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Energy, water and carbon exchange over a perennial Kernza wheatgrass crop

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ABSTRACT

The ecological impacts resulting from global warming and conventional agricultural practices are predicted to affect crop productivity and reduce the land area available for agriculture in the near future. Perennial crops can sustain high yields without replanting for numerous consecutive years, resulting in important climate benefits. At this time, the coupling between these ecosystems and the atmosphere is not well understood. The objective of this study was to examine the magnitude and temporal variability of the surface energy, water and carbon exchanges in a perennial Kernza wheatgrass crop in Salina, north-central region of Kansas (KS), USA. The study period comprised approximately 4.5 years (May 2012-October 2016) of eddy covariance observations collected at the US-KLS AmeriFlux tower established in April 2012. We analyzed the temporal dynamics of the fluxes of radiation, water and carbon in the perennial wheatgrass crop during five growing seasons. The results obtained here demonstrated the ability of the perennial Kernza in maintaining a relatively high water-use efficiency throughout the whole growing season and its highest evapotranspiration and net carbon uptake rates, particularly when compared to annual counterparts. These findings are important in order to better understand the coupling between the hydrologic and carbon cycles in these novel agroecosystems as well as to understand the benefits and disadvantages in relation to annual crops.

1. Introduction

The ecological impacts resulting from global warming and conventional agricultural practices, such as irrigation and the use of chemical herbicides, are predicted to affect crop productivity and reduce the land area available for agriculture in the near future (Popp et al., 2014; Stavridou et al., 2016). During the past few years, it has been shown that the cultivation of perennial crops provides a general increase of multiple key ecosystem services in comparison with annual food cropping systems (Tilman et al., 2006; Glover et al., 2007; Chimento and Amaducci, 2015; Amaducci et al., 2016).

Annual crops correspond to more than three quarters of the harvested global crop area with our primary food crops, including cereals, oil seeds, and pulses (Monfreda et al., 2008; Glover et al., 2010). In order to successfully grow annual crops, it is necessary to suppress the vegetation that competes with crops for sunlight, nutrients, and water. This is usually done by application of herbicides and/or tilling, which can result in soil erosion, nutrient leakage, low soil organic carbon levels and other impacts (Davis et al., 2010; Jarchow et al., 2015). Perennial species do not have to be replanted every year, resulting in many advantages over annual crops due to reduced fertilizer and tillage use and no requirements for irrigation, if planted in areas with abundant rainfall (Clifton-Brown and Lewandowski, 2000; Crews et al., 2016). In addition, perennial crops can contribute to increased soil carbon and nitrogen stocks, reduced soil erosion and a reduction in the nutrients removed by leaching and runoff (Smith et al., 2013; Ssegane et al., 2015). Despite the fact that an extensive root system can improve the soil carbon stocks over time, it can also contribute to a higher water-use efficiency (WUE) (Hickman et al., 2010; VanLoocke et al., 2012; Zeri et al., 2013; Abraha et al., 2016). A plant can partition its carbon above and below ground and those components have ecological and/or economic benefits. In this sense, an ideal plant for biofuel or food production would be one that makes the most of both benefits while using less water (Anderson-Teixeira et al., 2009; Zeri et al., 2013).

Perennial grain/forage crops can sustain high yields without replanting for 3–10 years or more, resulting in potentially important

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environmental benefits, such as water conservation/runnof, tillage reduction, soil health, and fertilizer/nutrient efficiency (Boody et al., 2005; Pimentel et al., 2012; Smith et al., 2013; Abalos et al., 2016). The area cultivated with perennial grasses has increased in the USA in the last decade. Some examples of perennial grasses cultivated in the USA include miscanthus, switchgrass, and intermediate wheatgrass (McLaughlin and Kszos, 2005; Heaton et al., 2008; Liebig et al., 2008; Zeri et al., 2011). Here, we examine intermediate wheatgrass, a widely adapted, high yielding, forage grass that has been shown to be a promising perennial grain crop that provides excellent feed for livestock in the Great Plains. In addition, the seed it produces has been identified as a nutritious and highly palatable grain (Karn et al., 2006; Culman et al., 2013). Intermediate wheatgrass has been under selection for improved fertility, seed size, and other traits since the 1980′s. Grain producing types of intermediate wheatgrass have been developed, and the grain is now sold under the trade name Kernza®, owned by the Land Institute, a non-profit sustainable agriculture research organization in Salina, Kansas, USA (Cox et al., 2010; Crews and DeHaan, 2015).

Although previous research has been conducted in relation to plant, insect and soil nematode community composition, and surface water chemical concentration in perennial food crops (Culman et al., 2010; Glover et al., 2010), the coupling between these ecosystems and the atmosphere is not well understood. Given the importance of the physical and biological phenomena involving energy, water and carbon fluxes in perennial crops, it is necessary to know the long-term patterns of micrometeorological fluxes such as net radiation (Rn), evapotranspiration (ET), gross primary productivity (GPP), and net ecosystem exchange (NEE). It is necessary to understand the differences in terms of magnitude and temporal variability of the fluxes in relation to native ecosystems and conventional agriculture. This information can also contribute to understanding the survival and fitness of these plants under different disturbance regimes (Raz-Yaseef et al., 2015; Crews et al., 2016; Zhang et al., 2016; Eichelmann et al., 2016).

