** 12: 533-540.

e) Rodell M, Beaudoing HK, L'Ecuyer TS, Olson WS, Famiglietti JS, Houser PR, Adler R, Bosilovich M, Clayson C, Chambers D, Clark E, Fetzer E, Gao X, Gu G, Hilburn K, Huffman G, Leitenmaier D, Liu W, Robertson F, Schlosser C, Sheffield J, Wood E. 2015. The observed state of the water cycle in the early twenty-first century. ***Journal of Climate*** 28: 8289-8318.

f) IPCC. 2013. Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.)]. pp. 3-29. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

g) USGCRP. 2017. *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles,D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp., doi: 10.7930/J0J964J6.

h) Foley JA, Costa MH, Delire C, Ramankutty N, Snyder P. 2003. Green surprise? How terrestrial ecosystems could affect earth's climate. ***Frontiers in Ecology and the Environment*** 1(1): 38-44.

i) Meir P, Cox P, Grace J. 2006. The influence of terrestrial ecosystems on climate. ***Trends in Ecology and Evolution*** 21(5): 254-260.

(2) Tue Jan 21, Thur Jan 23, and Tue Jan 28 - Carbon Cycle

a) Sabine CL. 2014. Global carbon cycle. In: *eLS*. John Wiley & Sons, Ltd: Chichester, UK. doi: 10.1002/9780470015902.a0003489.pub2

b) Houghton RA. 2014. The contemporary carbon cycle. IN: Karl WD, Schlesinger WH (eds.), *Treatise on Geochemistry* (2nd edition), Vol. 10: Biogeochemistry, pp. 399-435. Elsevier Science, Amsterdam.

c) Friedlingstein P, Jones MW, O'Sullivan M, Andrew RM, Hauck J, Peters GP, Peters W, Pongratz J, Sitch S, Le Quere C, Bakker DCE, Canadell JG, Ciais P, Jackson RB, et al. 2019. Global carbon budget 2019. ***Earth System Science Data*** 11: 1783-1838.

d) USGCRP. 2018. *Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report* [Cavallaro, N., G. Shrestha, R. Birdsey, M. A. Mayes, R. G. Najjar, S. C. Reed, P. Romero-Lankao, and Z. Zhu (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 878 pp., https://doi.org/10.7930/SOCCR2.2018.

(3) Thu Jan 30 and Tue Feb 4 - Nitrogen Cycle

a) Galloway JN. 2014. The global nitrogen cycle. IN: Karl WD, Schlesinger WH (eds.) *Treatise on Geochemistry* (2nd edition), Vol. 10: Biogeochemistry, pp. 475-498. Elsevier Science, Amsterdam.

b) Fowler D, Coyle M, Skiba U, Sutton M, Cape J, Reis S, Sheppard L, Jenkins A, Grizzeti B, Galloway J, Vitousek P, Leach A, Bouwman A, Butterbach-Bahl K, Dentener F, Stevenson D, Amann M, Voss M. 2013 The global nitrogen cycle in the twenty-first century. ***Philosophical Transactions of the Royal Society*** B 368: 20130164. http://dx.doi.org/10.1098/rstb.2013.0164

c) Robertson GP, Groffman PM. 2015. Nitrogen transformations: IN: Paul EA (ed), *Soil Microbiology, Biochemistry, and Ecology*, pp. 421-446. Academic Press, New York.

d) Holtgrieve GW, Schindler DE, Hobbs WO, Leavitt PR, Ward EJ, Bunting L, Chen G, Finney BP, Gregory-Eaves I, Holmgren S, Lisac MJ, Lisi PJ, Nydick K, Rogers LA, Saros JE, Selbie DT, Shapley MD, Walsh PB, Wolfe AP. 2011. A coherent signature of anthropogenic nitrogen deposition to remote watersheds of the northern hemisphere. ***Science*** 334: 1545-1548. (together with commentary: Elser JJ. 2011. A world awash with nitrogen. ***Science*** 334: 1504-1505).

e) Zhang L, Jacob DJ, Knipping EM, Kumar N, Munger JW, Carouge CC, van Donkelaar A, Wang YW, Chen D. 2012. Nitrogen deposition to the United States: Distribution, sources, and processes. ***Atmospheric Chemistry and Physics*** 12: 4539-4554.

