INFLUENCE OF LAND-USE CHANGE AND AGRICULTURE PRACTICES ON WATER, CARBON, ENERGY FLUXES

A Thesis

by

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ABSTRACT

The expansion of the urban area and agriculture field in the past centuries converted many natural prairies to crop fields and residence places, which brought many problems that influenced the interactions between biosphere and atmosphere. However, the effects caused by the land-use change were various at different locations and sometimes showed conflict results. In this study, we concentrated on agriculture development in Texas Blackland Prairies to investigate the regional influence of land-use change and agriculture practices on the carbon flux, evapotranspiration, and energy transformation. We expected (1) to estimate total carbon uptake water use efficiency(WUE), and total corn yields under different ecosystems and management practices, (2) to compare the gas fluxes, energy fluxes and micrometeorology in observation sites, (3) to determine the effect of agriculture strategies and land-use change on gas fluxes and energy partitioning. We collected flux data through the Eddy Covariance system in the native prairie (RFPr), conventional field (RFTA), and aspirational field (RFAA) at different biophysical statuses and monitored the plant growth with PhenoCam. The total carbon uptake was 1062 g/m^2,1388 g/m^2, and 2166 g/m^2 in RFPr, RFAA, and RFTA respectively. The total corn yield of the conventional field was higher than the aspirational field as well as the WUE. The RFPr and RFTA showed subtle differences in WUE, soil moisture and energy partitioning which indicated the land use change without disturbance from other agriculture practices might not influence the biosphere-atmosphere interactions. But the more significant difference between RFTA and RFAA in carbon, water and energy fluxes demonstrated the weed control might be more influential than the plant cover change.

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Contributors

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All other work conducted for the thesis was completed by the student independently.

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1. INTRODUCTION

The booming population in past centuries resulted in the expansion of urban areas and agriculture fields. Many natural ecosystems were converted to crop fields and residential areas. These conversions caused many problems such as soil erosion, water deficit, and the greenhouse effect. In this research, we concentrated on the land-use change due to the agriculture development and compared the carbon flux, energy fluxes, soil moisture, water use efficiency, and meteorological factors under different biophysical stages and post-harvest in three Texas Water Observatory (TWO) sites located in the United States Department of Agriculture Riesel Station in Central Texas USA. Our objectives were to demonstrate the influence of land-use change and agriculture management on the carbon flux, energy fluxes, evapotranspiration, and micrometeorological variables during the growing season.

1.1. Current Research on the USDA-Riesel Site

Previous studies in the USDA-Riesel watershed detailed its surface water runoff, water quality, and agriculture productivity. Hydrologic data for this site has been available since its founding in 1937. They are generally continuous and sufficient for a wide range of hydrology research (Baird et al., 1950). They provide valuable information for hydrologic structure design, water supply, and water quality management, which are also the necessary factors for model development (Harmel et al., 2003). Analysis of the long-term precipitation data can help predict future water supplies (Harmel et al., 2003).

Some research is pertinent to soil loss problems under different conservation managements like terracing cultivated fields, establishing grass waterways, and changing plant coverage (Baird et al., 1971; Harmel et al., 2006). Runoff is an important factor to control soil loss and was measured in different practice conditions with a rotation of crops such as corn, cotton and oats, and permanent grass (Baird et al., 1971). However, empirical data indicated that nearly half of the soil loss happened in the upper 10% soil erosion events which were not influenced by extreme precipitations or runoff (Furl et al., 2015). Utilization of a winter cover crop in row crop production and replacement of small grain production were effective methods for handling the soil erosion and pollutant problems (Harmel et al., 2006).

Because the Texas Blackland Prairies ecoregion is dominated by expansive soils, vertisol hydrology has also been studied since the site establishment. The formation mechanism of vertisol is fundamental research for the soil problems, and a comparison between modern and ancient vertisols development could show the future soil trend at the USDA-ARS Riesel site (Driese et al., 2003). Due to the special characteristics (high clay content (>30%), a high shrink-swell potential, and microrelief features known as gilgai, of the vertisol), the estimation of runoff and infiltration at Riesel site is difficult to determine precisely (Arnold et al., 2005). The temporal and spatial variabilities of runoff also influence the estimation of plant-available water and generation of streamflow (Kishné et al., 2014).

