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Climate regulation ecosystem services of biofuels: a new paired flux tower study comparing loblolly pines and switchgrass ecosystems

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Abstract

Land-conversion for biofuel use is a globally widespread land-use transition and is an explicit component of future scenarios developed to address climate change. Biofuels create climate benefits by potentially providing a fuel source that does not require burning fossil fuels. However, land conversion for biofuels can also alter the climate directly by modifying ecosystems' capacity to transfer energy to the atmosphere. Ideally, these modifications to the energy balance enhance the climate benefits associated with reducing CO_2 in the atmosphere. But the modifications to energy balance could counteract the benefits of CO_2 uptake, especially if the biofuel ecosystem is darker, thus reflecting less energy, than the ecosystem prior to biofuel establishment. To address the need for observations that quantify the net influence of land management for biofuels on climate, we established a new paired flux tower study (Sweet Briar Land-Atmosphere Research Station) that compares the carbon and energy balance between a managed loblolly pine forest and switchgrass field in Central Virginia, USA. Here we present the first year of observations from the paired sites. Our preliminary analysis indicates that the lower albedo of the pine compared to the switchgrass results in increased net radiation. This increased net radiation in pine is dissipated through elevated sensible and latent heat fluxes. The ratio of sensible to latent heat fluxes was higher in the switchgrass than the pine. Net ecosystem exchange of carbon dioxide over the first growing season was higher for the pine than the switchgrass. These data, combined with land-surface modeling, aim to help inform our understanding of how decisions to establish specific ecosystem types for supplying biofuel feedstocks influence local, regional, and global climate.

Key questions to be addressed at new flux site

1) How does albedo and energy partitioning differ between a managed loblolly pine stand and a managed switchgrass field in a region with temperate climate?
2) How does carbon uptake and storage differ between these two ecosystems?
3) When integrating both the energy balance and carbon storage, which ecosystem provides the greatest climate regulation service? How does the difference in climate regulation service change when the harvest products are used as a biofuel?