(4) Thu Feb 6 - Sulfur Cycle

a) Brimblecombe P. 2014. The global sulfur cycle. IN: Karl D, Schlesinger WH (ed), *Treatise on Geochemistry* (2nd edition), Vol. 10 (Biogeochemistry), pp. 645-682. Elsevier Science, Amsterdam.

b) Paul EA, Clark FE. 1996. Sulfur transformations in soil. IN: *Soil Microbiology and Biochemistry* (EA Paul and FE Clark), pp. 299-313. Academic Press, NY.

c) Iizuka Y, Uemura R, Motoyama H, Suzuki T, Miyake T, Hirabayashi M, Hondoh T. 2012. Sulphate-climate coupling over the past 300,000 years in inland Antarctica. ***Nature*** 490: 81-84.

(5) Tue Feb 11 - Phosphorus Cycle

a) Smil V. 2000. Phosphorus in the environment: Natural flows and human interferences. ***Annual Review of Energy and the Environment*** 25: 53-88.

b) Paul EA, Clark FE. 1996. Phosphorus transformations. IN: *Soil Microbiology and Biochemistry* (EA Paul and FE Clark), pp. 289-298. Academic Press, NY.

c) Gilbert N. 2009. The disappearing nutrient. ***Nature*** 461: 716-718.

d) Elser J, Bennett E. 2011. A broken biogeochemical cycle. ***Nature*** 478: 29-31.

e) Obersteiner M, Penuelas J, Ciais P, van der Velde M, Janssens I. 2013. The phosphorus trilemma. ***Nature Geoscience*** 6: 897-898.

Thu Feb 13 – Test I

(B) KEY BIOGEOCHEMICAL PROCESSES IN ECOSYSTEMS

(1) Tue Feb 18 - Soil Respiration

a) Hogberg P, Read DJ. 2006. Towards a more plant physiological perspective on soil ecology. ***Trends in Ecology and Evolution*** 21(10): 548-554.

b) Gibson CM, Estop-Aragones C, Flanigan M, Thompson DK, Olefeldt D. 2019. Increased deep soil respiration detected despite reduced overall respiration in permafrost peat plateaus following wildfire. ***Environmental Research Letters*** 14: 125001, doi.org/10.1088/1748-9326/ab4f8d

(2) Thu Feb 20 - Root Production and Turnover

a) Rasse D, Rumpel C, Dignac MF. 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilization. ***Plant and Soil*** 269: 341-356.

b) Keiluweit M, Bougoure J, Nico P, Pett-Ridge J, Weber P, Kleber M. 2015. Mineral protection of soil carbon counteracted by root exudates. ***Nature Climate Change*** 5: 588-595.

(3) Tue Feb 25 - Organic Matter Stabilization and Decay

a) Jackson RB, Lajtha K, Crow SE, Hugelius G, Kramer MG, Pineiro G. 2017. The ecology of soil carbon: Pools, vulnerabilities, and biotic and abiotic controls. ***Annual Review of Ecology, Evolution, and Systematics*** 48: 419-445.

b) Lehmann J, Kleber M. 2015. The contentious nature of soil organic matter. ***Nature*** 528: 60-68.

(4) Thu Feb 27 - Nitrogen Fixation

a) Vitousek PM, Menge DNL, Reed SC, Cleveland CC. 2013. Biological nitrogen fixation: rates, patterns and ecological controls in terrestrial ecosystems. ***Philosophical Transactions of the Royal Society*** B 368: 20130119. http://dx.doi.org/10.1098/rstb.2013.0119

b) Soper FM, Boutton TW, Sparks JP. 2015. Investigating patterns of symbiotic nitrogen fixation during vegetation change from grassland to woodland using fine scale $\delta^{15}N$ measurements. ***Plant, Cell, and Environment*** 38: 89-100.

(5) Tue Mar 3 - Nitrogen Transformations

a) Schimel JP, Bennett J. 2004. Nitrogen mineralization: Challenges of a changing paradigm. ***Ecology*** 85(3): 591-602.

b) Soper FM, Boutton TW, Groffman PM, Sparks JP. 2016. Nitrogen trace gas fluxes from a semi-arid subtropical savanna under woody legume encroachment. ***Global Biogeochemical Cycles*** 30: 614-628.