Effects of poultry litter on soil and water quality as a soil amendment and nutrient source were focused by researchers. Application of poultry litter had an influence on soil microbial communities and enzyme activities which could further affect the crop and forage production (Acosta-Martínez et al., 2006). The water quality and ago-economics were also under the influence of the poultry litter application as fertilizer on the site (Harmel et al., 2009).

Research about air pollution in rural areas was also conducted according to the atmospheric aerosol records from the Riesel site(Barrett et al., 2014). Studies at Riesel watershed provided vital information for the models that are used worldwide on water quality problems and assisted analysis of the agronomic and environmental effects of different agricultural management. The research at the Riesel site is an important resource for future research on water availability, soil conservancy, and agricultural management (Harmel et al., 2007).

1.2. Influence of Land Use Change on Land-Atmosphere Interactions

Land-use change affects the ecosystem significantly. It can be triggered by various kinds of driving force such as wildfire and anthropogenic influence. Agriculture is one of the dominant anthropogenic factors that caused the land-use change (Kalnay et al., 2003). Although the influence of agriculture cannot be clearly distinguished from urbanization, the conversion from the natural ecosystem to agriculture fields still showed overwhelming effects on the regional climate in California (Kueppers et al., 2012). The shift from prairie to agriculture field can result in increased soil erosion, soil nutrient loss, and groundwater contamination caused by the nitrate leaching (Wagai et al., 1998). This conversion also influences the exchanges of water, energy, and carbon between land surface and atmosphere through changing the surface roughness, albedo, leaf conductance, and other characteristics of the ecosystems (Kueppers et al., 2012). Research in Mexico and Latin America indicated that irrigated agriculture can reduce water loss by advanced irrigation techniques and improve the water use efficiency (WUE) (Huang et al., 2006). The increasing soil organic carbon accumulation after the reversion of grassland from the maize field also demonstrated the land-use change influence on the ecosystem (Post et al., 2000).

Management practices play an important role in the land-use change caused by agriculture. Current studies of agriculture management practices concentrated on the timing of the harvest, tillage practice, and irrigation (Kueppers et al., 2012). The land productivity of crops is various with different management practices. The variation of land productivity could reflect the carbon emission or sequestration potential of the fields under different management strategies (West et al., 2003). If crop yields decreased after the change of management, the net carbon flux to the atmosphere would increase under the same system (West et al., 2003). Kueppers and Snyder (2011) proposed that decreased tillage, efficient use of fertilizer and irrigation can lead to the increase of carbon sequestration in soil and decreasing carbon flux between the soil surface and atmosphere (West et al., 2003). However, our emphasis on agriculture management was the adoption of herbicides.

1.2.1. Water Use Efficiency

As a result of the plant community change, water use efficiency (WUE) would change with different land cover. In the research conducted in Southwest Michigan, the WUE of cornfields was higher than perennial grassland even the grasslands were dominated by C4 grass which showed stronger adaptability of water-limited conditions compared with C3 grass (Abraha et al., 2016). The WUE of corn is a function of the biophysical characteristics of corn, soil characteristics such as soil moisture, climate conditions, and agriculture management practices (Huang et al., 2006). In this study, the weed-control practice was discussed as the variable that influenced the WUE.