Site location and instrumentation

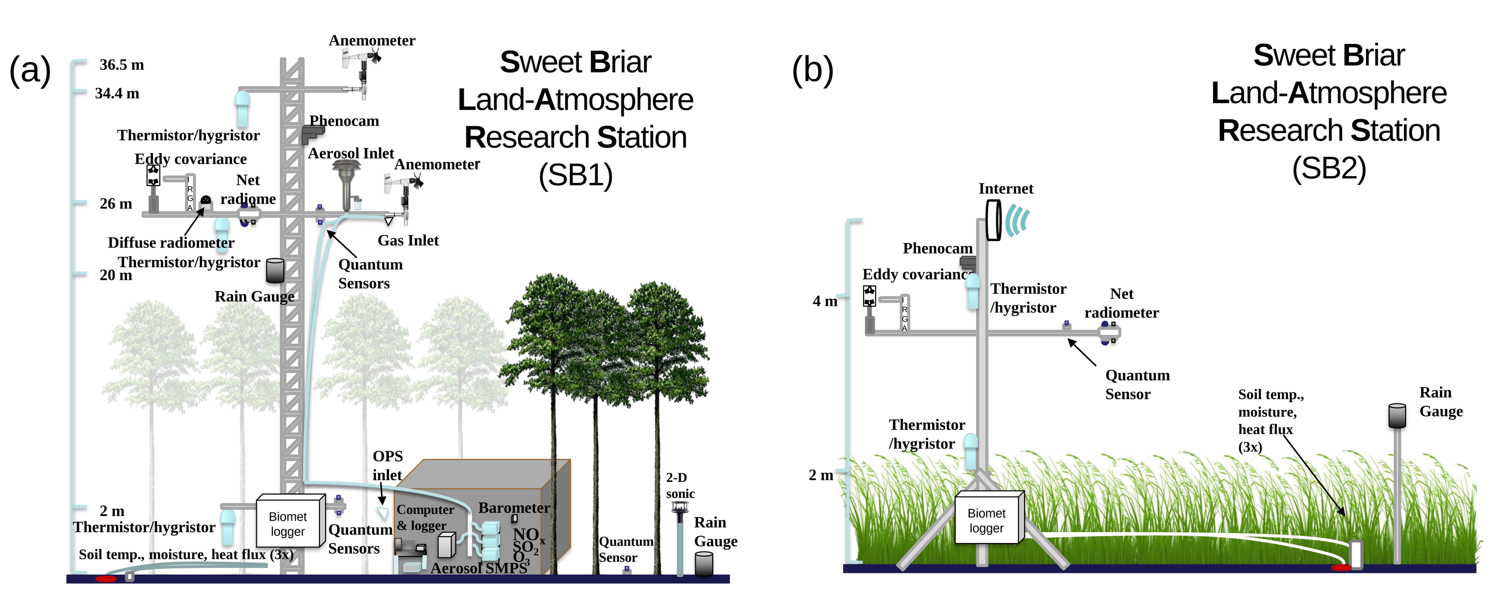

Figure 1. Schematic of the instrumentation at the (a) loblolly pine and (b) switchgrass eddy covariance towers.

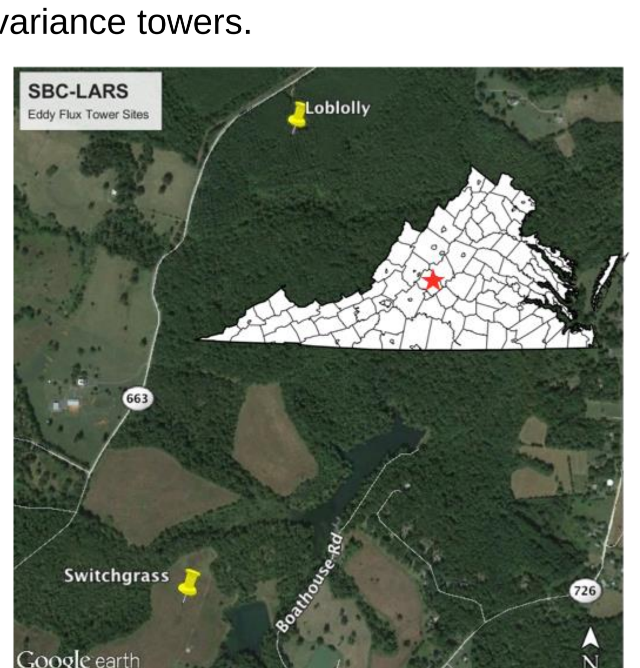

Figure 2. Location of two eddy covariance sites. The two sites are 1.5 km apart.

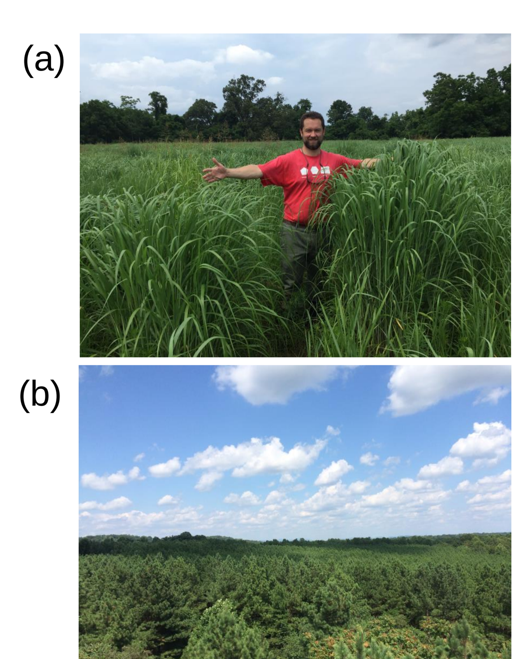

Figure 3. Photographs of the (a) switchgrass and (b) loblolly canopies during the growing season