(6) Thu Mar 5 - Phosphorus Transformations and Storage

a) Vitousek PM, Porder S, Houlton B, Chadwick OA. 2010. Terrestrial phosphorus limitation: Mechanisms, implications, and nitrogen-phosphorus interactions. ***Ecological Applications*** 20(1): 5-15.

b) Zhou Y, Boutton TW, Wu XB. 2018. Woody plant encroachment amplifies spatial heterogeneity of soil phosphorus to considerable depth. ***Ecology*** 99: 136-147.

Tue **Mar 10** ***Spring Break***

Thur **Mar 12** ***Spring Break***

(C) SOIL STRUCTURE, BIOLOGY, AND BIOCHEMISTRY

(1) Tue Mar 17 - Soil Physical Structure

a) Liao JD, Boutton TW, Jastrow JD. 2006. Organic matter turnover in soil physical fractions following woody plant invasion of grassland: Evidence from natural ^{13}C and ^{15}N. ***Soil Biology and Biochemistry*** 38: 3197-3210.

b) Lavallee JM, Soong JL, Cotrufo MF. 2020. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. ***Global Change Biology*** 26: 261-273.

(2) Thu Mar 19 - Organic Matter Chemistry

a) Angst G, John S, Mueller CW, Kogel-Knabner I, Rethemeyer J. 2016. Tracing the sources and spatial distribution of organic carbon in subsoils using a multi-biomarker approach. ***Scientific Reports*** 6: 29478, doi: 10.1038/srep29478.

b) van der Voort TS, Zell CI, Hagedorn F, Feng X, McIntyre CP, Haghipour N, Graf Pannatier E, Eglinton TI. 2017. Diverse soil carbon dynamics expressed at the molecular level. ***Geophysical Research Letters*** 44: 11840–11850.

(3) Tue Mar 24 - Dissolved Organic Matter

a) van Hees P, Jones DL, Finlay R, Godbold DL, Lundstrom US. 2005. The carbon we do not see – the impact of low molecular weight compounds on carbon dynamics and soil respiration in forest soils: a review. ***Soil Biology and Biochemistry*** 37: 1-13.

b) Roth VN, Lange M, Simon C, Hertkorn N, Bucher S, Goodall T, Griffiths RI, Mellado-Vazquez PG, Mommer L, Oram NJ, Weigelt A, Dittmar T, Gleixner G. 2019. Persistence of dissolved organic matter explained by molecular changes during its passage through soil. ***Nature Geoscience*** 12: 755-761.

(4) Thu Mar 26 - Soil Microbial Diversity and Function

a) Prosser JI. 2015. Dispersing misconceptions and identifying opportunities for the use of "omics" in soil microbial ecology. ***Nature Reviews: Microbiology*** 13: 439-446.

b) Zhalnina K, Louie KB, Hao Z, Mansoori N, Nunes da Rocha U, Shi S, Cho H, Karaoz U, Loque D, Bowen BP, Firestone MK, Northern T, Brodie EL. 2018. Dynamic root exudate chemistry and microbial substrate preferences drive patterns in rhizosphere microbial community assembly. ***Nature Microbiology*** 3: 470-480.

(5) Tue Mar 31 - Mycorrhizae

a) Walder F, van der Heijden MGA. 2015. Regulation of resource exchange in the arbuscular mycorrhizal symbiosis. ***Nature Plants*** 1: doi:10.1038/nplants. 2015.159.

b) Zhang Z, Phillips RP, Zhao W, Yuan Y, Liu Q, Yin H. 2019. Mycelia-derived C contributes more to nitrogen cycling than root-derived C in ectomycorrhizal alpine forests. ***Functional Ecology*** 33: 346–359.

(6) Thu Apr 2 - Soil Enzymes

a) Burns RG, DeForest JL, Marxsen J, Sinsabaugh RL, Stromberger ME, Wallenstein MD, Weintraub MN, Zoppini A. 2013. Soil enzymes in a changing environment: Current knowledge and future directions. ***Soil Biology and Biochemistry*** 58: 216-234.

b) Schnecker J, Wild B, Takriti M, Eloy Alves RJ, Gentsch N, Gittel A, Hofer A, Klaus K, Knoltsch A, Lashchinskiy N, Mikutta R, Richter A. 2015. Microbial community composition shapes enzyme patterns in topsoil and subsoil horizons along a latitudinal transect in Western Siberia. ***Soil Biology and Biochemistry*** 83: 106-115.