1.2.2. Climate Change

Many studies focused on climate change after the shift of the land cover, since the ecosystem conversion altered the land cover characteristics such as surface roughness, leaf area index, and surface albedo which would further influence net radiation and energy partitioning (Bonan, 1997). However, the climate response to the land-use change was variable in space and time (Kueppers et al., 2012; Zhao et al., 2002). The moistening of the near-surface air atmosphere ranged from 0.5 to 1.5 g/kg in spring and summer over most places in the US. From the continental scenario, the conversion from natural vegetation to modern vegetation resulted in air temperature 1 ℃ cooler in the eastern US and 1 ℃ warmer in the western US in spring, while air temperature cooling up to 2 ℃ over a wide region of central US in summer (Bonan, 1997). The diurnal air temperature was reported to change with the agriculture practice. Irrigation increased the soil heat capacity and raised the minimum diurnal temperature in the east of Rockies. Thus, the diurnal temperature range decreased (Kalnay et al., 2003). Results from regional climate simulations indicated that the impact of irrigated agriculture on diurnal temperature variation was coherent with the variation in surface energy partitioning and net radiation differences. The change in air temperature could further affect regional wind speed. A study in California Central Valley simulated the sensible heat and air temperature change after the agriculturalization. The results showed a slight abatement of onshore wind due to the decreased air pressure gradient resulted from decreasing sensible heat and surface temperature (Kueppers et al., 2012). However, most of the research on the influence of agriculture on regional climate change concentrated on the irrigation process. In this research, we will discuss the effects of land-use change and agriculture practices on the micrometeorology to investigate more possibility that caused by anthropogenic activities.

1.2.3. Current Research on Carbon, Energy, and Water

The estimation of carbon exchange is significant in the research on climate change and the productivity influenced by agriculture practice. The carbon sequestration in the surface 15 cm is believed to offset the increasing carbon emission in the rotationally grazed pasture system (Sanford et al., 2012). The factors that will influence the carbon sequestration in the soil and plants have been studied, such as the climate, vegetation canopy, and anthropogenic management. Results from past research indicated that the change of management practices in the tillage and season of the cover crop didn't affect the carbon sequestration (Baker et al., 2005; West et al., 2002). The daily net CO_2 exchange (NCE) trend in a tallgrass prairie was not directly influenced by the weather either. Whereas the carbon flux was influenced by the leaf area, radiation and soil water content and the total annual carbon sequestration varied with the plant types and growth duration (Dugas et al., 1999; Zeri et al., 2011). The senescence of the canopy controlled the daily net CO_2 exchange (NCE) trend in tallgrass prairie (Ham et al., 1998).

The understanding of the energy balance is closely related to the research on the evapotranspiration pattern. The sensible heat and latent heat are dominant components of the energy balance during the daytime They vary with the season change and respond directly to the canopy change (Burba et al., 1999; Ham et al., 1998). Many models have been established to describe the relationship between energy and water balance, especially under agricultural conditions (Douglas et al., 2006; Kellner, 2001; Milly, 1986). Application of Bowen Ratio method on evapotranspiration brought hydrologists a better understanding of improving water use efficiency in agricultural management (Zeggaf et al., 2008).

Eichelmann et al. (2016) showed that the carbon uptake for switchgrass was higher than corn in Southwestern Ontario Canada. The annual net ecosystem exchange of switchgrass was -336 ± 44 g C m^{-2}, while the annual NEE of corn was $+64 \pm 41$ g C m^{-2} (Eichelmann et al., 2016). However, under different meteorological and geographical conditions, the type of native grass and the efficiency of corn carbon uptake were diverse. The results of the comparison were changed. The study conducted in Central Illinois, USA indicated that although the carbon uptake of switchgrass was higher, carbon absorption of both plants was higher than the carbon release. The carbon uptake of switchgrass was 344 ± 20 g C m^{-2} which was similar to the corn (307 ± 40 g C m^{-2}) (Zeri et al., 2011). With the application of Bowen ratio/energy balance method, the measurement of carbon dioxide fluxes in Blackland Prairie represented that the annual carbon uptake in the prairie was 50 g C m^{-2} and 80 g C m^{-2} in 1993 and 1994 respectively (Dugas et al., 1999). The reported ET for a tallgrass prairie ranged from 663 mm/y to 813 mm/y depending on the environmental condition (Wagle et al., 2015). Since corn is a C4 plant that has a high-temperature optimum, the carbon uptake of corn in Texas would be higher than that in a cooler area. In this research, the ecosystem of native prairie is composed of C3 and C4 grass. The growth duration of the native grass is longer than that of switchgrass growing in the cold area. Therefore, the annual NEE of three observation sites at USDA-Riesel Station are expected to be higher than the results above.

