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Seasonal variations in net ecosystem exchange of CO₂ and conservation of water use efficiency of cotton in the Mississippi Delta

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Abstract

Accurately quantifying the net ecosystem exchange (NEE) of CO₂ is a critical prerequisite for developing alternative farm management strategies to enhance carbon sequestration in biological systems and reduce greenhouse gas emissions. A 2-year study quantified the NEE of CO₂ from cotton (*Gossypium hirsutum* L.) on silty clay in farm-scale fields using an eddy covariance approach. On a seasonal scale, NEE and evapotranspiration were 8836 kg CO₂ ha⁻¹ and 367 mm, respectively, in 2017, and 10,759 kg CO₂ ha⁻¹ and 430 mm in 2018. Harvested cotton lint yields were 1269 and 1569 kg ha⁻¹ in 2017 and 2018, respectively. The water use efficiency (WUE) for lint production (WUE_{lint}) and ecosystem level WUE for NEE (WUE_{NEE}) across the two seasons was nearly constant. WUE_{lint} was 3.5 and 3.6 kg lint ha⁻¹ mm⁻¹, respectively, in 2017 and 2018, and WUE_{NEE} was 24 and 25 kg CO₂ ha⁻¹ mm⁻¹. The NEE and WUE measured in this study can be used as a benchmark for comparing carbon sequestration potential in cotton production. However, further research is needed to understand NEE responses to long-term climate variability and to develop climate-smart crop-soil management strategies.

Plain Language Summary

The balance between the amount of carbon dioxide absorbed by crops through photosynthesis and released back into the atmosphere through respiration is known as the net ecosystem exchange (biomass production) of carbon dioxide. Through this process, plants and soil remove carbon dioxide in the air that causes global warming and store it away in soil-plant systems. The efficiencies of the water pumped for

Abbreviations: CT, conventional tillage; EC, eddy covariance; ET, evapotranspiration; GHG, greenhouse gas; GPP, gross primary productivity; IRGA, infrared gas analyzer; LAI, leaf area index; LMD, Lower Mississippi Delta; NEE, net ecosystem exchange; R_{eco} , ecosystem respiration; WUE, water use efficiency; WUE_{lint}, water use efficiency for lint production; WUE_{NEE}, water use efficiency for net ecosystem exchange.

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irrigation in producing biomass and yield of interest (e.g., cotton lint) are known as their water use efficiencies. Accurately quantifying the net ecosystem exchange is critical for developing alternative climate-smart farm management strategies to adapt and reduce climate change impacts. We conducted a multiyear study in large farm-scale fields and assessed the carbon storage potential of cotton and their water use efficiency. Reducing consumptive water use in lint production appears less feasible, but improving WUE through efficient irrigation techniques needs to be explored.

1 | INTRODUCTION

A global evaluation by the Food and Agriculture Organization shows that agriculture contributes to approximately 31% of the total greenhouse gas (GHG) emissions (FAO, 2022), surpassing those from the entire transportation sector. In terrestrial landscapes and ecosystems, carbon dioxide (CO_2) is continuously absorbed as a substrate for photosynthetic reactions in the Calvin cycle for biomass production and released back into the air through the respiratory processes and biomass degradation owing to microbial ingestion of biomass. The balance of these processes constitutes the primary mechanism for sequestering atmospheric CO_2 by plant communities on the Earth (Hugler & Sievert, 2011). The balance between the amount of carbon dioxide absorbed by an ecosystem through photosynthesis and released back into the atmosphere through organic respiration and microbial decomposition is known as the net ecosystem exchange (NEE) of CO_2 . In crop production systems, NEE quantifies different farming practices' potential to impact the carbon balance for mitigating GHG emissions by utilizing carbon sequestration avenues (D. Baldocchi et al., 2020; Law et al., 2006). Soil carbon sequestration involves the absorption and storage of atmospheric CO_2 by plants and soil, helping to offset GHG emissions. Monitoring NEE in the crop ecosystems requires observing the gas exchange at the plant canopy to the landscape level, for which eddy covariance (EC) methods based on sound micrometeorological and statistical sciences have gained wide acceptance in recent years (D. Baldocchi, 2014, 2020; Hernandez-Ramirez et al., 2011; Wagle et al., 2024). In the EC method, NEEs of CO_2 and evapotranspiration (ET) are estimated by (tracking and measuring the turbulent transport of eddies carrying the gases (water vapor and CO_2) from the plant canopy boundary layer of the atmosphere.

In this regard, the use of ground-level closed chambers cannot estimate gas fluxes from land-plant ecosystems for quantifying NEE, as the chambers installed on soil surfaces can only measure gas fluxes in and out of the soil but cannot include the carbon assimilated into the system through photosynthesis and losses through plant maintenance respiration (D. D. Baldocchi, 2003; Katayanagi & Hatano, 2005). NEE, which represents the balance between gross ecosystem pro-

ductivity and ecosystem respiration (R_{eco}), is influenced by climate factors such as air and soil temperatures, solar radiation, and water inputs (precipitation and irrigation) (Janssens et al., 2001).

To understand the linkages between climate change—global connotation—and the fluxes of CO_2 , water (ET), and energy from landscapes, monitoring at the ecosystem level to elucidate climate-ecosystem interactions and feedback analysis are required (Pielke et al., 1998). In this context, continuous EC-based measurements of NEE and gross canopy photosynthesis (gross primary productivity [GPP]) have been conducted globally since the 1990s (D. Baldocchi et al., 2018). A study by Byrne et al. (2020) examined interannual variability in NEE and GPP across the global forest ecosystems and their relationship with potential drivers in North America using the EC flux measurements. The study revealed that the arid western region of America contributes more to the observed interannual variability than the eastern regions.

An analysis of NEE in cotton (*Gossypium hirsutum* L.) systems in Texas, reported by Menefee et al. (2020), found significant variability in NEE between crop seasons due to variabilities in meteorological conditions, especially rainfall receipts, affecting water availabilities to support optimum growth. D. Baldocchi et al. (2018), reviewing 20 years of research on NEE from forest ecosystems and their interannual variability, concluded that most of the variabilities were caused by climate and ecological factors like phenology, rainfall, temperature, and solar radiation. Quantifying NEE is essential in crop production as it can help understand how different farming practices affect the carbon balance of agricultural ecosystems. Certain practices, such as cover cropping or reduced tillage, increase carbon stored in the soil, thereby decreasing NEE and potentially offsetting some of the GHG emissions associated with agriculture.

NEE from soybean (*Glycine max* L.)–corn (*Zea mays* L.) rotations under various conservation tillage under rainfed and irrigated systems in the central United States were extensively investigated using the EC system (Baker & Griffis, 2005; Hernandez-Ramirez et al., 2011; Suyker et al., 2005). The studies concluded that NEE over cropping systems could vary considerably across soil landscapes; therefore, monitoring it across soils and climates was advised (Falge et al., 2001).

Additionally, using the EC method, Zheng et al. (1988) monitored NEE and its seasonal variation over a semiarid grassland in northwest China.

The Lower Mississippi Delta (LMD) is an important agricultural production region in the Southeast United States where cotton is one of the staple crops grown (<http://extension.msstate.edu/agriculture/crops/cotton>). Anapalli et al. (2020) quantified cotton's consumptive water use (ET) in the region using the EC method. Anapalli et al. (2019) compared NEE from cotton with soybean and corn by monitoring CO₂ and H₂O fluxes using the EC technology in the LMD region. The research presented in this paper is an extension of the investigation by Anapalli et al. (2020) to understand further the extent to which NEE and water use efficiency (WUE) for NEE and cotton lint production varied in cotton fields in response to the realized climates across crop seasons.

2 | MATERIALS AND METHODS

2.1 | Cotton experiment

Experiments for this study (2017–2018) were conducted in a ~50-ha cotton farm situated about 1 km from the research farm of the Crop Production Systems Research Unit, USDA-ARS at Stoneville, MS (33° 42' N, 90° 55' W, 32 m elevation above mean sea level). On average, the location receives about 1300 mm of rainfall year⁻¹, and the climate is classified as subtropical humid with warm summers. The cotton growing season is from May through October, during which about 30% of the annual rainfall is received (Anapalli, Fisher, et al., 2016; Anapalli, Pettigrew, et al., 2016). The soil was a Tunica clay loam (clayey over loamy, montmorillonitic, nonacid, thermic Vertic Halaquepet) up to about 1.2-m depth and did not vary spatially substantially. The soil was graded to have a slope of about 1% to support surface irrigation and was managed under conventional tillage (CT). In brief, the CT consisted of three rounds of primary tillage to remove crop residues and control weeds. Another secondary tillage was conducted before crops were planted to create furrows and ridges for row crop planting with furrows in between for irrigation water to run. The cotton variety Deltapine Land 152 was planted on May 2, 2017, and May 10, 2018, with a row spacing of about 97 cm. Plant density was an average of 42,000 seeds ha⁻¹. Crops were harvested on September 23, 2017, and September 26, 2018. In both years, N fertilizer was applied at 160 kg N ha⁻¹. Starting with the first square growth stage, mepiquat chloride was applied three times to control excessive plant height and vegetative growth.

Irrigations were applied by releasing water at the head of the furrows through lay-flat poly tubes, roughly when the plant-available water in the 45-cm soil profile was at 60% of

Core Ideas

- Net ecosystem exchange of CO₂ (NEE) signifies the carbon balance in plants from its absorption and release in the photosynthetic processes.
- The study quantified the NEE from cotton on silty clay in farm-scale fields using an eddy covariance approach.
- The average seasonal WUE for cotton NEE was 24 kg CO₂ ha⁻¹ mm⁻¹.
- The average seasonal WUE for cotton lint production was 3.5 kg ha⁻¹ mm⁻¹.
- NEE and lint yield between cropping seasons varied by 22% and 24%, but their WUE for NEE and lint differed only between 3–4%.

maximum. Each irrigation consumed about 3 cm of water, and there were three irrigations each in both years. We followed the Oosterhuis (1990) method for determining cotton phenological growth stages by visual observations; when 50% or more of the plants crossed a particular growth stage, they were recorded as crops actively growing in that stage (Table 1). Leaf area index (LAI) was measured biweekly using the AccuPAR LP-80 Ceptometer (Decagon Devices Inc.). Plant height was measured biweekly to adjust the EC flux tower height for positioning the wind sensors and gas analyzers in the constant flux layer. The cotton was harvested 26 days in 2017 and 29 days after the open boll stages.