In this study, we examined the magnitude and temporal variability of the surface energy and carbon exchanges in a perennial Kernza wheatgrass crop in Salina, north-central Kansas (KS), USA. More specifically, we aimed to (1) analyze the radiation balance at the crop surface and the redistribution of moisture and heat in soil and the atmosphere, (2) evaluate the energy balance closure for the US-KLS (Kansas Land Institute site) eddy covariance tower, (3) determine the carbon balance of the ecosystem, and (4) assess the water and light-use relationships in the Kernza field. We highlight that this is the first work presenting the flux tower measurements and examining the biosphere-atmosphere interactions in this perennial crop.

2. Materials and methods

2.1. Site description

The study site is located in Salina, KS, USA, in an experimental farm of the Land Institute. It is situated between latitudes 38.7724 N and 38.7747 N and longitudes 97.5699 W and 97.5679 W, with an area of ~3 ha. Salina is located within the Smoky Hills region known for native prairies characterized by moderate to high fragmentation, row crop agriculture, and low intensity cattle stocking (Ganser and Wisely, 2013). The site is cultivated with perennial Kernza wheatgrass. Kernza, a cousin of annual wheat, is a domesticated perennial grain originating from a forage grass called intermediate wheatgrass (*Thinopyrum intermedium*). Perennial Kernza grows to approximately 90 cm to 1.20 m tall. It is a long-lived, cool season grass with short rhizomes and a deep feeding root system. The seed spikes are approximately 10–20 cm long and leaves are 4–8 mm wide. The lemmas, paleas and glumes are smooth to pubescent. The glumes are acute to blunt, generally five nerved, awnless to awn tipped. The florets are generally less than seven (Ogle et al., 2013). Kernza roots can extend 3 m or more under the soil surface. This is more than twice the depth of and with greater density than annual wheat roots. The seed heads can contain more seeds than an annual wheat head, but Kernza seeds are currently about 1/5th the size of most conventional wheat seeds (Culman et al., 2013; Crews et al., 2016). Kernza was planted in this field in October 2009. Prior to that, this field had been cropped with annual wheat for many years. The seed used for planting in October 2009 was from the population TLI-C1. This breeding population was derived from one cycle of selection primarily for seed size and yield per spike (Cox et al., 2010; DeHaan and Van Tassel, 2014). The field was seeded with a drill at a depth near 1.2–2.5 cm. Seeding rates were ~11 to 13 kg of pure live seed (PLS) per hectare. Planting was initially at a 75 cm row spacing, and inter-row cultivation was used to control weeds through spring 2011. After this point, the plants had spread rhizomatously and the stand became solid, effectively excluding weeds.

The nitrogen (N) fertilization in the field has changed over time, beginning with ~110 kg per ha in 2012 and gradually decreasing to ~80 kg per ha in the later years. High rates of N fertilization resulted in a quick production of large amounts of aboveground biomass in the early spring. By decreasing these rates, there was less growth in the early spring, extending the soil moisture into the summer and allowing the plant to fill grain in June and July. It is important to highlight here that the purpose of this field is primarily to produce grain. Kernza is typically harvested in mid-July and harvesting occurred during the study period on 10 July 2012, 23 July 2013, 15 July 2014, 7 July 2015, and 20 July 2016. Aboveground biomass was periodically measured at regular time intervals during the 4.5 years study period. Following all harvests, biomass samples were dried for 5 days in a drying room with relative humidity of the air maintained at 9%. Air temperature was about 18 °C. The samples were weighed before and after the drying process.

The phenological stages for this perennial Kernza wheatgrass field are primary divided in: (1) early vegetative, (2) late vegetative, and (3) reproductive. The early vegetative stage refers to the developmental period comprising leaf regrowth and development after harvest (which usually occurs in July, as described previosuly) until the start of the cold season. In shis stage, which is defined between August and October, grass shoots are mostly leaves. The late vegetative stage comprises the period when stems are beggining to elongate just before flowering. It is situated between the start of the cold season (November) and beginning of the spring (April). In this phase, nutrient concentrations are usually lower than in early vegetative stages. During the winter, when moisture is adequate but temperatures are low, photosynthesis and plant growth are slow. With the arrival of spring, photosynthesis and plant growth rates increase. The perennial Kernza will remain vegetative for several weeks but will eventually flower and develop seeds. As the growing season progresses, the conversion from vegetative to floral bud production is completed and the unseen inflorescence emerges from the leaf sheath. This period, which comprises the months of May to July, is defined as the reproductive stage. Following clipping in July, a new cycle starts and the crop can recover growth.

The eddy covariance tower, designated as US-KLS (Kansas Land Institute site) (38.7745 N and 97.5684 W, ~373 m above sea level), was established in April 2012. The predominant Köppen-Geiger classification for the region is Cfa (warm temperate, fully humid, hot summer) (Peel et al., 2007). According to the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) historic climate data (1981–2010), the mean annual temperature is 13.4 °C and the mean accumulated rainfall is 800.1 mm per year. The last spring and first fall freeze in Salina, considering data collected by NOAA/NWS since 1948, generally occurs on May 2 and November 3, respectively.

2.2. Data

The observational data were obtained at KLS using the eddy