1.3. Objectives

By comparing the carbon flux, energy fluxes, soil moisture, water use efficiency, and meteorological factors under different biophysical stages and post-harvest in three TWO sites, our aim was to determine the influence of land-use change and agriculture management on the carbon flux, energy fluxes, evapotranspiration, and micrometeorological variables during the growing season on the USDA-Riesel Station. The specific goals were: (a) to evaluate the differences in carbon flux, ET, and water use efficiency under different plant coverage and management strategies, (b) to determine the alteration of energy partitioning and net radiation after weed-control practice and land-use change, (c) to compare the micrometeorology variables in three observation sites at USDA-Riesel Station. Our hypotheses were: (a) the carbon flux, water flux and net radiation decreased after conversion from native prairie to cornfields ;(b) water use efficiency of the native prairie was higher than that of cornfields and the corn productivity of aspirational field was higher than that of the traditional field;(c) land-use change would influence the micrometeorology variables.

2. MATERIAL AND METHOD

2.1. Study Site

USDA-ARS Riesel site (31 28’30” N, 96 55’64” W) in central Texas, USA is owned and managed by the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS) Grassland, Soil, and Water Research Laboratory. It has been operational since the mid-1930s (Barrett et al., 2014), and it is currently part of the USDA’s network of Long-Term Agroecosystem Research (LTAR) stations, which aimed to provide knowledge of agricultural sustainability in future development and solutions of long-lasting problems linked to soil, water energy, and economic aspects (Kleinman et al., 2018; Robertson et al., 2006; Walbridge et al., 2011).

The site is representative of a significant agricultural region, the Texas Blackland Prairies ecosystem, which covers 4.45 million ha. The soil type in this site is Houston Black clay, which consists of fine, smectitic, thermic, and udic haplusterts. These soils respond strongly and visibly to changes in soil water content by shrinking when dry and swelling when wet (Harmel et al., 2013). The land is used for growing different crops like corn, wheat, and cotton and for livestock grazing with various agricultural management methods including conventional tillage and fertilizer treatment.

The collection of precipitation and hydrologic data started in 1938. In the period between 1939 to 1999, annual precipitation was approximately 890 mm (Harmel et al., 2003) and the annual temperature was 19.5 ℃ (Potter, 2010). Generally, precipitation reaches a maximum in the spring and a minimum in the summer. Intense precipitation of up to 16 inches per month can occur with the passing of the Canadian continental and

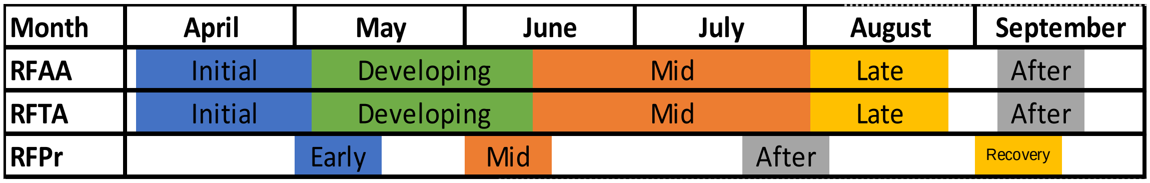
Pacific maritime fronts, occasional tropical storms and hurricanes, and convective storms (Hershfield, 1971). The annual precipitation in 2019 was 652 mm which was lower than the average annual precipitation. The mean air temperature of 2019 was 18.8 ℃ which was also lower than the mean annual temperature Thus, it was a dry and cool year in 2019 at USDA-Riesel watershed.

This study focused on three sites within the USDA Riesel watershed: the Native Prairie Site (RFPr), the Traditional Agriculture Site (RFTA), and the Aspirational Agriculture (RFAA) sites. Monitoring was established in 2018 by the Texas Water Observatory (TWO) in collaboration with the USDA, and data from the first full growing season (2019) is used in this study. Additionally, the USDA Riesel Farm Weather Station (RFWS) located at the edge of the RFPr provided climate data at a one-hour time interval to facilitate weather monitoring. The climatic and hydrologic conditions of the three sites were identical.

