Science of the Total Environment 637–638 (2018) 163–173

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Net ecosystem exchange of CO_2 and H_2O fluxes from irrigated grain sorghum and maize in the Texas High Plains

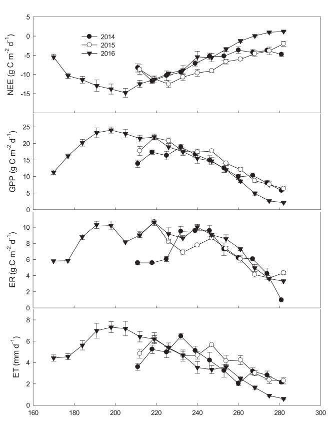
Pradeep Wagle [a,*], Prasanna H. Gowda [a], Jerry E. Moorhead [b], Gary W. Marek [b], David K. Brauer [b]

[a] USDA, Agricultural Research Service, Grazinglands Research Laboratory, El Reno, OK 73036, USA
[b] USDA, Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, TX 79012, USA

HIGHLIGHTS

- We reported eddy fluxes from irrigated grain sorghum and maize in Texas High Plains.
- Daily peak NEE reached −12 and −14.78 g C m^{-2} for sorghum and maize, respectively.
- Evapotranspiration (ET) reached 6.5 and 7.3 mm d^{-1} for sorghum and maize, respectively.
- NEE and ET were more sensitive for maize at high air temperature (T_a) and VPD.
- Sorghum had higher adaptability at high T_a and vapor pressure deficit (VPD).

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 January 2018
Received in revised form 13 April 2018
Accepted 2 May 2018
Available online xxxx

Editor: José Virgílio Cruz

Keywords:
Bioenergy
Eddy covariance
Evapotranspiration
Gross primary production
Lysimeter
Net ecosystem exchange

ABSTRACT

Net ecosystem exchange (NEE) of carbon dioxide (CO_2) and water vapor (H_2O) fluxes from irrigated grain sorghum (*Sorghum bicolor* L. Moench) and maize (*Zea mays* L.) fields in the Texas High Plains were quantified using the eddy covariance (EC) technique during 2014–2016 growing seasons and examined in terms of relevant controlling climatic variables. Eddy covariance measured evapotranspiration (ET_{EC}) was also compared against lysimeter measured ET (ET_{Lys}). Daily peak (7-day averages) NEE reached approximately −12 g C m^{-2} for sorghum and −14.78 g C m^{-2} for maize. Daily peak (7-day averages) ET_{EC} reached approximately 6.5 mm for sorghum and 7.3 mm for maize. Higher leaf area index (5.7 vs 4–4.5 m^2 m^{-2}) and grain yield (14 vs 8–9 t ha^{-1}) of maize compared to sorghum caused larger magnitudes of NEE and ET_{EC} in maize. Comparisons of ET_{EC} and ET_{Lys} showed a strong agreement (R^2 = 0.93–0.96), while the EC system underestimated ET by 15–24% as compared to lysimeter without any corrections or energy balance adjustments. Both NEE and ET_{EC} were not inhibited by climatic variables during peak photosynthetic period even though diurnal peak values (~2-weeks average) of photosynthetic photon flux density (PPFD), air temperature (T_a), and vapor pressure deficit (VPD) had reached over 2000 μmol m^{-2} s^{-1}, 30 °C, and 2.5 kPa, respectively, indicating well adaptation of both C_4 crops in the Texas High Plains under irrigation. However, more sensitivity of NEE and H_2O fluxes beyond threshold T_a and VPD for maize than for sorghum indicated higher adaptability of sorghum for the region. These findings provide baseline information on CO_2 fluxes and ET for a minimally studied grain sorghum and offer a robust geographic comparison for

* Corresponding author.
E-mail address: pradeep.wagle@ars.usda.gov (P. Wagle).

https://doi.org/10.1016/j.scitotenv.2018.05.018

maize outside the United States Corn Belt. However, longer-term measurements are required for assessing carbon and water dynamics of these globally important agro-ecosystems.

1. Introduction

The increasing energy costs and declining oil and gas reserves are leading to the expansion of alternative energy sources such as biofuels. Predominantly listed potential bioenergy crops in the United States are maize (*Zea mays* L.), switchgrass (*Panicum virgatum* L.), Miscanthus (*Miscanthus* × *giganteus*), sugarcane (*Saccharum officinarum* L.), and tree species poplar (*Populus* spp.). Although sorghum (*Sorghum bicolor* L. Moench) has not been widely mentioned, it is another promising bioenergy crop (Rooney et al., 2007). Maize and grain sorghum are two most widely grown cereal crops in the world. Recently, utilization of maize and grain sorghum by the ethanol industry has been growing. Consequently, maize and grain sorghum rank first and second, respectively, for grain-based ethanol production in the United States (Kubecka, 2011; Sarath et al., 2008). Furthermore, the acreage of maize and grain sorghum may continue to increase in the United States to meet requirements of the emerging biofuel industries.