Site Characterization

Table 1. Characteristics of the two sites with eddy covariance measurements

Shared site characteristics		
Climate Koeppen	Cfa (Humid Subtropical: mild with no dry season, hot summer)	
Mean annual temperature	12.7 °C	
Mean annual precipitation	1016 mm	
Soils (SSURGO mapping)	Physiographic province: Piedmont Typic Kanhaplults (fine sandy loam)/Paleudults (loam) Well drained, parent material is residual felsic crystalline rock	
Annual days of snow cover	17 days per year (mean 2014-2016)	
Key differences between the two sites		
	Loblolly Pine (*Pinus taeda*) (US-SB1)	Switchgrass (*Panicum virgatum*) (US-SB2)
Vegetation IGBP	ENF (Evergreen Needleleaf Forests)	CRO (Croplands)
Canopy Height	21 m	2 m
Aboveground carbon	269 Mg C ha^{-1}	Clipped Plots: 4.3 Mg C ha^{-1} Bailed: 1.5 Mg C ha^{-1}
Peak leaf area index	4.4 m^2 m^{-2}	2.0 m^2 m^{-2}
Land-use history	Small land-owner forest management, multiple ages in footprint (1981, 1988, 1995, and 1999 establishment years)	Switchgrass established in 2013. Prior land-use was a grass field used for hay production
Albedo (summer)	0.10	0.18
Energy balance closure (30 min. Rn + G vs. LE + H)	Slope: 0.79 R^2: 0.87	Slope: 0.93 R^2: 0.92

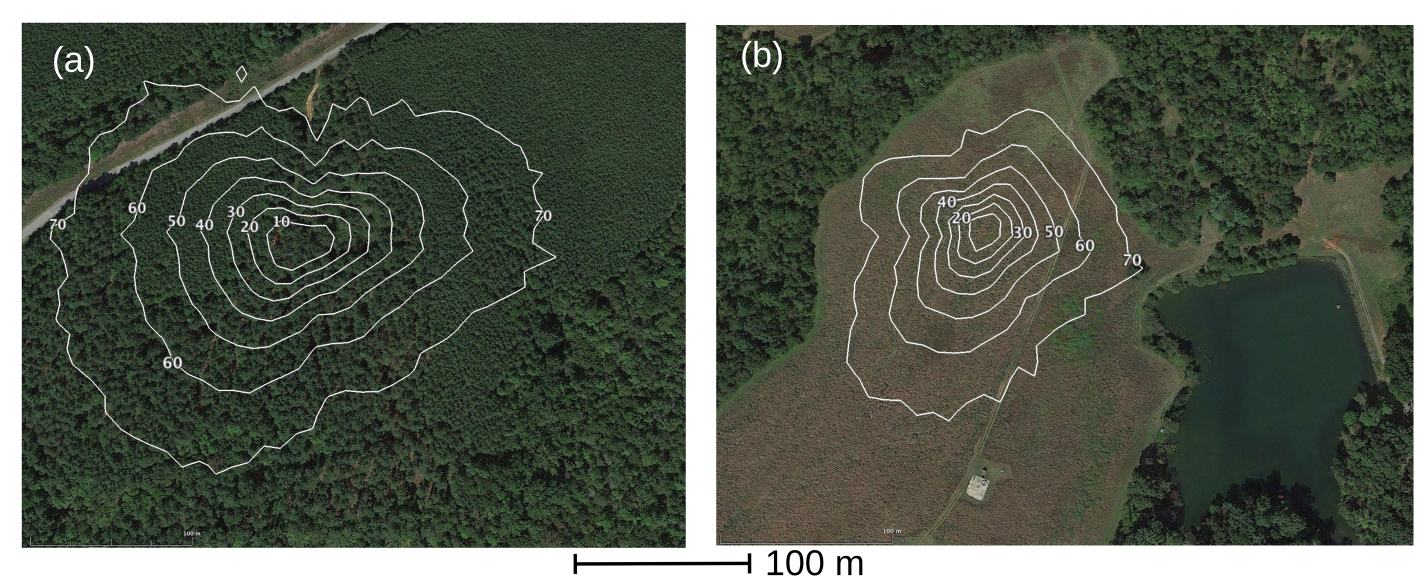

Figure 4. An estimation of the tower footprints at the (a) loblolly pine and (b) switchgrass sites. The 10 to 70% contours for the flux contribution are shown based the method in Schuepp *et al.* 1990, *Boundary-Layer Meteorology*