Historically, the RFPr was established since 1955 as pasture/meadow. Generally, the grass growing at RFPr was baled twice a year on average. The adoption of herbicide started in 1990 and stopped in 2011. The RFTA has been crop fields since it was established in 1943. It grew crops such as oats, corn, and wheat, which was managed under the conventional tillage practice including Tandem Disc, Chisel Plow, etc. The adoption of herbicides and fertilizer started in 1982. It stopped growing wheat and restarted growing corn in the growing season of 2018. The RFAA was established as pasture/meadow at first since 1945. It was converted into the crop field since 1956. Similar to RFTA, it was managed under conventional tillage practice and became corn field since 2018. The poultry litter was sprayed as fertilizer from 2001 to 2016.

During our research period, the PFPr was a native prairie field growing native grass and forbs including little bluestem, indiangrass, big bluestem, and prairie bishop (Singhurst et al.). There was no management conducted on this site, except for late-season cutting for forage, which occurred on July 19th, 2019. The RFTA and RFAA were agricultural fields; they were planted with maize on April 3rd, 2019, and harvested on August 26th, 2019. In RFTA, fertilizer was applied at a traditional rate, and crops are managed without tillage practice. In RFAA, fertilizer was applied based on the Haney Soil Test. Herbicides and pesticides were sprayed after planting. After the maize was harvested, the field sits fallowed until late fall when herbicides were applied to prepare the field for planting of winter pea in 2019

Corn was planted on April 4th, 2019, and harvested on August 26th, 2019 at agriculture sites. We separated the corn growing season into four growth stages according to the time intervals of corn single crop coefficient. The single crop coefficient was able to reflect the ET of cornfields under different biophysical statuses. Besides, we selected a two-week interval to monitor the change of fields after the harvest immediately because a two-week interval could provide sufficient data to analyze the field response and avoid the disturbance caused by the recovery of cool grass in agriculture fields. Similarly, we chose four two-week intervals to monitor the gas fluxes and energy fluxes under different growth statuses. These four intervals were determined from plant stages reflected in PhenoCam.



Month	April	May	June	July	August	September
RFAA	Initial	Developing		Mid	Late	After
RFTA	Initial	Developing		Mid	Late	After
RFPr		Early	Mid	After		Recovery

Figure 1 Time intervals of the growth stages at RFAA, RFTA, and RFPr

2.2. Observational Methods

2.2.1. Eddy Covariance Instrument and Methodology

In this research, the carbon flux, energy flux, and micrometeorology data are collected using an eddy covariance system at each of the TWO-Riesel sites. The EC system contains an integrated open-path infrared gas analyzer, a 3-d sonic anemometer (IRGASON), and a net radiation sensor (CNR4). Ancillary measurements include two soil water content reflectometers (CS655), two soil temperature probes (TCAV), four soil heat flux plates (HFP01), a temperature/RH probe (HMP155A), two quantum sensors (LI190R) for photosynthetically active radiation (PAR), and two rain gages (TE525WS).

Fluxes were calculated from 10-Hz measurements of wind and scalar fluctuations and upscaled to a 30-min interval using the EasyFlux® DL software (Campbell Scientific, version 1.03). The calculation is based on the following formulas (Burba, 2013):

$$G = \overline{\rho_d}\,\overline{u's'}$$

$$H = \bar{\rho}\, C_p \overline{u'T'}$$

$$ET = \frac{r}{\overline{P}}\overline{\rho_d}\,\overline{u'e'}$$

$$LE = \lambda\frac{r}{\overline{P}}\overline{\rho_d}\,\overline{u'e'}$$

Where ρ_d is the air density, u’ is the vertical wind speed, s’ is the dry mole fraction, C_p is the Isobaric specific heat ($C_p = 1.00\frac{kJ}{kg}$ $when$ T’ $= 300\ K$), T’ is the temperature, P is the air pressure, r is the ratio of molecular weight of the dry air to that of the water vapor (Ma/Mw=0.622), λ is the latent heat of evaporation ($\lambda = 2435.9\ K, when$ T' $= 300\ K$), and G, H, ET, and LE are carbon flux, sensible heat, water vapor flux, and latent heat respectively. Although eddy covariance is complex from a mathematical perspective, it is still one of the most reliable and direct ways to measure the carbon and energy fluxes.