(7) Tue Apr 7 - Soil Animals

a) Crowther TW, Stanton DWG, Thomas SM, A'Bear AD, Hiscox J, Jones TH, Voriskova J, Baldrian P, Boddy L. 2013. Top-down control of soil fungal community composition by a globally distributed keystone consumer. ***Ecology*** 94: 2518-2528.

b) Pollierer MM, Larsen T, Potapov A, Bruckner A, Heethoff M, Dyckmans J, Scheu S. 2019. Compound-specific isotope analysis of amino acids as a new tool to uncover trophic chains in soil food webs. ***Ecological Monographs*** 89(4): e01384. 10.1002/ecm.1384

(D) LAND USES AND BIOGEOCHEMISTRY

(1) Thu Apr 9 - Plant Species Effects, Invasive Species, Vegetation Change

a) Fanin N, Kardol P, Farrell M, Kempel A, Ciobanu M, Nilsson MC, Gundale MJ, Wardle DA. 2019. Effects of plant functional group removal on structure and function of soil communities across contrasting ecosystems. ***Ecology Letters*** 22: 1095-1103.

b) Gould IJ, Quinton JN, Weigelt A, De Dyn GB, Bardgett RD. 2016. Plant diversity and root traits benefit physical properties key to soil function in grasslands. ***Ecology Letters*** 19: 1140-1149.

(2) Tue Apr 14 - Agricultural Lands: Management Effects

a) Sebilo M, Mayer B, Nicolardot B, Pinay G, Mariotti A. 2013. Long-term fate of nitrate fertilizer in agricultural soils. ***Proceedings of the National Academy of Sciences*** 110: 18185-18189.

b) Barel JM, Kuyper TW, Paul J, de Boer W, Cornelissen JHC, De Deyn GB. 2019. Winter cover crop legacy effects on litter decomposition act through litter quality and microbial community changes. ***Journal of Applied Ecology*** 56: 132-143.

(3) Thu Apr 16 – Rangelands: Grazing and Woody Encroachment Effects

a) Wilson CW, Strickland MS, Hutchings JA, Bianchi TS, Flory SL. 2018. Grazing enhances belowground carbon allocation, microbial biomass, and soil carbon in a subtropical grassland. ***Global Change Biology*** 24: 2997-3009.

b) Zhou Y, Boutton TW, Wu XB. 2018. Soil phosphorus does not keep pace with soil carbon and nitrogen accumulation following woody plant encroachment. ***Global Change Biology*** 24: 1992-2007.

(4) Tue Apr 21 – Forests and Forest Management

a) Bowd EJ, Banks SC, Strong CL, Lindenmayer DB. 2019. Long-term impacts of wildfire and logging on forest soils. ***Nature Geoscience*** 12: 113-118.

b) Mushinski RM, Gentry TJ, Dorosky RJ, Boutton TW. 2017. Forest harvest intensity and soil depth alter inorganic nitrogen pool sizes and ammonia oxidizer community composition. ***Soil Biology and Biochemistry*** 112: 216-227.

(E) GLOBAL CHANGES AND BIOGEOCHEMISTRY

(1) Thu April 23 – Some Global Change Impacts on C and N Cycles

a) Magnani F, Mencuccini M, Borghetti M, Berbigier P, Berninger F, Delzon S, Grelle A, Hari P, Jarvis P, Kolari P, Kowalski A, Lankreijer H, Law B, Lindroth A, Loustau D, Manca G, Moncrieff J, Rayment M, Tedeschi V, Valentini R, Grace J. 2007. The human footprint in the carbon cycle of temperate and boreal forests. ***Nature*** 447: 848-852. (*together with associated commentaries*)

b) Bowman WD, Ayyad A, Bueno de Mesquita CP, Fierer N, Potter TS, Sternagel S. 2018. Limited ecosystem recovery from simulated chronic nitrogen deposition. ***Ecological Applications*** 28: 1762-1772.

FRI MAY 1 FINAL EXAM (1:00 - 3:00 PM)