Results from 1st year

Higher albedo and Bowen ratio in switchgrass than loblolly pine

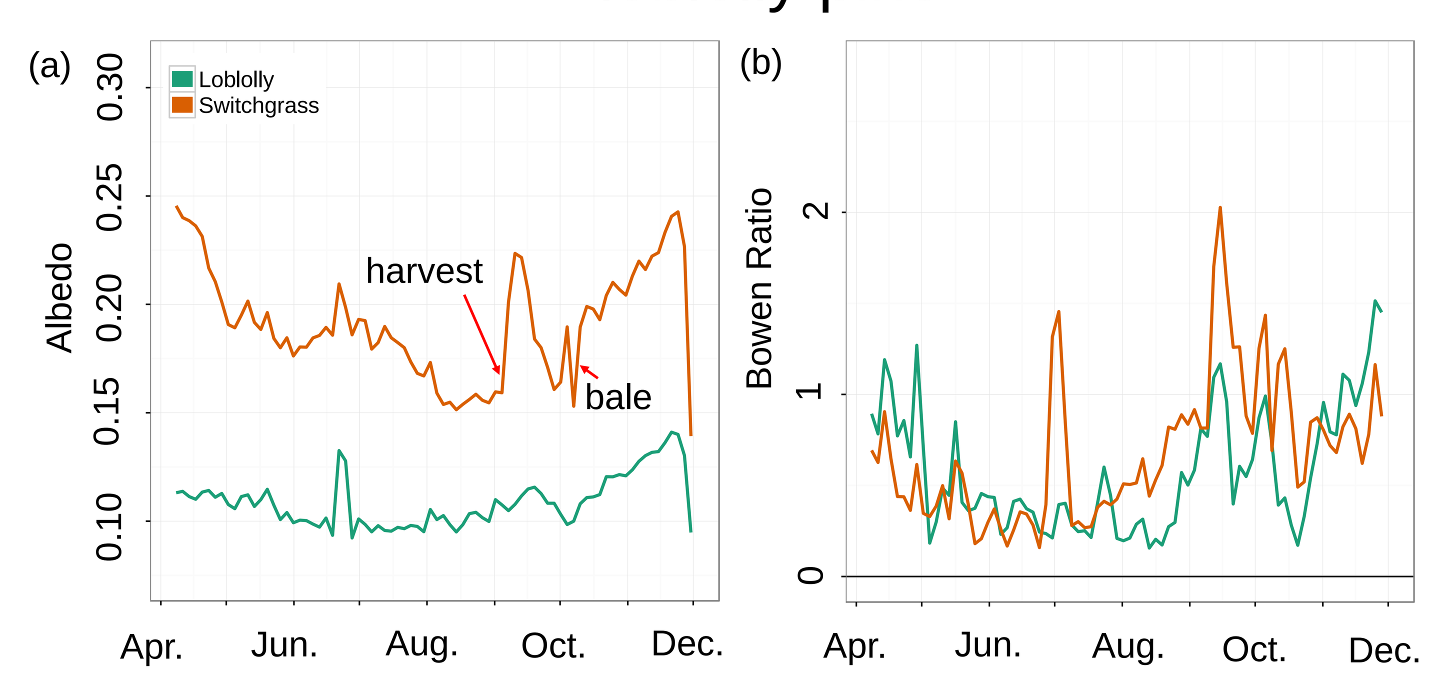

Figure 5. (a) Albedo and (b) Bowen ratio at the the loblolly pine and switchgrass sites. Albedo are the mid-day values. The latent heat and sensible heat fluxes used to calculate the Bowen ratios were filtered for data quality.

Results from 1st year, cont.