2.2.2. PhenoCam Network System

Each site had an automated, web-enabled digital camera that monitored its dynamics over time and sent data to the PhenoCam Network repository (Seyednasrollah et al., 2019). Cameras were set to a fixed white balance, and the images were dominated by the native grass or maize and included approximately 20-30% sky view. A region of interest (ROI) was defined for each site to characterize the vegetation objective in each image. The PhenoCam servers store the camera imagery at a 30-min interval in a 24-bit JPEG image (1960*960 pixels). The JPEG images stores the color information into three layers (red, green, and blue; RGB). Each pixel is associated with a digital number (DN) triplet which represents the intensity of each color layer. Among the chromatic coordinates, green chromatic coordinate (GCC) is able to effectively reduce the impact of weather, atmospheric effects, and illumination conditions and is applied in the analysis of plant growth status:

$$G_{CC} = \frac{G_{DN}}{R_{DN} + G_{DN} + B_{DN}}$$

where R_{DN}, G_{DN}, B_{DN} are the RGB DN triplets. The daily average GCC is calculated to support the analysis of seasonal plant growth observations (Richardson et al., 2018; Sonnentag et al., 2012).

2.2.3. Time-Domain Reflectometry

Two soil monitoring nodes were installed at each site, at distances of approximately 50-400 m from the EC system, and each soil node included ten water content reflectometers at 5 different depths (sampling at 5 cm, 15cm, 30cm, 75cm, 100cm) underground, accompanied by ten heat dissipation matric to measure the soil moisture and soil temperature. Soil moisture data were collected at a 30-min time interval using the water content reflectometers (CS655-12 cm). The volumetric soil water content measurement range of the sensors is between 5% and 50% with an accuracy of ± 3%. The measurement range of the sensor is between -10 ℃ and 70℃ with an accuracy of ± 0.5 ℃

The Topp equation was used to convert the permittivity measured by the reflectometer to water content (Topp et al., 1980).

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} K_a - 5.5 \times 10^{-4} K_a^2 + 4.3 \times 10^{-6} K_a^3$$

where θ_v is the volumetric soil water content, K_a is the bulk dielectric permittivity of the soil. This equation is empirical and used in the calibration of CS 655 soil water content reflectometer.

2.3. Data Analysis

2.3.1. Gap Filling Methodology

Although the EC technique and equipment are well-developed, data gaps are inevitable due to system failures caused by power outages, instrument damage, and wildlife. Certain atmospheric conditions can also reduce data quality. According to the classification system proposed by Foken et al. (1996), the quality flag boundary was set as three which is believed suitable for fundamental research (Foken et al., 1996).

The outputs from sonic anemometer and infrared gas analyzer were applied in the determination of quality flags. EasyFlux could provide three types of quality flag: relative non-stationarity (RN_{cov}), relative integral turbulence characteristics (ITC), and horizontal wind angle in the sonic anemometer coordinate system. The system used ITC for sensible heat, carbon, and water fluxes.

$$ITC = 100 \times \frac{\left| ITC_{T-model} - \frac{\sqrt{\overline{T^2}}}{|T'|} \right|}{ITC_{model}}$$

$$T' = -\frac{\overline{Tw}}{u^*}$$

Where $ITC_{T\text{-}model}$ depends on the surface layer stability and ratio of aerodynamic height to the Obukhov length, T is average air temperature in Kelvin, w is the vertical velocity in m/s, u* is the friction velocity in m/s (Foken et al., 2012). The range of ITC can be classified into 9 grades and grades 1-3 were adopted in this research (Foken et al., 2004).Common gap-filling methods include mean diurnal variation (MDV), look-up table (LUT), artificial neural network (ANN), and nonlinear regression (Falge et al., 2001). Among these methods, LUT, ANN, and nonlinear regressions need to establish relationships between meteorology drivers simulated variables (Aubinet et al., 2012). In this research, MDV is applied due to the deficiency of the drivers. For the daytime data, a non-linear regression is conducted between the time and diurnal average of valid value at a 30-day interval. The missing observations within the 30-day interval were replaced by the predicted values of regression results. For the nighttime data, the missing observations within the 30-day interval were replaced by the diurnal average of valid values directly.