Quantitative evaluation of carbon dynamics and evapotranspiration (ET) of major biofuel crops across different climatic regions is important to develop sustainable bioenergy crops for those regions since carbon dynamics and ET can vary substantially depending on climate. In addition, management practices such as irrigation can influence carbon dynamics and ET of the ecosystems (Moinet et al., 2017; Suyker and Verma, 2009). Maize and grain sorghum are major crops in the Texas High Plains where irrigated agriculture accounts for the majority of the agricultural crop production (Marek et al., 2010). The eddy covariance (EC) technique has recently been the most commonly used method to study carbon dynamics and ET of terrestrial ecosystems at the ecosystem scale (Baldocchi, 2003). Concurrent measurements of high frequency carbon dioxide (CO_2) fluxes, ET, and climatic variables by the EC systems allow us to investigate the dynamics of carbon fluxes and ET, and their climatic controls as well as estimations of ecosystem water use efficiency [EWUE, the ratio of gross primary production (GPP) to ET] and ecosystem light use efficiency [ELUE, the ratio of gross primary production (GPP) to photosynthetically active radiation (PAR)] (Barr et al., 2007; Law et al., 2002; Wagle and Kakani, 2014; Wagle et al., 2015b). A better understanding of these processes provides valuable information for developing best management practices and optimizing resource use efficiencies of these globally important agro-ecosystems. In addition, EC datasets are considered prime datasets to develop/validate crop growth models and satellite-based production efficiency (Running et al., 1999) and ET algorithms (Glenn et al., 2007; Wagle et al., 2017b).

Although several EC-based studies have reported carbon dynamics and ET for maize (Baker and Griffis, 2005; Hollinger et al., 2005; Suyker and Verma, 2012; Wagle et al., 2016a), those studies have been mainly focused in the north-central United States (i.e., U.S. Corn Belt). The EC measurements in maize ecosystems outside the U.S. Corn Belt, especially in the U.S. southern Great Plains, are still lacking. Very few recent EC studies have provided information on carbon dynamics and ET, and the influence of relevant climatic variables on fluxes for high biomass sorghum (Oikawa et al., 2015; Sharma et al., 2017; Wagle et al., 2015a, 2016b), but such measurements are still lacking for grain sorghum except a study for few selected days during the 1983 growing season at Mead, Nebraska (Anderson and Verma, 1986). Moreover, there is no comparison of the seasonal dynamics of sensible (H) and latent heat (LE) fluxes, CO_2 fluxes, and ET, and their climatic controls between grain sorghum and maize (two major biofuel C_4 crops) at the same site. To address these knowledge gaps, the following questions were addressed in this study: (1) what were the magnitudes of H, LE, CO_2 fluxes, and ET for grain sorghum and maize? (2) how comparable were the magnitudes of fluxes for grain sorghum and maize in the Texas High Plains to those for sorghum (grain and high biomass) and maize in other locations? (3) were NEE and ET inhibited by high photosynthetic photon flux density (PPFD), air temperature (T_a), and vapor pressure deficit (VPD) in the Texas High Plains? (4) what were the growing season distributions of CO_2 fluxes and ET for grain sorghum and maize?, and (5) what were the magnitudes of EWUE and ELUE for grain sorghum and maize during peak growth? Since EC flux measurements were made in the lysimeter field, EC measured ET (ET_{EC}) was also compared with lysimeter measured ET (ET_{Lys}).

2. Material and methods

2.1. Site description

The study was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, Texas (35° 11′ N, 102° 6′ W, and 1170 m elevation above sea level). The climate is semi-arid, with average annual precipitation of approximately 450 mm (Colaizzi et al., 2009). Soil type is well-drained Pullman silty clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) (Evett et al., 2015). A 19 ha square field is sub-divided into four 4.75 ha quadrants measuring approximately 210 m in both E-W and N-S directions. The four fields are designated according to the cardinal points as NE (northeast), SE (southeast), NW (northwest), and SW (southwest). The east fields (NE and SE) were irrigated by a sub-surface drip irrigation system and the west fields were irrigated by N-S oriented lateral move sprinkler system. Because the predominant wind direction at the site is SW to SSW, the EC system was deployed in the NE quadrant to provide the greatest fetch for flux measurements. A large weighing lysimeter (surface dimension of 3 × 3 m) installed in the center of each quadrant was managed to be representative of the surrounding field. To compare ET_{Lys} with ET_{EC}, we chose lysimeter data from the NE field because the EC system and NE lysimeter were better aligned with the prevailing wind direction. The ET_{Lys} values were processed in accordance with quality assurance and control techniques (Marek et al., 2014).

Grain sorghum (cv. Channel 5C35) was planted (209,950 seeds ha^{-1}) on June 20, 2014 and on June 23, 2015, and harvested during November 20–25, 2014 and November 12–15, 2015. Maize (cv. Pioneer 1151) was planted (~87,000 seeds ha^{-1}) on May 10, 2016 and harvested during October 13–17, 2016. Crops were managed for high yield potential using practices common to the Texas Panhandle, including nitrogen and phosphorus fertilizer applications based on commercial soil testing. Crops were planted in rows on raised beds with 0.76 m spacing with four rows on the lysimeter box. Other agronomic operations included disk and sweep plow tillage and pesticide applications as needed for weed and pests controls. Details about fertilizer and herbicide applications during the 2014–2016 growing seasons are presented in Table 1.

2.2. Rainfall, irrigation, weather conditions, crop growth, and yields

As compared to the 30-year (1981–2010) mean rainfall from June to October (282 mm), the site received 1.26 and 1.58 times more rainfall in 2014 (355 mm) and 2015 (446 mm), respectively. The site received only 237 mm (84% of the 30-year mean) of rainfall from June to October in 2016. The amount of irrigation water supplied to the field was approximately 238 mm July 1 to September 5 in 2014, 198 mm from July 1 to September 16 in 2015, and 505 mm from May 24 to August