2.2 | Computing water vapor (ET) and CO₂ fluxes (NEE) from the EC data

To quantify fluxes of CO₂ and ET from the cotton field, their densities in vertically propagated eddies from the crop field were measured using LI-7500-RS open-path infrared gas analyzers (IRGAs) (LI-COR, Inc.). Velocities for vertical transport of eddies in the air were measured using an omnidirectional Gill New Wind Master sonic 3D anemometer (Gill Instruments). IRGA, anemometer, and sensors for other ancillary micrometeorological variables were installed and maintained in the constant flux layer about 1.5 times canopy height above the plant canopy on telescopically height-adjustable towers. The maximum average canopy height of cotton plants across seasons was 1 m. Sensor height on the tower was adjusted when the measured canopy height increased by about 10 cm from the previous measured height. CO₂ and water fluxes were measured using the IRGA at a fixed frequency of 10 Hz.

TABLE 1 Cotton lint yield, net ecosystem exchange (NEE) of CO₂, consumptive water use (evapotranspiration [ET]), water use efficiency (WUE) for NEE (WUE_{NEE}) and WUE for lint production (WUE_{lint}) during the 2017 and 2018 crop seasons. NEE, the net CO₂ removed from the air, was expressed as a positive quantity.

Year	NEE (kg CO ₂ ha ⁻¹)	ET (mm)	Lint yield (kg ha ⁻¹)	WUE _{NEE} (kg ha ⁻¹ mm ⁻¹)	WUE _{lint} (kg ha ⁻¹ mm ⁻¹)
2017	8836	367	1269	24	3.5
2018	10,759	430	1569	25	3.6
% change compared to 2017	22	17	24	4	3

Ancillary micro-meteorological data measured along with the above fluxes were air temperature (T_{air}) and relative humidity using HMP 155 (Vaisala), net radiation (NR-LITE2, Kipp & Zonen B.V.) installed above the crop canopy (within the cropped field) along with the EC sensors. Heat flux into the soil at 8-cm depth was measured at three locations using self-calibrating soil heat flux sensors (HP01SC, Hukseflux Thermal Sensors B.V.). Soil temperature, water content, and heat flux plates were measured using a Stevens HydraProbe (Stevens Water Monitoring Systems, Inc.). From the soil water and temperature data, the heat energy stored in the layer of soil above the heat flux plates was computed using eqs. (1) and (2) in Anapalli et al. (1997). Additional micrometeorological data were collected at 1-min intervals, averaged every 30 min, and used in the analysis. All the data collected in the study were averaged in 30-min intervals, from planting until harvest in both years. All the sensors were recalibrated and maintained yearly.

2.3 | Data processing, screening, and gap-filling of fluxes

The EddyPro software version 6.1.0 (LI-COR Inc.) installed on a SmartFlux microprocessor installed inside the IRGA datalogger enclosure box attached to the flux tower was used to process raw flux data collected at 10 Hz intervals and accumulated at 30-min averages. In the Smartflux, EddyPro-standardized corrections for anemometer tilt by double coordinate rotation, time-lag compensation following Vickers and Mahrt (1997), wind speed spike removal by spectral correction (Moncrieff et al., 1997, 2004), corrections for air density changes by Webb et al. (1980), and eddy velocity corrections for humidity by van Dijk et al. (2004) were applied.

The EddyPro-processed output of 30-min CO₂ and H₂O fluxes and other micrometeorological data were post-processed meticulously, eliminating low-quality and unreliable data using the Tovi software (LI-COR Inc.). The Tovi was built based on the OzFlux method developed by Isaac et al. (2017). We used Tovi in a human-machine mix approach for data quality control. The software removed the periods with negligible air turbulence due to low windspeed using the

Mauder and Foken (2006) method. The energy balance imbalance in the data was corrected by the De Roo et al. (2018) method.

In Tovi, the process of filling gaps in the eddy covariance fluxes was achieved by using the method proposed by Falge et al. (2001), in which covariation of fluxes with weather variables and autocorrelation of fluxes in the time series were also incorporated for computing the possible value to fill the gap with Reichstein et al. (2005). Cotton ET was quantified from the quality-controlled and gap-filled lateen heat flux using latent heat of evaporation of water corrected for variations in air temperatures.

2.4 | Net R_{eco} and GPP

Further data gaps in ancillary micrometeorological measurements were filled, and R_{eco} and GPP were computed using the online REddyProc program available from the Max Planck Biogeochemistry Institute (<https://www.bgc-jena.mpg.de/5622399/REddyProc>) (Wutzler et al., 2018). Using REddyProc, in this study, R_{eco} was computed from measured NEE and nighttime air temperatures using the procedure outlined by Reichstein et al. (2005). In micrometeorological measurements, the fluxes directed away from the surface of the earth or matter removed from the air (e.g., CO₂ used in photosynthesis—a sink for the gas) are designated as –ve, and the fluxes directed toward the earth or matter added to the air are +ve (e.g., CO₂ emitted in plant respiration—a source for the gas) (Lee, 1998). However, all quantities are real or +ve; before using NEE for computing WUE, as this quantity cannot be –ve, daily NEE values computed from the above method were converted to +ve and used. The WUE for NEE (WUE_{NEE}), expressed as kg CO₂ ha⁻¹ mm⁻¹ of water, was computed by dividing the half hourly NEE by the corresponding ET values.

2.5 | WUE_{NEE} and WUE for lint production (WUE_{lint})

The WUE of crop plants at the leaf level refers to the amount of photosynthate produced by taking in CO₂ from the air at the expense of the amount of water lost through the

stomatal openings (transpiration) (Anapalli et al., 2019; Guo et al., 2021; Lei et al., 2018). At the cotton production level, in the context of the measured CO_2 and water fluxes at the canopy level quantified using the EC method, WUE can be defined as the carbon assimilated in biomass in the ecosystem from water consumed in the process (WUE_{NEE} , ecosystem WUE). As lint production is the prime objective of cultivating the cotton plants, the WUE_{lint} was computed as the ratio of lint produced per unit of lint harvested from the system.

3 | RESULTS AND DISCUSSION

3.1 | Weather and crop performance

Plant growth, development, and yield are affected by several factors, including genetic makeup and weather conditions, primarily solar radiation, air and soil temperatures, and precipitation. In 2017, the daily solar radiation (R_g) during the crop season varied between $29.9 \text{ MJ m}^{-2} \text{ day}^{-1}$ on the 10th day after crop emergence (DAE) and $7.7 \text{ MJ m}^{-2} \text{ day}^{-1}$ on the 36 DAE (Figure 1). The differences in the amount of R_g recorded between observations were due to the differences in clouding that masked the sunlight from reaching the crop canopy (Figure 1). In 2018, the highest observed R_g was $30.1 \text{ MJ m}^{-2} \text{ day}^{-1}$ on 19 DAE, and the minimum was $5.1 \text{ MJ m}^{-2} \text{ day}^{-1}$ on 34 DAE. These observed maximum and minimum values represented the R_g receipts on clear skies and near-overcast days, respectively. The average R_g during the crop season was $22.2 \text{ MJ m}^{-2} \text{ day}^{-1}$ in 2017 and $22.4 \text{ MJ m}^{-2} \text{ day}^{-1}$ in 2018. The difference of $0.2 \text{ MJ m}^{-2} \text{ day}^{-1}$ between the 2 years was not substantial in the solar radiation receipts during the two crop seasons at a seasonal scale. Solar radiation received in half-hour intervals, that is, the interval used for accumulating the fluxes of CO_2 and ET, were between 298 and 1120 W m^{-2} in 2017 and 252 and 1116 W m^{-2} in the 2018 crop season (Figure 1).

In the 2017 season, the observed T_{air} maximum ranged from 17°C in September (when the crop matures) to 36°C in August (94 DAE) during the active crop growing season. Likewise, the daily minimum T_{air} ranged from 12°C in June to 27°C in July. In 2018, the daily maximum air temperatures were between 36°C in July and 23°C toward the end of July. The fluctuations in T_{air} at the site were influenced by varying cloud cover, with overcast and sunny skies. The daily minimum T_{air} in 2018 was 18°C in June and 27°C in July. None of the T_{air} in the 2017 and 2018 seasons were strong enough to cause significant heat stress, which could have substantially impacted the cotton growth (Figure 1). During the crop growth period from May 2 to September 23, 2017 (132 days), the total rainfall received was 71.9 cm, exceeding the 30-year average of 47.3 cm. In the crop growth season 2018, from May

10 to September 29, the total rainfall received was 54.2 cm, compared to the 30-year average of 46.2 cm (Figure 2).

In 2017, there were 63 days of rainfall; in 2018, there were 49 days of rainfall during the crop growth period. The amount of rainfall received and water stored in the soil profile is usually sufficient to support optimum growth of cotton. However, due to erratic amounts and uneven distribution of the rainfall events, whenever the dry spell exceeds about 2 weeks, it causes a depletion in available water in the active root zone of cotton (at a depth of 45 cm) to fall below 60% of maximum. At this point, irrigations were provided as described above.