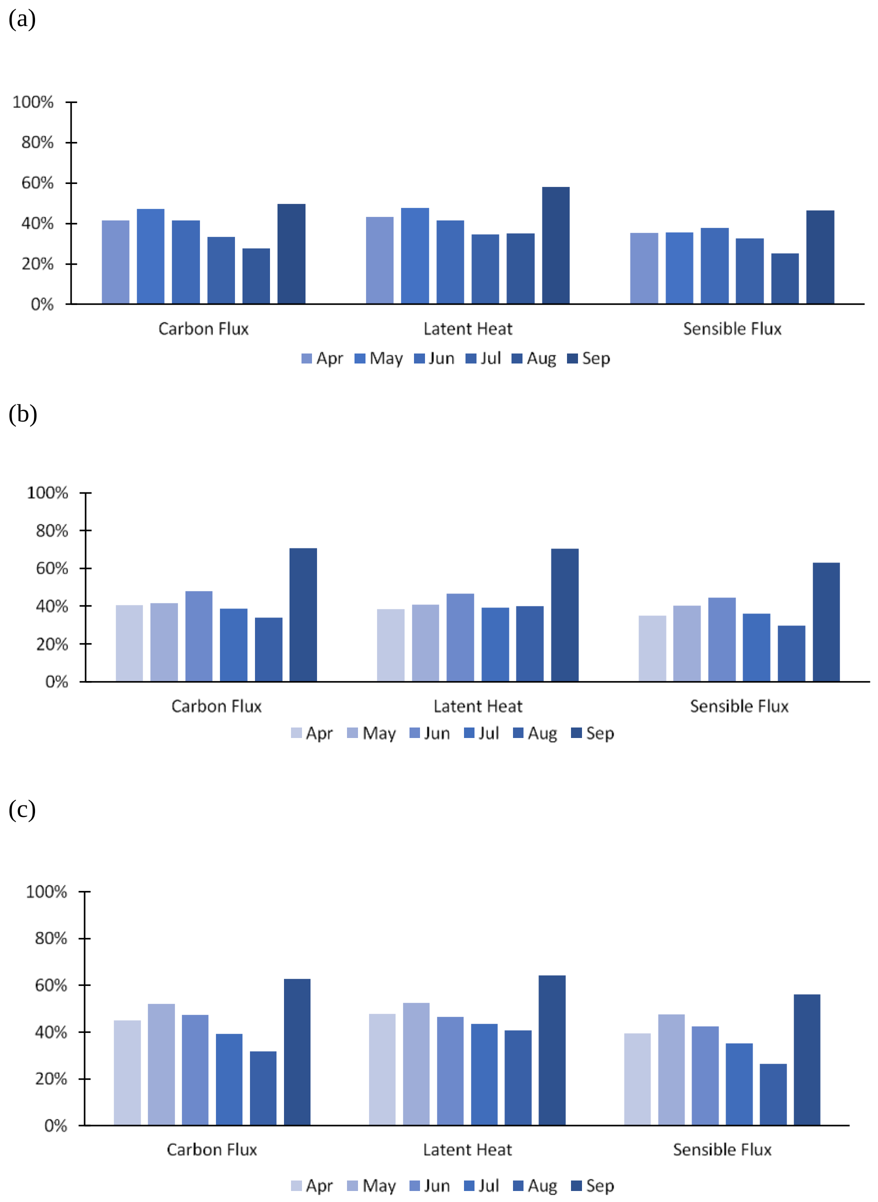


Figure 2 Percentage of the missing data in each month during the growing season at RFAA(a), RFTA(b), and RFPr(c)

2.3.2. Water Use Efficiency

Water use efficiency is the amount of carbon uptake per unit of water consumption by plants. Theoretically, the water use efficiency of each site is calculated as the ratio of the GPP and ET (Abraha et al., 2016; Hatfield et al., 2019). In this research, the regression slope of the daily GPP over daily ET is regarded as the water-use efficiency:

$$\mathrm{WUE} = \frac{GPP}{ET}$$

Where GPP is in C $\mathrm{g/m^2}$, ET is in mm, c is the intercept of the linear regression in C $\mathrm{g/m^2}$.