Similar summer NEP but greater respiration from switchgrass in fall

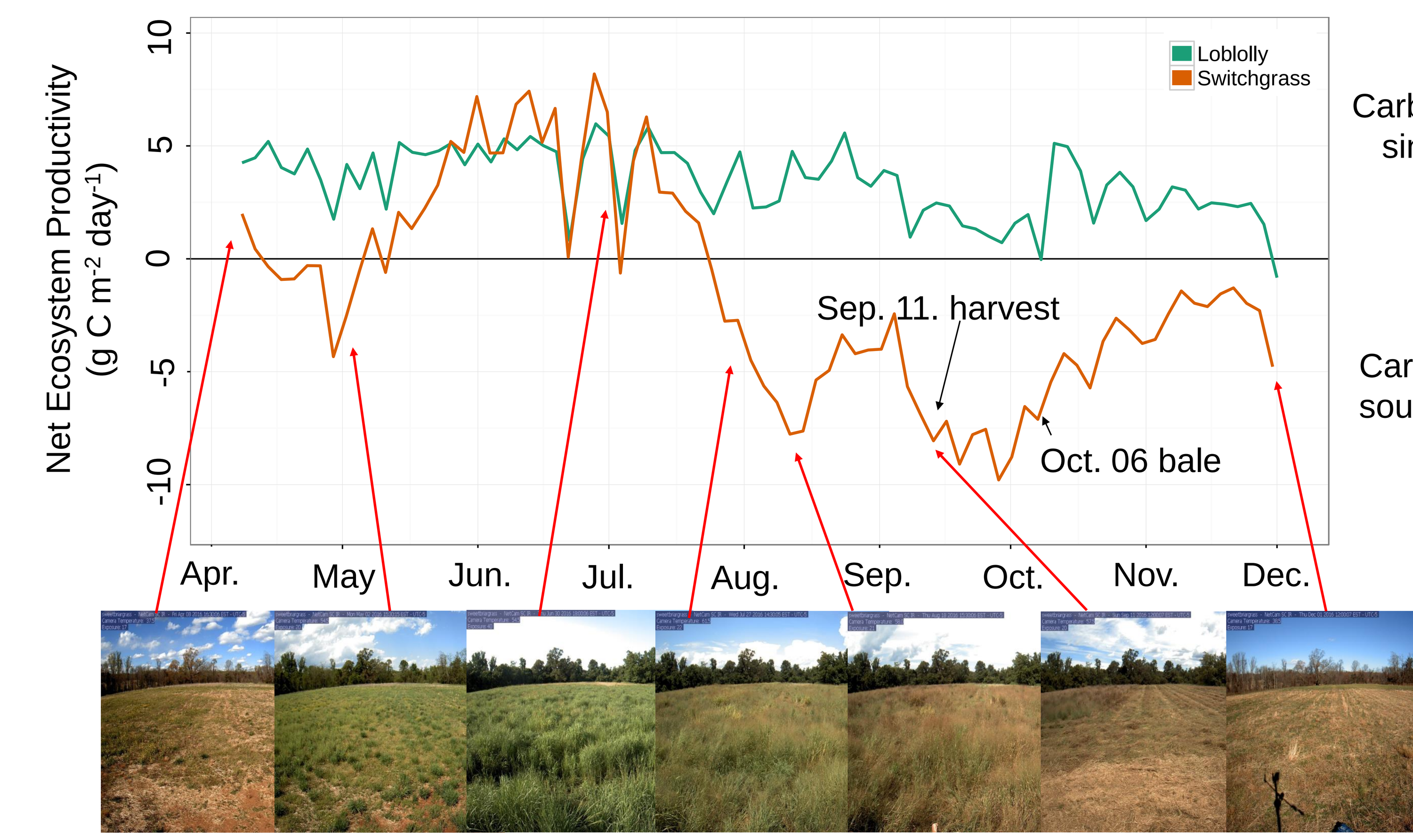

Figure 6. Net ecosystem productivity (NEP) from April 8 to December 1, 2016. Gap filled observations are shown. Images from the switchgrass Phenocam are shown to highlight how the NEP varies with phenology and harvest. A loess local regression was used to smooth daily NEP values.