Crop phenology depends on the weather, especially the T_{air} , during crop growth (Hatfield et al., 2011; Oosterhuis, 1990). In 2017, cotton seedlings emerged after 12 days after planting (DAP), and in 2018, 9 DAP. The difference in the number of days to emergence was primarily from differences in air and soil temperatures, up to about 8 cm in the soil, between the crop seasons (Figure 1). The average soil temperature in the first week after planting in 2017 was 22°C ; in 2018, it was 26°C . In the 2017 crop season, the subsequent growth stages—the first square, first flower, first boll, and first cracked boll—occurred on 36, 59, 77, and 106 DAE. In 2018, these growth stages were observed on 33, 57, 78, and 100 DAE. The seed cotton harvested in 2017 was on 132 DAE; in 2018, it was on 129 DAE. Cotton is a plant characteristic of indeterminate growth, and the plants continue to grow even after flowering and active reproductive growth; as such, the growth regulator, mepiquat chloride, was applied three times each in 2017 and 2018 between the first square and full flower stage to control excess vegetative growth and promote photosynthate translocations into the reproductive sinks. For these reasons, maximum leaf growth occurred at the flowering stage, with an LAI of 3.9 in 2017 and 4.1 in 2018. Cotton lint harvested was 1269 kg ha^{-1} in 2017 and 1569 kg ha^{-1} in 2018 (24% higher lint yield in 2018 than in 2017, Table 1).

3.2 | Diurnal and seasonal variations in NEE

The average daily patterns of NEE across the two growing seasons exhibited substantial variations (Figure 3). July was the month with the highest NEE during both seasons. In 2018, NEE in August was slightly higher than in July, from 1:00 p.m. to 7:00 p.m. The highest amount of NEE was $-15 \text{ kg CO}_2 \text{ ha}^{-1}$ in 2017, while in 2018, it was $-18 \text{ kg CO}_2 \text{ ha}^{-1}$. The peak value in NEE in both seasons occurred between noon and 1:00 p.m. May is the month the crop was planted, with measured LAI below 1 (Figure 3 for NEE; Figure 4 for LAI). Consequently, the NEE exchange this month was the lowest among the four months of the crop season (May, June, July, and September). NEE increased with the crop growth in June and July (Figure 3), while LAI increased to values between 1 and 4 (Figure 4). Daily NEE, after reaching its peak

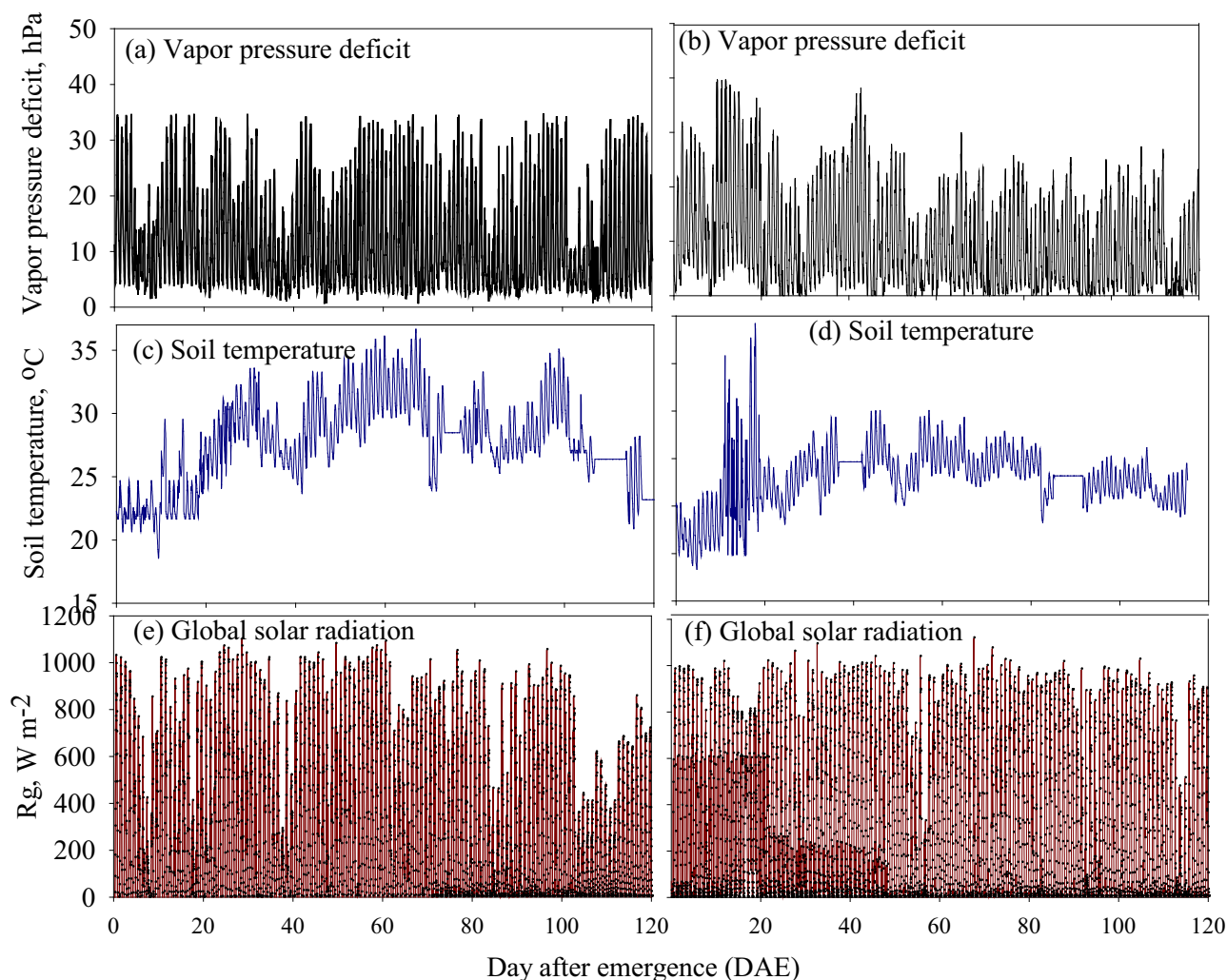


FIGURE 1 Measured half hourly 8 cm soil temperature and global solar radiation, and computed air vapor pressure deficit during the cotton growing season in 2017 and 2018.

in July, substantially decreased in August 2017 when LAI also decreased to 2 with senescing leaves as the crop reached physiological maturity. However, the decline in NEE in August was relatively less in 2018, and the values were comparable to those observed in July, mainly due to the late planting (May 12, 2018 vs. May 2, 2017). Solar radiation, the primary driver of photosynthetic biomass production in plants, received in August 2018, was comparable to July with younger plants. The NEE measured in September for maturing plants with open bolls was the lowest.

On a half hourly basis, in 2017, the measured NEE fluxes ranged from a maximum value of $-31 \text{ kg CO}_2 \text{ ha}^{-1}$ on 108 DAE during the later stages of boll development and the open boll growth of the cotton plants, and a minimum value of $+27 \text{ kg CO}_2 \text{ ha}^{-1}$ on 34 DAE during the active squaring (bud development) stage of the plant. There were rain events during this period, and it was reported that soil emissions of CO_2 increased tremendously after rain events through the enhancement of microbial activity in the soil (Rajan et al., 2013). In a rainfed cotton production system in a semiarid climate at Col-

lege Station, TX, the maximum daily NEE reported in 2017 was $-64 \text{ kg CO}_2 \text{ ha}^{-1}$ in 2017 and $-66 \text{ kg CO}_2 \text{ ha}^{-1}$ in 2018 (Menefee et al., 2020). However, the daily NEE we obtained in this study was only about half of that value. This is possibly an artifact of the difference in climate and soil between the locations of the studies. In 2018, the maximum we measured was -31 kg ha^{-1} on 85 DAE during the boll development stage of the plants (Figure 4), while the minimum half-hour NEE in 2018 was $36 \text{ kg CO}_2 \text{ ha}^{-1}$ on 80 DAE, coinciding with the end of the flowering stage of cotton. Generally, the daily CO_2 flux progression followed the measured LAI (Figure 4).

In 2017, the measured daily NEE of the cotton crop ranged from 120 on 104 DAE to $-274 \text{ kg CO}_2 \text{ ha}^{-1}$ on 38 DAE (Figure 4) from the emergence of cotton seedlings until it reached physiological maturity. The highest NEE value occurred when the LAI reached 3.3. Around 104 DAE, there was a substantial decrease in measured solar radiation at the crop canopy due to heavy clouds (solar radiation values in Figure 1); the soil and plant respiratory loss of CO_2

