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Examining the short-term impacts of diverse management practices on plant phenology and carbon fluxes of Old World bluestems pasture

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ABSTRACT

Burning, grazing, and baling (hay harvesting) are common management practices in grassland. To develop and adopt sustainable management practices, it is essential to better understand and quantify the impacts of management practices on plant phenology and carbon fluxes. In this study, we combined multiple data sources, including *in-situ* PhenoCam digital images, eddy covariance data, and satellite data (Landsat and Moderate Resolution Imaging Spectroradiometer (MODIS)) to examine the impacts of burning, baling, and grazing on canopy dynamics, plant phenology, and carbon fluxes in a pasture in El Reno, Oklahoma in 2014. Landsat images were used to assess the baling area and the trajectory of vegetation recovery. MODIS vegetation indices (VIs) were used in the Vegetation Photosynthesis Model (VPM) to estimate gross primary production (GPP_{VPM}) at a MODIS pixel for the flux tower (baled) site. For comparison between baled and unbaled conditions, we used MODIS VIs for a neighbor MODIS pixel (unbaled) and ran VPM. Daily PhenoCam images and green chromatic coordinate (GCC) tracked canopy dynamics and plant phenology well. The grassland greened up immediately after burning in April. GCC values showed two peaks with the similar magnitude because of quick recovery of grassland after baling. Satellite-derived VIs and GPP_{VPM} showed that the pasture recovered in one month after baling. The GPP_{VPM} matched well ($R^2 = 0.89$) with the eddy covariance-derived GPP (GPP_{EC}). Grazing in the late growing season did not influence plant phenology (VIs and GCC) and carbon uptake (GPP) as plants were in the late growing stage. Neither did it affect GPP differently in those two conditions because of even grazing intensity. The reduction in GPP after baling was compensated by higher GPP after large rain events in late July and early September, causing little seasonal differences in GPP (-0.002 $g\,C\,m^{-2}\,day^{-1}$) between the baled and unbaled conditions. Interactions of different management practices with climate make it complicated to understand the impacts of different management practices on carbon dynamics and plant phenology. Thus, it is necessary to further investigate the responses of pastures to different management practices under different climate regimes at multiple temporal and spatial scales.

1. Introduction

Grassland (both native prairie and planted/introduced pasture) is a major forage source for millions of beef cattle in the Great Plains of the United States. Management practices in pasture are diverse (e.g., burning, grazing, baling, fertilizing), complex (e.g., mixture of management practices such as grazing and baling, different duration and timing), and can vary over space and time. Prescribed burning is a recommended management practice to

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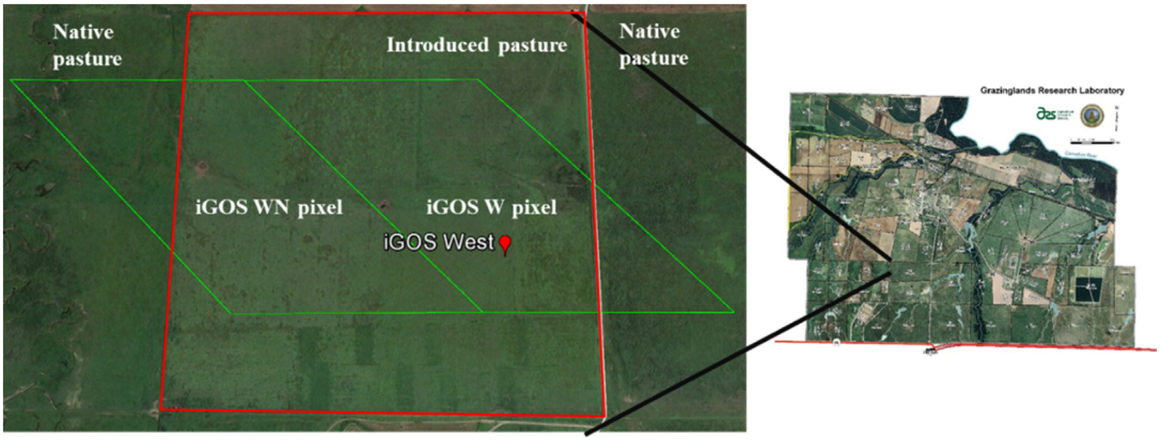

Fig. 1. Location of flux tower site and overlapping with MODIS pixels. Location of the flux tower site is marked as red point and labeled. Red rectangle is the boundary of the study field. Green diamonds are boundaries of MODIS pixels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

recycle plant nutrients, remove senesced vegetation, and to control weeds and inhibit woody species encroachment (Brockway et al., 2002; Reinhart et al., 2016; Twidwell et al., 2013; Valkó et al., 2014). Grazing and baling remove aboveground biomass and reduce canopy coverage and vegetation photosynthesis. The effects of grazing on carbon fluxes (e.g., gross primary production, GPP) vary under different ecological conditions and grazing intensity (Rogiers et al., 2005). Field experiments that mechanically clip vegetation to mimic hay or biofuel feedstock harvest, showed that grassland ecosystems may not be a sink of carbon depending on the amount of biomass removal (Luo et al., 2009; Niu et al., 2013; Wagle and Kakani 2014). These management practices can have multiple impacts on vegetation canopy, phenology, and carbon dynamics (Campioli et al., 2015; Wilson et al., 2013). Thus, it is a challenging task to track those management practices and assess their impacts on pasture as well as beef cattle production.