Cumulative carbon fluxes show greater difference between sites than annual water fluxes

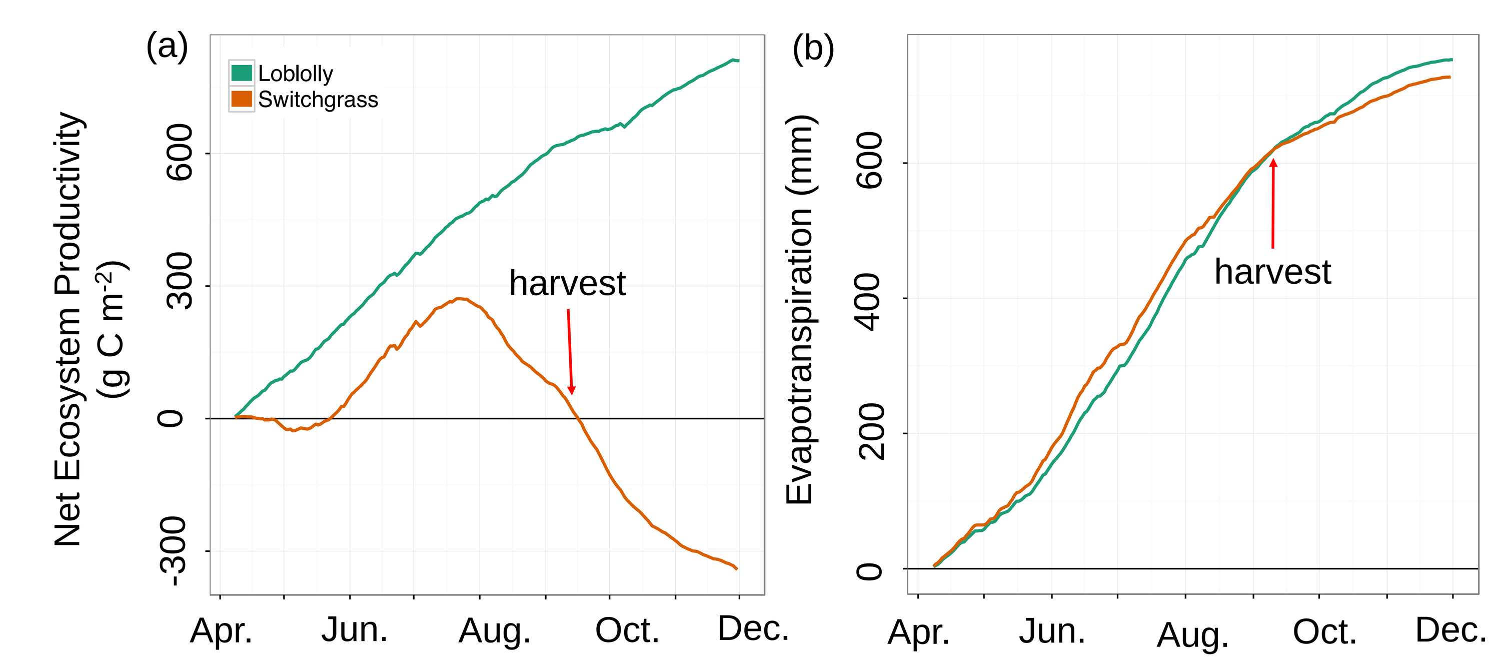

Figure 7. Cumulative sums of (a) net ecosystem productivity and (b) evapotranspiration at the two sites between April 8 and December 1, 2016. Gap-filled observations were used to calculate the sums.

Future work

1) Analyze how energy fluxes in the two ecosystems influence surface and atmospheric temperature using meteorology measurements and the Community Land Model.
2) Partition gross ecosystem production and ecosystem respiration to evaluate how respiration dynamics associated with harvesting and phenology in the switchgrass influence cumulative NEP.
3) Use future measurements and modeling to integrate NEP in each ecosystem over the length of the loblolly pine harvest cycle (~25 years) to evaluate how they differ in carbon storage.

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