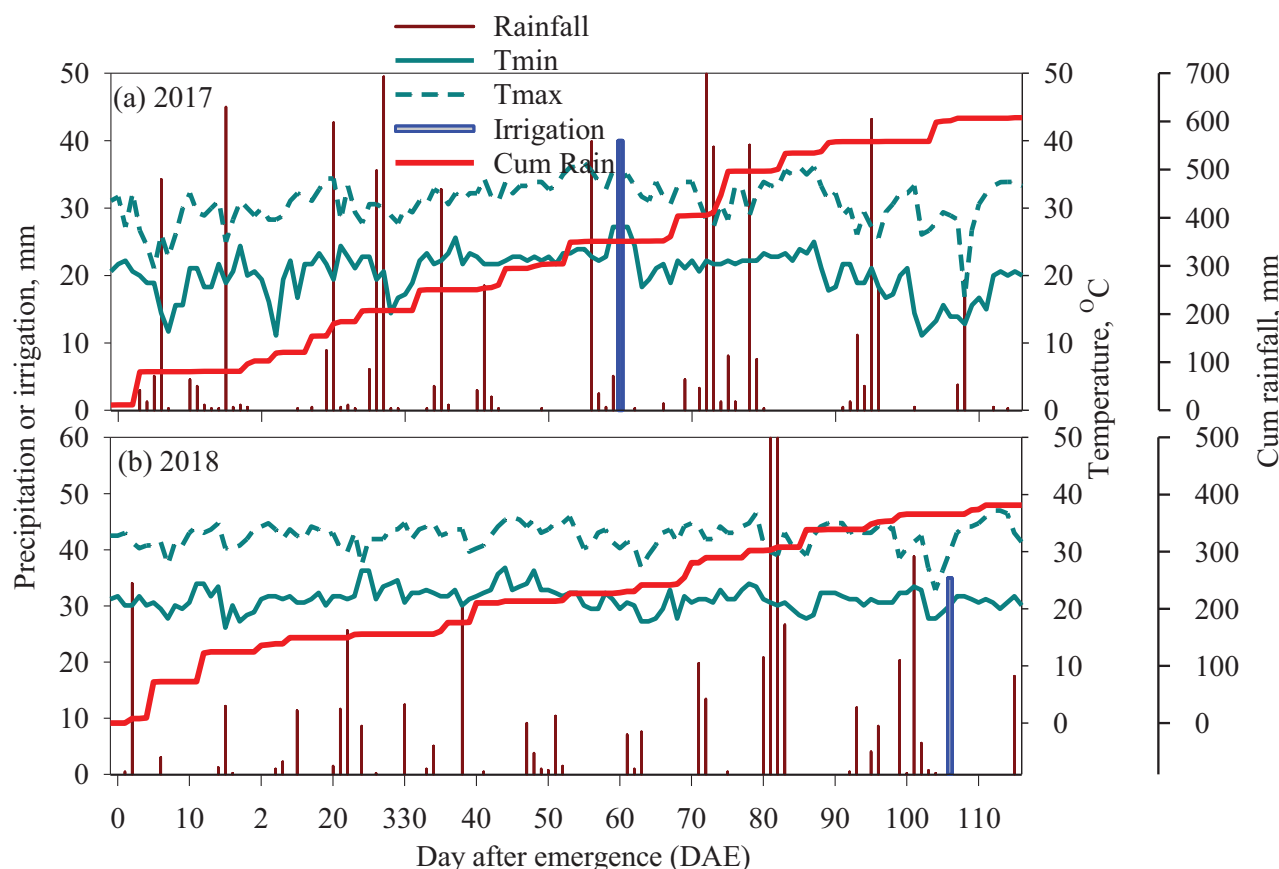


FIGURE 2 Daily rainfall, maximum ($T_{\max}$) and minimum ($T_{\min}$) air temperature, and rainfall recorded during the cotton growing season in 2017 and 2018. Cumulative (Cum) daily rainfall for the season is also presented.

dominated during the day. Corroborating our findings, Amthor (1995) reported that the daily plant maintenance respiration could be as high as 40%–60% of the carbon assimilated. Ray et al. (2020) also indicated that soil microbial activity may significantly contribute to net CO_2 flux from cropping systems. The total CO_2 captured from the atmosphere through photosynthesis and sequestered in cotton plants during the crop season was $8836 \text{ kg CO}_2 \text{ ha}^{-1}$ in 2017 and $10,759 \text{ kg CO}_2 \text{ ha}^{-1}$ in 2018 (Table 1), representing a 22% decrease from 2018. These results highlight, irrespective of their inherent variabilities arising from realized climate across seasons, the high potential of the cotton production system as a carbon sink to absorb the GHG emitted into the atmosphere. In a rainfed cotton production scenario in a semiarid climate, at College Station, TX, the crop seasonal NEE reported in 2017 was 8830 and $9470 \text{ kg CO}_2 \text{ ha}^{-1}$ in 2018. Given the differences in climate between the two locations (the location of our experiments was a humid subtropical), these measurements corresponded well with ours. They also reported significant differences between measured NEE between the two seasons that were attributed to differences in rainfall between the years. Though our experiments were irrigated, they were not always enough to compensate for

the soil water stress imposed by the absence of rainfall during such dry periods when crop water uptake was high, especially during the peak crop growth periods; as such, CO_2 fixed in photosynthesis during this period was affected as reflected in the measured NEE (Table 1; Figure 2). For example, in 2017, when rainfall was absent during the 45–55 DAP period, there could have been some soil water stress impacting biomass production.

3.3 | Net R_{eco} and GPP

In 2017, the computed daily R_{eco} ranged from 56 at emergence to $257 \text{ kg CO}_2 \text{ ha}^{-1}$ at 58 DAE with a seasonal total of $17,397 \text{ kg CO}_2 \text{ ha}^{-1}$ (Figure 5). In 2018, the seasonal total R_{eco} was $26,232 \text{ kg CO}_2 \text{ ha}^{-1}$, with daily values ranging between 47 at emergence and $433 \text{ kg CO}_2 \text{ ha}^{-1}$ at 87 DAE.

The daily values of GPP and R_{eco} were $26,227 \text{ kg CO}_2 \text{ ha}^{-1}$ (NEE was $8836 \text{ kg CO}_2 \text{ ha}^{-1}$) in 2017 and $37,081 \text{ kg CO}_2 \text{ ha}^{-1}$ (NEE was $10,759 \text{ kg CO}_2 \text{ ha}^{-1}$) in 2018 (Figure 6). In 2017, the half hourly GPP rates varied between 1 at emergence (beginning of crop growth) and $39 \text{ kg CO}_2 \text{ ha}^{-1}$ during the active growth, closely following the LAI growth.

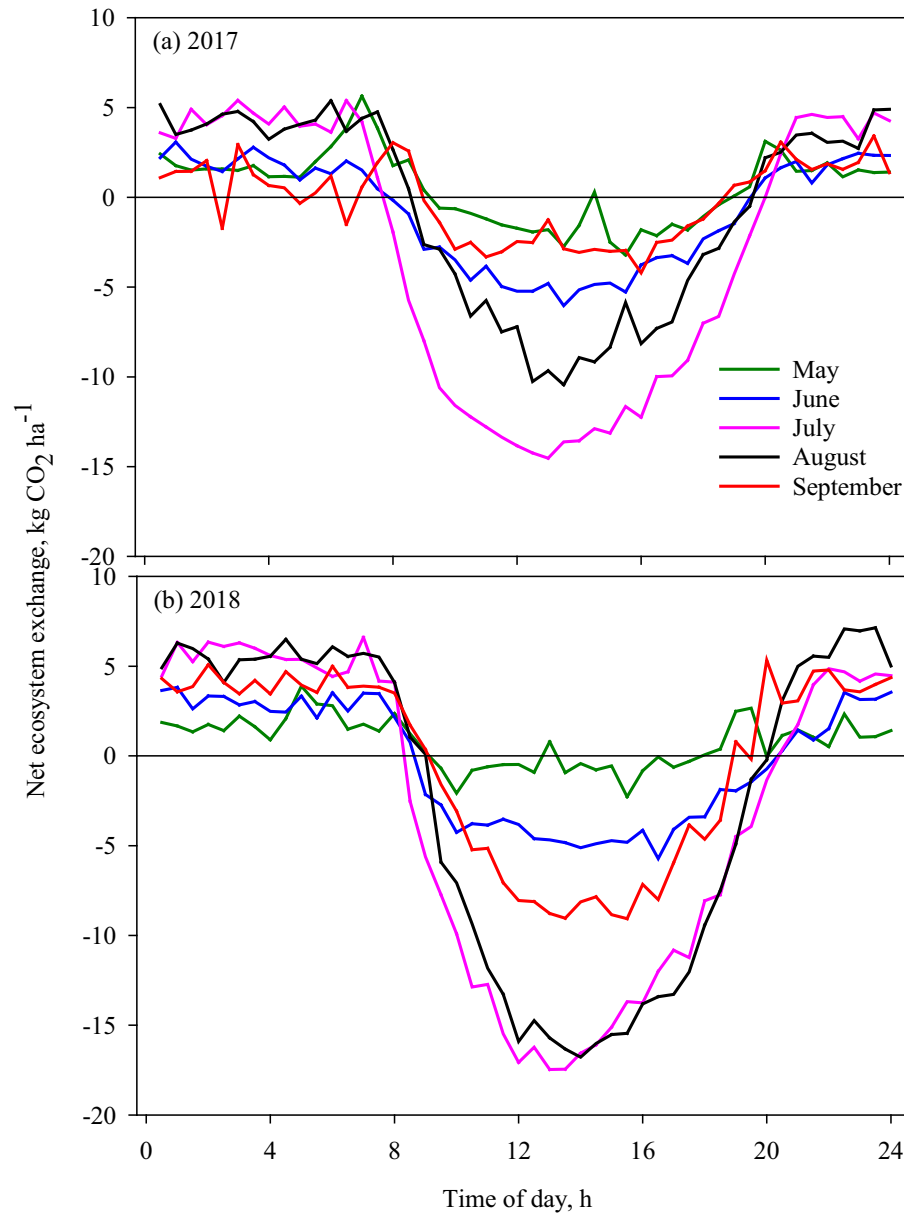


FIGURE 3 Monthly (May, June, July, August, and September) averaged diurnal patterns of net ecosystem exchange of CO_2 quantified using the eddy covariance method during cotton growing seasons in 2017 and 2018.

Increased leaf area intercepted more light for photosynthesis and biomass assimilation (Figure 6). Daily GPP in 2017 varied between $90 \text{ kg CO}_2 \text{ ha}^{-1}$ at the beginning of the growth season and $501 \text{ kg CO}_2 \text{ ha}^{-1}$ when the plants attained LAI values above 4. In 2018, GPP ranged from 90 at emergence to $545 \text{ kg CO}_2 \text{ ha}^{-1}$ when LAI progressed to 3.9.