A number of tools are available to study the impacts of management practices on vegetation phenology and carbon fluxes of grasslands, including *in-situ* digital cameras (PhenoCam), eddy covariance (EC) measurements, and satellite remote sensing. PhenoCam takes multiple digital photography in a day and provides “near surface” observations of plant phenology with high temporal resolution (Migliavacca et al., 2011; Richardson et al., 2009). Satellite remote sensing acquires consistent and periodic observations of the land surface to track vegetation phenology (Zhang et al., 2003). Vegetation indices (VIs) derived from satellite images are also used in production efficiency models to estimate gross and net primary production of vegetation (Potter et al., 1993; Running et al., 2004; Sims et al., 2008; Wu et al., 2010; Xiao et al., 2004a; Xiao et al., 2004b; Yuan et al., 2007). Because of the higher temporal resolution (8-day), the Moderate Resolution Imaging Spectroradiometer (MODIS) is used more often in GPP modeling than Landsat which has a higher spatial resolution (30 m) but lower temporal resolution (16-day). EC observations reflect effects of land use and management on the exchange of carbon dioxide, water vapor, and energy fluxes (Chi et al., 2016; Fischer et al., 2012; Owensby et al., 2006; Suyker et al., 2003). As the footprint of eddy flux tower is often comparable with the spatial resolution of the MODIS surface reflectance products, EC-derived GPP (GPP_{EC}) are widely used to evaluate modeled GPP using MODIS data (Dong et al., 2015; Jin et al., 2013; Sims et al., 2008; Wagle et al., 2014; Wu et al., 2010; Yuan et al., 2007).

Although field experiments help to examine the effects of management practices on carbon dynamics (Luo et al., 2009; Niu et al., 2013; Wagle and Kakani 2014), the influence of management practices on canopy scale carbon dynamics is not well understood, necessitating the integration of EC and remote sensing observations to study the effects of grazing, baling, or other management practices on canopy and carbon dynamics. Ideally, paired towers are needed in both the control and manipulated (e.g., unbaled and baled) area for the comparison. However, the high construction cost and logistical requirements of EC systems prohibit the utilization of paired towers in most cases (Chi et al., 2016; Fischer et al., 2012). Alternatively, modeling approaches can be used. Remote sensing-based production efficiency models estimate GPP as the product of the absorbed photosynthetically active radiation (APAR) and light use efficiency (LUE, ϵg) (Potter et al., 1993; Running et al., 2004; Xiao et al., 2004a; Xiao et al., 2004b; Yuan et al., 2007). Most of these models use VIs and meteorological parameters as inputs. In the case of a single eddy flux tower site with disturbances or management practices, VIs of the nearby undisturbed area of similar vegetation cover, can be combined with the meteorological parameters of the flux tower site to simulate GPP for the undisturbed condition. By comparing the two scenarios (e.g., baled and unbaled), we can show the effects of management practices or disturbances on GPP.

The objective of this study is to examine the impacts of burning, baling, and grazing on canopy and carbon fluxes in a pasture through integrating PhenoCam images, satellite remote sensing, and eddy covariance data. In addition, the impacts of management practices (e.g., baling and grazing) on GPP were investigated using the satellite-based vegetation photosynthesis model (VPM) for disturbed and undisturbed conditions. This case study, using multiple observation techniques to detect the impacts of diverse management practices, can serve as an example of utilizing different data sources to better understand the impacts of management practices on vegetation phenology and carbon fluxes.

2. Materials and methods

2.1. Study site description

The study site (Fig. 1) is located at the United States Department of Agriculture—Agricultural Research Service (USDA-ARS) Grazinglands Research Laboratory (GRL) in El Reno, Oklahoma (35.54679°N, 98.04529°W, 435 m above sea level). The field (red rectangle in Fig. 1) is an introduced warm-season, pasture which was planted with old world bluestem (*Bothriochloa caucasica* C. E. Hubb.) (Samuel and Forbes 1998). The pasture’s soil is classified as Norge silt loam (Fine-silty, mixed, active, thermic Udic Paleustolls) (Staff 1999) with a depth greater than 1 m and high water holding capacity (Fischer et al., 2012).