The GPP and R_{eco} from cropping systems are controlled primarily by air and soil temperatures, solar radiation, precipitation, and irrigation (Janssens et al., 2001). In nature, R_{eco} results from complex interactions between climate, soil (physical, chemical, and biological), and crop characteristics. In the absence of measurements, the computed R_{eco} can only be a preliminary (modeled) estimate of the quantity. The lin-

ear correlation between R_{eco} and NEE obtained in this study showed an R^2 (coefficient of determination) of 0.67 in 2017 and 0.41 in 2018 (Figure 7). Lasslop et al. (2010) developed an algorithm (model) for partitioning NEE to GPP and R_{eco} using a light response curve fitted to daytime NEE and modified for temperature sensitivity and vapor pressure deficit impacts. They obtained correlations between GPP and R_{eco} with R^2 between 0.7 and 0.8. However, comparing the two methods (Reichstein et al., 2005 vs. Lasslop et al., 2010), Lasslop et al. (2010) reported some differences in the computed values of R_{eco} and GPP across sites, but the overall pattern remained the same. The method, however, is not widely adopted for flux partitioning (Wutzler et al., 2018).

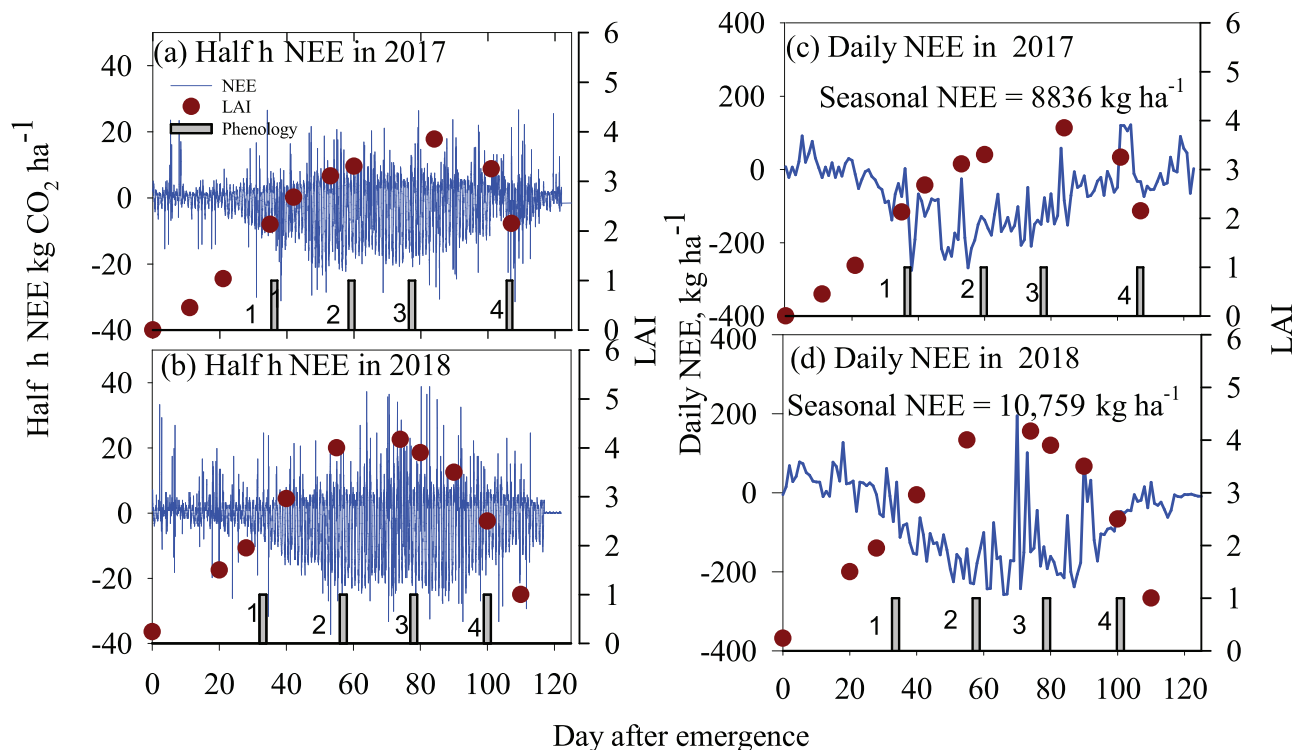


FIGURE 4 Half hourly and daily net ecosystem exchange (NEE) of CO₂, quantified using the eddy covariance method during cotton growing seasons in 2017 and 2018. Leaf area indices (LAIs) measured during the crop seasons are also presented. Numbers 1, 2, 3, and 4 marked on the X axis crop stages (phenology) correspond to the first square, flower, boll, and open boll stages, respectively.

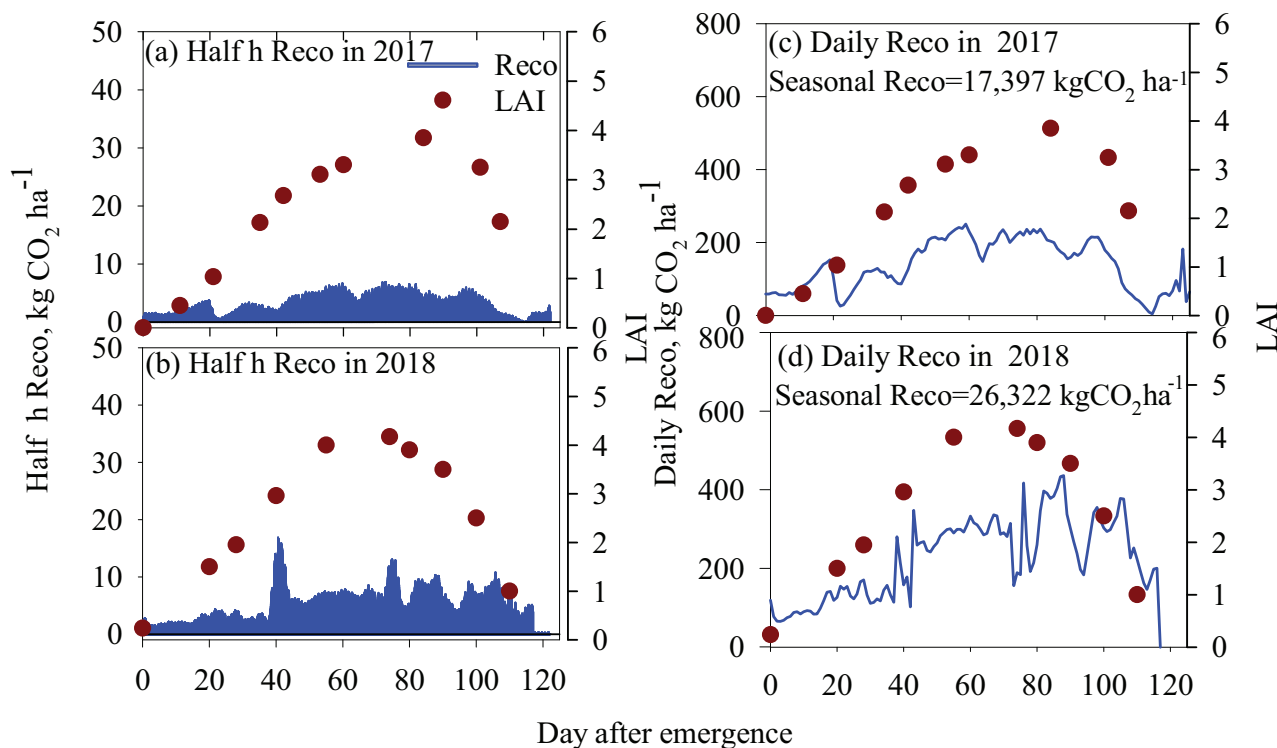


FIGURE 5 Half hourly and daily ecosystem respiration (R_{eco}) of CO₂ was quantified using the eddy covariance method for the cotton growing seasons in 2017 and 2018. Leaf area indices (LAIs) measured during the crop seasons were also presented.

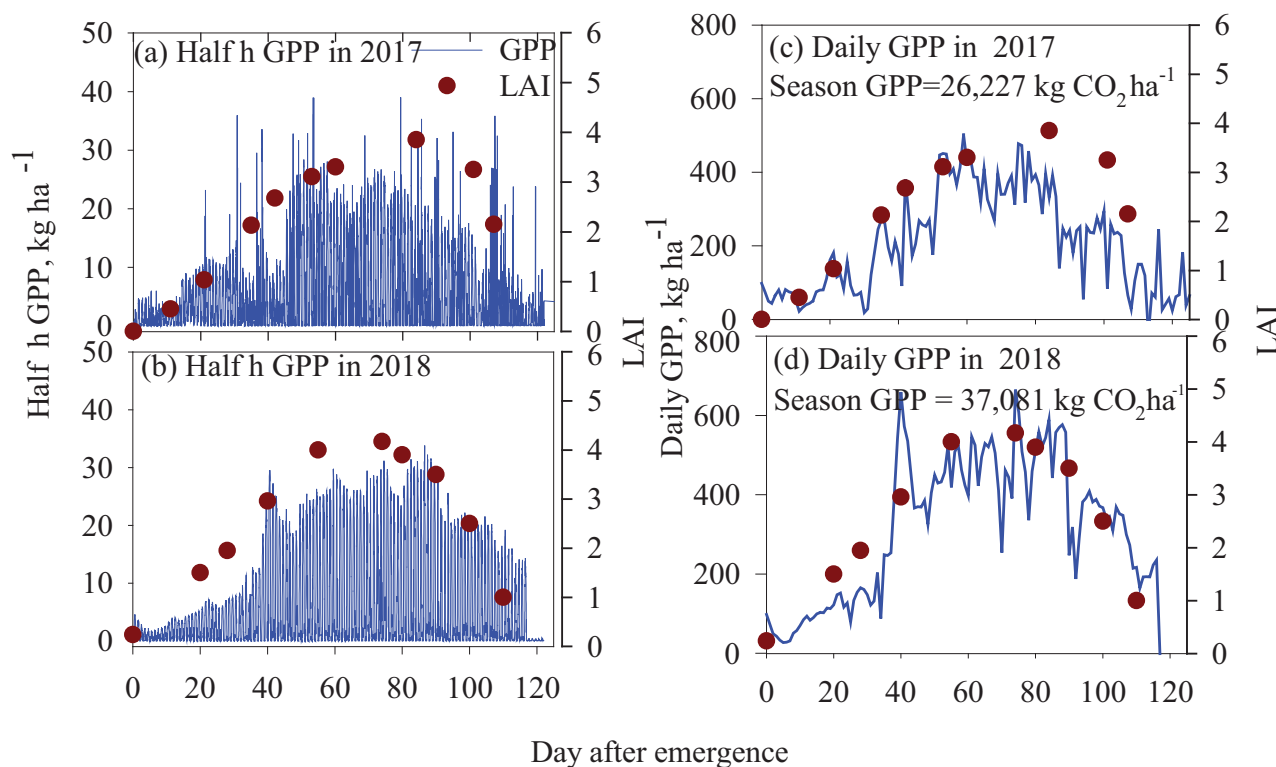


FIGURE 6 Half hourly and daily gross primary productivity (GPP) of CO₂, quantified using the eddy covariance method for the cotton growing seasons in 2017 and 2018. Leaf area indices (LAIs) measured during the crop seasons were also presented.

3.4 | ET of cotton

Anapalli et al. (2020) quantified cotton ET using the EC approach, in which the latent heat data collected in the experiments presented in this study were used. In that study, the quantified ET was used to compute crop coefficients, which can be used by irrigation researchers, consultants, and farmers to predict actual cotton ET from reference ET computed using realized weather data in the field during the growing season. The ET data were used in this study to calculate the water use efficiencies of cotton NEE and lint production. A summary of the results of the Anapalli et al. (2020) study that was adopted in this study for quantifying WUE was presented here: Cotton seasonal ET was 367 mm in 127 days in 2017 and 439 mm in 132 days in 2018 (Table 1; Figure 8). Wide variations in daily values of ET were noticed in both years. The highest daily ET reported in 2017 was 5.6 mm, against 6.7 mm in 2018. The variations in ET, daily and seasonal, were attributed to the measured variations in realized weather during the crop seasons, which left the soil surface dry between dry and wet conditions, contributing to variable soil surface evaporation components of ET (figs. 1 and 2 in Anapalli et al. [2020]). In an attempt to quantify the contribution of weather in explaining the variabilities in quantified ET, Anapalli et al. (2020) reported that the highest correlation between ET and weather factors, R_g ranked highest with

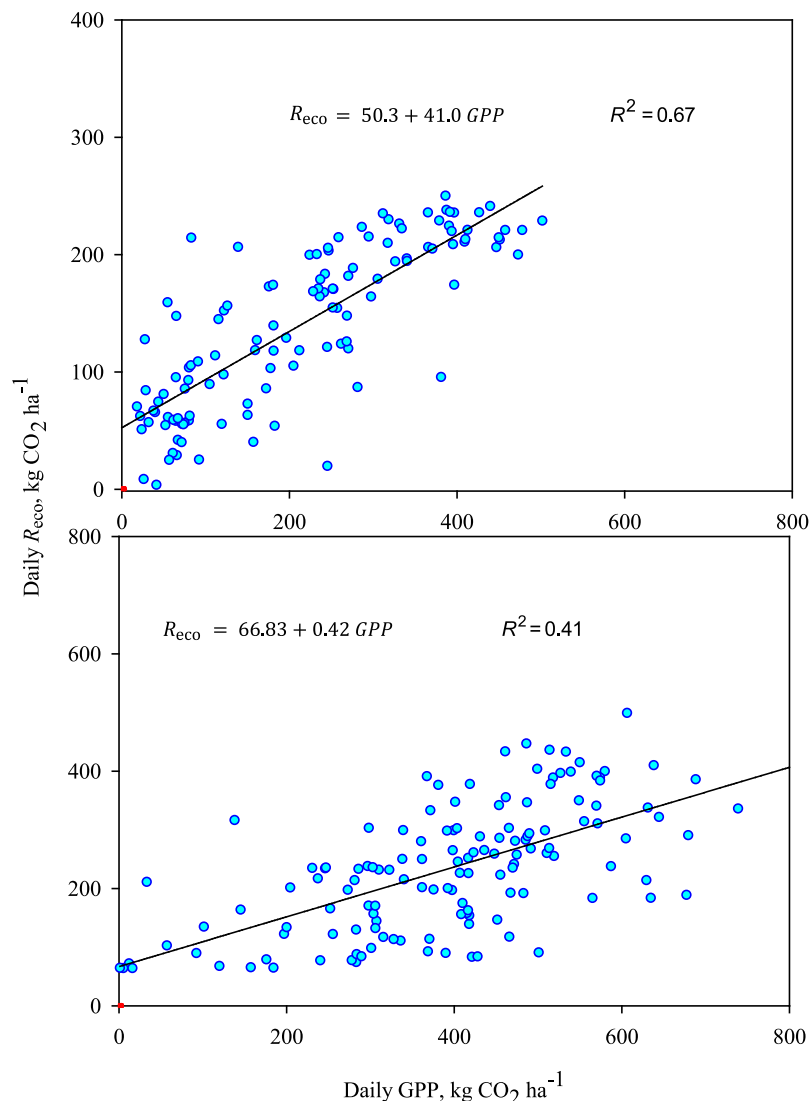
R² values 0.85 and 0.78, respectively, in 2017 and 2018. The relationship of measured ET with air temperatures was the least, with R² values of 0.28 and 0.44 in 2017 and 2018, respectively.

3.5 | WUE_{NEE} and WUE_{lint}

In 2017, the computed daily WUE_{NEE} (NEE is expressed as a +ve quantity when there is a CO₂ sequestration in plant biomass) varied from -4 kg CO₂ ha⁻¹ mm⁻¹ (-ve sign shows net CO₂ release from the system) on 38 DAE to 81 kg CO₂ ha⁻¹ mm⁻¹ on 40 DAE. The average seasonal WUE_{NEE} was 24 kg CO₂ ha⁻¹ mm⁻¹ (Figure 8). In 2018, the average seasonal WUE_{NEE} was 25 kg CO₂ ha⁻¹ mm⁻¹, varying between -2 and 92 kg CO₂ ha⁻¹ mm⁻¹ (Figure 8). The slightly lower values of WUE_{NEE} in 2017 were due to decreased solar radiation received throughout the season from excessive clouding and rainfall (Figures 1 and 2). In 2017, the seasonal average half hourly solar radiation received was 470 W m⁻², compared to 554 W m⁻² in 2018.

In 2017, the cotton's seasonal average daily WUE_{lint} was 3.5 kg ha⁻¹ mm⁻¹; in 2018, it was 3.6 kg ha⁻¹ mm⁻¹, a 3% change across seasons (Figure 8). The WUE_{NEE} computed for 2017 was less than that of 2018 by 4%. For the two-season data presented, we conclude that WUE_{NEE} and WUE_{lint} in cotton

FIGURE 7 The relationship between computed ecosystem gross primary productivity (GPP) and ecosystem respiration (R_{eco}) in the 2017 and 2018 cotton seasons.



systems in the region remain constant across seasons. In this context, it is important to note that the water availability for irrigated agricultural production systems in the region is being challenged by users of this natural resource from other competing human enterprises (Powers, 2007; Runkle et al., 2017). In the emerging scenario, soil–water–crop management that can enhance WUE in agriculture can help alleviate some pressure on the consumptive water demands for irrigated crop production in the region (Cai et al., 2003). However, when WUE, the crop produced per unit of water consumed (ET), is a conservative property, there is little room for drastically reducing ET to save water. Reducing water use in irrigated systems by adopting more efficient irrigation methods like sprinkler irrigation in place of furrow-flooded irrigation as prevalent in the Mississippi Delta region and reducing water losses between its source and delivery at the crop potentially help in addressing the issue (Burt et al., 1997; Evans & Sadler, 2008). As in any other crop cultivated for human use, water consumption and crop production in cotton also depend on

genotype by environment by management interactions that determine its growth, development, and yield (Kang et al., 2021). Further investigations on the physiological processes in cotton for optimum WUE in NEE production are critical for sustainable cotton production, especially in the face of increasing water scarcity.

4 | CONCLUSIONS

Quantifying NEE is crucial for effectively managing crop ecosystems and reducing GHG emissions by sequestering CO_2 removed from the atmosphere into terrestrial biomass to combat climate change. Using an EC approach, seasonal variations in fluxes of ET and NEE from cotton in the Mississippi Delta region were quantified. WUE_{NEE} and WUE_{lint} were computed for quantifying their seasonal variations. This study demonstrated the possible variations in quantified NEE (22%), lint yield (24%), and ET (17%) between the two

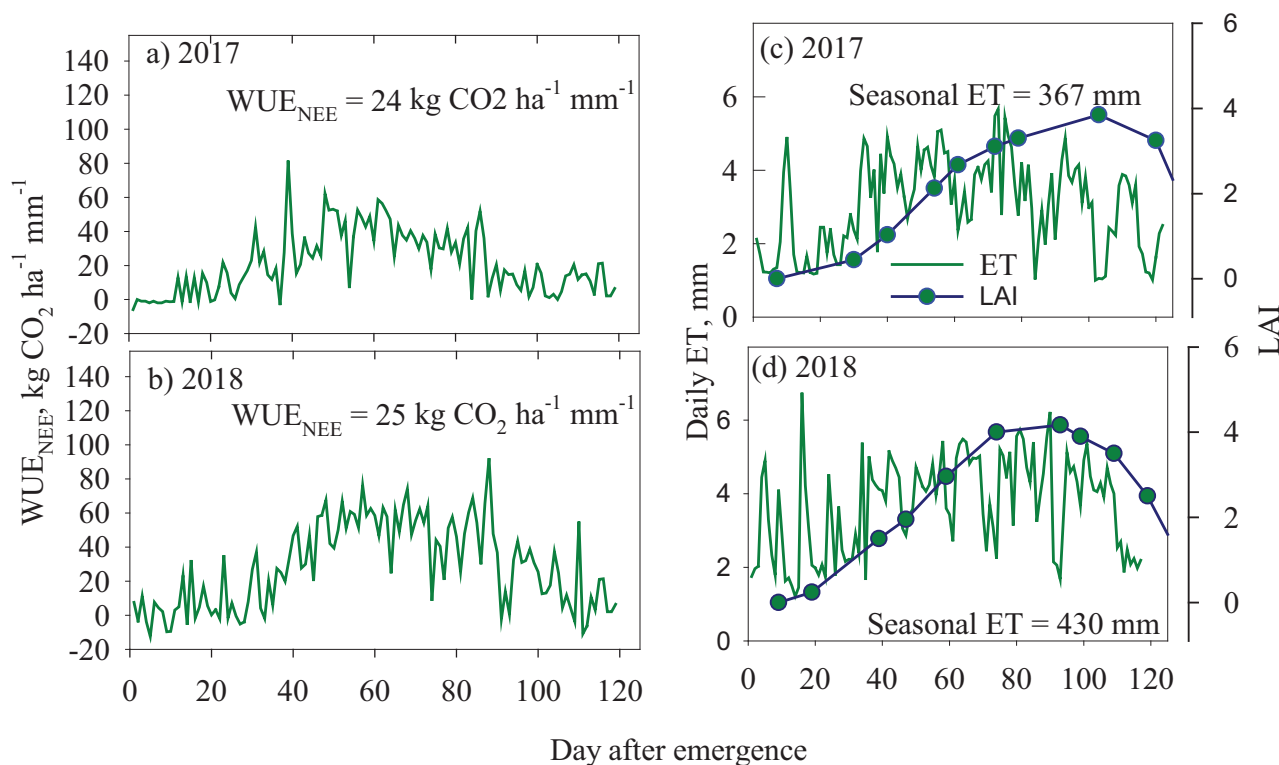


FIGURE 8 Eddy covariance quantified daily water use efficiency for net ecosystem exchange (WUE_{NEE}) during the cotton growth seasons in 2017 and 2018. ET, evapotranspiration; LAI, leaf area index.

growing seasons. Irrespective of the 22% difference in NEE and 24% difference in harvested lint yield between the seasons, the WUE_{int} and WUE_{NEE} differed by only 3% and 4%, respectively, suggesting WUE conservation across seasons in the region's climate. These findings can provide invaluable insights for researchers and policymakers in developing irrigation water management practices for enhanced productivity of water pumped from aquifers for irrigation. Quantified NEE and its variabilities across the seasons enable researchers to gain in-depth knowledge of cotton ecosystems' role in the global carbon cycle and develop climate-smart decisive actions to enhance their carbon sequestration capabilities. The results of this investigation highlighted the high carbon sink potential of cotton production systems in the Mississippi Delta region. However, the study did not investigate the carbon source-sink relationships during crop-fallow season. Further studies will be necessary to recommend fallow season soil management to achieve the system's carbon sink potential throughout the year. This study also highlights the need for continued long-term monitoring of NEE and WUE across soils and climates, as the data developed can be crucial for understanding and managing these ecosystems for sustainable agriculture.

AUTHOR CONTRIBUTIONS

Saseendran S. Anapalli: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing—original draft; writing—review and editing. **Ammar B. Bhandari:** Data curation; visualization; writing—review and editing. **Rajanna G. Adireddy:** Data curation; visualization; writing—review and editing. **Krishna N. Reddy:** Conceptualization; project administration; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data used in the study are available on request. Further inquiries can be directed to the corresponding author.

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REFERENCES

- Amthor, J. S. (1995). Terrestrial higher-plant response to increasing atmospheric $[CO_2]$ in relation to the global carbon cycle. *Global Change Biology*, 1, 243–274. <https://doi.org/10.1111/j.1365-2486.1995.tb00025.x>
- Anapalli, S. S., Fisher, D. K., Pinnamaneni, S. R., & Reddy, K. N. (2020). Quantifying evapotranspiration and crop coefficients for cotton (*Gossypium hirsutum* L.) using an eddy covariance approach. *Agricultural Water Management*, 233, 106091. <https://doi.org/10.1016/j.agwat.2020.106091>
- Anapalli, S. S., Fisher, D. K., Reddy, K. N., Krutz, J. L., Pinnamaneni, S. R., & Sui, R. (2019). Quantifying water and CO_2 fluxes and water use efficiencies across irrigated C_3 and C_4 crops in a humid climate. *Science of the Total Environment*, 63, 338–350. <https://doi.org/10.1016/j.scitotenv.2018.12.471>
- Anapalli, S. S., Fisher, D. K., Reddy, K. N., Pettigrew, W. T., Sui, R., & Ahuja, L. R. (2016). Vulnerability and adaptation of cotton to climate change in the Mississippi Delta. *Climate*, 4(4), 55. <https://doi.org/10.3390/cli4040055>
- Anapalli, S. S., Green, T. G., Gowda, P., Reddy, K. N., Fisher, D. K., & Sui, R. X. (1997). Adaptation and application of an energy balance method for estimating evapotranspiration in cropping systems. *Agricultural Water Management*, 240, 107–117.
- Anapalli, S. S., Pettigrew, W. T., Reddy, K. N., Ma, L., Fisher, D. K., & Sui, R. (2016). Climate optimized planting windows for cotton in the lower Mississippi Delta region. *Agronomy*, 6(4), 1–15. <https://doi.org/10.3390/agronomy6040046>
- Baker, J. M., & Griffis, T. J. (2005). Examining strategies to improve the carbon balance of corn/soybean agriculture using eddy covariance and mass balance techniques. *Agricultural and Forest Meteorology*, 128, 163–177. <https://doi.org/10.1016/j.agrformet.2004.11.005>
- Baldocchi, D. D. (2003). Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: The past, present, and future. *Global Change Biology*, 9, 479–492. <https://doi.org/10.1046/j.1365-2486.2003.00629.x>
- Baldocchi, D. (2014). Measuring fluxes of trace gases and energy between ecosystems and the atmosphere—the state and future of the eddy covariance method. *Global Change Biology*, 20, 3600–3609. <https://doi.org/10.1111/gcb.12649>
- Baldocchi, D. (2020). How eddy covariance flux measurements have contributed to our understanding of global change biology. *Global Change Biology*, 26, 242–260. <https://doi.org/10.1111/gcb.14807>
- Baldocchi, D., Chu, H., & Reichstein, M. (2018). Inter-annual variability of net and gross ecosystem carbon fluxes: A review. *Agricultural and Forest Meteorology*, 249, 520–533. <https://doi.org/10.1016/j.agrformet.2017.05.015>
- Baldocchi, D., Falge, E., Gu, L., Olson, R., & Hollinger, D. (2020). FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities. *American Meteorological Society*, 82, 2415–2434. [https://doi.org/10.1175/1520-0477\(2001\)082\(2415:FANTTS\)2.3.CO;2](https://doi.org/10.1175/1520-0477(2001)082(2415:FANTTS)2.3.CO;2)
- Burt, C. M., Clemmens, A. J., Strelkoff, T. S., Solomon, K. H., Bliesner, R. D., Hardy, L. A., Howell, T. A., & Eisenhauer, E. (1997). Irrigation performance measures: Efficiency and uniformity. *Journal of Irrigation and Drainage Engineering*, 123(6), 423–442. [https://doi.org/10.1061/\(ASCE\)0733-9437\(1997\)123:6\(423\)](https://doi.org/10.1061/(ASCE)0733-9437(1997)123:6(423))
- Byrne, B., Liu, J., Bloom, A. A., Bowman, K. W., Butterfield, Z., Joiner, J., Keenan, T. F., Keppel-Aleks, G., Parazoo, N. C., & Yin, Y. (2020). Contrasting regional carbon cycle responses to seasonal climate anomalies across the east-west divide of temperate North America. *Global Biogeochemical Cycles*, 34(11), e2020GB006598. [10.1029/2020GB006598](https://doi.org/10.1029/2020GB006598)
- Cai, X., Rosegrant, M. W., & Ringler, C. (2003). Physical and economic efficiency of water use in the river basin: Implications for efficient water management. *Water Resources Research*, 39(1), 1013. <https://doi.org/10.1029/2001WR000748>
- De Roo, F., Zhang, S., Huq, S., & Mauder, M. (2018). A semi-empirical model of the energy balance closure in the surface layer. *PLoS ONE*, 13(12), e0209022. <https://doi.org/10.1371/journal.pone.0209022>
- Evans, R. G., & Sadler, E. J. (2008). Methods and technologies to improve the efficiency of water use. *Water Resources Research*, 44(7), 1–15. <https://doi.org/10.1029/2007WR006200>
- Falge, E., Baldocchi, D., Olson, R., Anthoni, P., Aubinet, M., Bernhofer, C., Burba, G., Ceulemans, R., Clement, R., Dolman, H., Granier, A., Gross, P., Grünwald, T., Hollinger, D., Jensen, N. O., Katul, G., Keronen, P., Kowalski, A., Lai, C. T., ... Wofsy, S. (2001). Gap filling strategies for defensible annual sums of net ecosystem exchange. *Agricultural and Forest Meteorology*, 107, 43–69. [https://doi.org/10.1016/S0168-1923\(00\)00225-2](https://doi.org/10.1016/S0168-1923(00)00225-2)
- FAO. (2022). *Greenhouse gas emissions from agrifood systems—Global, regional and country trends, 2000–2020* (FAOSTAT Analytical Brief Series No. 50). FAO. <https://www.fao.org/about/who-we-are/departments/statistics-division>
- Guo, X., Shang, G., Tian, Y., Jia, X., Zha, T., Li, C., Yang, H., & Zhang, X. (2021). Dynamics of nocturnal evapotranspiration and its biophysical controls over a desert shrubland of Northwest China. *Forests*, 12(10), 1296. <https://doi.org/10.3390/f12101296>
- Hatfield, K. J., Boote, B. A., Kimball, L. H., Ziska, R. C., Izaurralde, D., Ort, A. M., Thomson, D., & Wolfe, W. (2011). Climate impacts on agriculture: Implications for crop production. *Agronomy Journal*, 103(2011), 351–370. <https://doi.org/10.2134/agronj2010.0303>
- Hernandez-Ramirez, G., Hatfield, J. L., Parkin, T. B., Sauer, T. J., & Prueger, J. H. (2011). Carbon dioxide fluxes in corn–soybean rotation in the midwestern U.S.: Inter- and intra-annual variations, and biophysical controls. *Agricultural and Forest Meteorology*, 151(12), 1831–1843. <https://doi.org/10.1016/j.agrformet.2011.07.017>
- Hugler, M., & Sievert, S. (2011). Beyond the Calvin cycle: Autotrophic carbon fixation in the ocean. *Annual Review of Marine Science*, 3, 261–289. <https://doi.org/10.1146/annurev-marine-120709-142712>
- Isaac, P., Cleverly, J., McHugh, I., van Gorsel, E., Ewenz, C., & Beringer, J. (2017). OzFlux data: Network integration from collection to curation. *Biogeosciences*, 14(12), 2903–2928. <https://doi.org/10.5194/bg-14-2903-2017>
- Janssens, I. A., Lankreijer, H., Matteucci, G., Kowalski, A. S., Buchmann, N., Epron, D., Pilegaard, K., Kutsch, W., Longdoz, B., Grünwald, T., Montagnani, L., Dore, S., Rebmann, C., Moors, E. J., Grelle, A., Rannik, U., Morgenstern, K., Clement, R., Oltchev, S., ... Valentini, R. (2001). Productivity overshadows temperature in determining soil and ecosystem respiration across European forests. *Global Change Biology*, 7, 269–278. <https://doi.org/10.1046/j.1365-2486.2001.00412.x>
- Kang, J., Hao, X., Zhou, H., & Ding, R. (2021). An integrated strategy for improving water use efficiency by understanding physiological mechanisms of crops responding to water deficit: Present and prospect. *Agricultural Water Management*, 255, 107008. <https://doi.org/10.1016/j.agwat.2021.107008>

- Katayanagi, N., & Hatano, R. (2005). Spatial variability of greenhouse gas fluxes from soils of various land uses on a livestock farm in Southern Hokkaido, Japan. *Phyton*, 45, 309–318.
- Lasslop, G., Reichstein, M., Papale, D., Richardson, A., Arneth, A., Barr, A., Stoy, P., & Wohlfahrt, G. (2010). Separation of net ecosystem exchange into assimilation and respiration using a light response curve approach: Critical issues and global evaluation. *Global Change Biology*, 16(1), 187–208. <https://doi.org/10.1111/j.1365-2486.2009.02041.x>
- Law, B. E., Turner, D., Lefsky, M., Campbell, J., Guzy, M., Sun, O., Van Tuyl, S., & Cohen, W. (2006). Carbon fluxes across regions: Observational constraints at multiple scales. In J. Wu, B. Jones, H. Li, & O. Loucks (Eds.), *Scaling and uncertainty analysis in ecology: Methods and applications* (pp. 167–190). Springer. <https://doi.org/10.1007/1-4020-4663-4>
- Lee, X. (1998). On micrometeorological observations of surface-air exchange over tall vegetation. *Agricultural and Forest Meteorology*, 91, 39–49. [https://doi.org/10.1016/S0168-1923\(98\)00071-9](https://doi.org/10.1016/S0168-1923(98)00071-9)
- Lei, F., Crow, W. T., Holmes, T. R. H., Hain, C., & Anderson, M. C. (2018). Global investigation of soil moisture and latent heat flux coupling strength. *Water Resources Research*, 54, 8196–8215. <https://doi.org/10.1029/2018WR023469>
- Mauder, M., & Foken, T. (2006). Impact of post-field data processing on eddy covariance flux estimates and energy balance closure. *Meteorologische Zeitschrift*, 15, 597–609. <https://doi.org/10.1127/0941-2948/2006/0167>
- Menefee, D., Rajan, N., Cui, S., Bagavathiannan, M., Schnell, R., & West, J. (2020). Carbon exchange of a dryland cotton field and its relationship with PlanetScope remote sensing data. *Agricultural and Forest Meteorology*, 294(2), 108130. <https://doi.org/10.1016/j.agrformet.2020.108130>
- Moncrieff, J. B., Clement, R., Finnigan, J., & Meyers, T. (2004). Averaging, detrending and filtering of eddy covariance time series. In X. Lee, W. J. Massman, & B. E. Law (Eds.), *Handbook of micrometeorology: A guide for surface flux measurements* (pp. 7–31). Kluwer Academic.
- Moncrieff, J. B., Massheder, J. M., de Bruin, H., Elbers, J., Friborg, T., Heusinkveld, B., Kabat, P., Scott, S., Soegaard, H., & Verhoef, A. (1997). A system to measure surface fluxes of momentum, sensible heat, water vapor and carbon dioxide. *Journal of Hydrology*, 188–189, 589–611. [https://doi.org/10.1016/S0022-1694\(96\)03194-0](https://doi.org/10.1016/S0022-1694(96)03194-0)
- Oosterhuis, D. M. (1990). Growth and development of the cotton plant. In W. N. Miley, & D. M. Oosterhuis (Eds.), *Nitrogen nutrition of cotton: Practical issues* (pp. 1–24). American Society of Agronomy.
- Pielke, R. A., Avissar, R., Raupach, M., Dolman, A. J., Zeng, X., & Denning, A. S. (1998). Interactions between the atmosphere and terrestrial ecosystems: Influence on weather and climate. *Global Change Biology*, 4(5), 461–475. <https://doi.org/10.1046/j.1365-2486.1998.t01-1-00176.x>
- Powers, S. (2007). Agricultural water use in the Mississippi Delta. Delta groundwater. In *37th Annual Mississippi water resources conference proceedings* (pp. 47–51). Mississippi State University. <https://www.wrri.msstate.edu/pdf/powers07.pdf>
- Rajan, N., Maas, S. J., & Cui, S. (2013). Extreme drought effects on carbon dynamics of semi-arid pasture. *Agronomy Journal*, 105, 1749–1760. <https://doi.org/10.2134/agronj2013.0112>
- Ray, R. L., Griffin, R. W., Fares, A., Elhassan, A., Awal, R., Wollesenbet, S., & Risch, E. (2020). Soil CO₂ emission in response to organic amendments, temperature, and rainfall. *Scientific Reports*, 10, 1–14. [10.1038/s41598-020-62267-6](https://doi.org/10.1038/s41598-020-62267-6)
- Reichstein, M., Falge, E., Baldocchi, D., Papale, D., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Gilmanov, T., Granier, A., Grünwald, T., Havránková, K., Ilvesniemi, H., Janous, D., Knohl, A., Laurila, T., Lohila, A., Loustau, D., Matteucci, G., ... Valentini, R. (2005). On the separation of net ecosystem exchange into assimilation and ecosystem respiration: Review and improved algorithm. *Global Change Biology*, 11, 1424–1439. <https://doi.org/10.1111/j.1365-2486.2005.001002.x>
- Runkle, B. R. K., Rigby, J. R., Reba, M. L., Anapalli, S. S., Bhattacharjee, J., Krauss, K. W., & Liang, L. (2017). Delta-Flux: An eddy covariance network for a climate-smart Lower Mississippi Basin. *Agricultural & Environmental Letters*, 2, 170003. <https://doi.org/10.2134/ael2017.01.0003>
- Suyker, A. E., Verma, S. B., Burba, G. G., & Arkebauer, T. J. (2005). Gross primary production and ecosystem respiration of irrigated maize and irrigated soybean during a growing season. *Agricultural and Forest Meteorology*, 131(3–4), 180–190. <https://doi.org/10.1016/j.agrformet.2005.05.007>
- van Dijk, A., Moene, A. F., & de Bruin, H. A. R. (2004). *The principles of surface flux physics: Theory, practice and description of the EC PACK library*. Meteorology and Air Quality Group, Wageningen University.
- Vickers, D., & Mahrt, L. (1997). Quality control and flux sampling problems for tower and aircraft data. *Journal of Atmospheric and Oceanic Technology*, 14, 512–526. [https://doi.org/10.1175/1520-0426\(1997\)014<0512:QCAFSF>2.0.CO;2](https://doi.org/10.1175/1520-0426(1997)014<0512:QCAFSF>2.0.CO;2)
- Wagle, P., Zhou, Y., Northup, B. K., Moffet, C., & Gunter, S. A. (2024). Carbon dioxide fluxes over irrigated and rainfed alfalfa in the Southern Great Plains, US. *European Journal of Agronomy*, 159, 127265. <https://doi.org/10.1016/j.eja.2024.127265>
- Webb, E. K., Pearman, G. I., & Leuning, R. (1980). Correction of the flux measurements for density effects due to heat and water vapour transfer. *Quarterly Journal of the Royal Meteorological Society*, 106, 85–100. <https://doi.org/10.1002/qj.49710644707>
- Wutzler, T., Lucas-Moffat, A., Migliavacca, M., Knauer, J., Sickel, K., Sigut, L., Menzer, O., & Reichstein, M. (2018). Basic and extensible post-processing of eddy covariance flux data with REddyProc. *Bio-geosciences, Copernicus*, 15, 5015–5030. <https://doi.org/10.5194/bg-15-5015-2018>
- Zheng, X., Yang, F., Mamtimin, A., Huo, X., Gao, J., Ji, C., Abudukade, S., Li, C., Sun, Y., Wang, W., Cui, Z., Wang, Y., Ma, M., Huo, W., Zhou, C., & Yang, X. (1988). Farmland carbon and water exchange and its response to environmental factors in Arid Northwest China. *Land*, 2023, 12. <https://doi.org/10.3390/land12111988>

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