2.3.3. Root-Weighted Average Soil Moisture

The soil moisture data are collected at five depths: 5 cm, 15 cm, 30 cm, 75 cm, and 100 cm. Because the plant roots uptake water from soil happens in different ways at different depths, the average soil moisture was calculated using the root-weighted method at each soil node:

$$\bar{\theta} = \frac{\int_{Z}^{0} \theta(Z)(dp(z)\ /\ dz)\,dz}{\int_{Z}^{0} (dp(z)\ /\ dz)\,dz}$$

$$p(z) = 1 - b^{z}$$

where Z is the depth of the root zone (cm), z is the positive downward depth in (cm), and b is a dimensionless curve-fitting parameter (Miller et al., 2007). In this research, the b values are 0.961 and 0.94 in the agricultural and prairie fields respectively (Baldocchi et al., 2004; Jackson et al., 1996).

2.3.4. Standardization between Stations

The climate data from the Riesel Farm Weather Station (RFWS) is set as the reference axis to eliminate the temporal variation caused by the environmental climate change. The differences of the climate data at RFWS and TWO are regarded as the standard climate data that is used in the comparison:

$$W_s = W_T - W_R$$

where W_s represents the standard climate variables (air temperature in °C, soil temperature in °C, relative humidity in %, wind speed in m/s, and solar radiation in W/m^2), W_T represents the climate variables of TWO, and W_R represents the climate variables of RFWS. The standardization results would provide direct responses of weather variables to the land-use change.

2.3.5. Statistical Comparison

One of our aims was to test if the aspirational agriculture practice would improve water use efficiency and the corn productivity. Therefore, we hypothesized that aspirational agriculture practices would increase the gas fluxes, and energy fluxes due to higher canopy density so that the mean value of the variables in each growing period would be significantly different ($P<0.001$) between RFTA and RFAA. We conducted the ANOVA test in JMP® Pro 14 with the climate data, gap-filled carbon, and energy data and then compared each variable in each period individually.

3. RESULTS

We hypothesized: (1) the carbon flux, water flux, and energy fluxes were decreased by the land-use change from native prairie and would show variations among different biophysical stages, (2) the water use efficiency was higher at RFPr and crop yields at RFAA would were larger than that of RFTA, (3) land-use change also would lead to the micrometeorology change. Hypothesis tests are described in the following sections.

3.1. Water Use Efficiency

Between the two agricultural sites, more carbon uptake occurred in the field under traditional agricultural practice. The absorption of carbon in RFAA was about 60% of that in RFTA, which were -1388 g/m^2 and -2166 g/m^2 respectively (Table 1). About 35% of the carbon uptake contributed to the final corn yield. The total NEE of RFPr was -1062.68 g/m^2, indicating that the prairie had less carbon uptake than the crops (Figure 1). The evapotranspiration in the three sites was almost the same throughout the whole growing season (Figure 2). This indicates that the conventional agriculture field had higher water use efficiency at 6.3 kg/m^3/d than the aspirational agricultural field at 3.5 kg/m^3/d. The higher water use efficiency led to higher productivity of the corn.

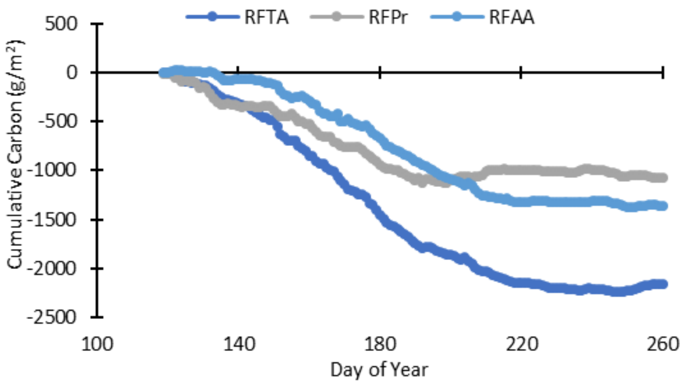


Figure 3 Cumulative carbon uptake during the growing season

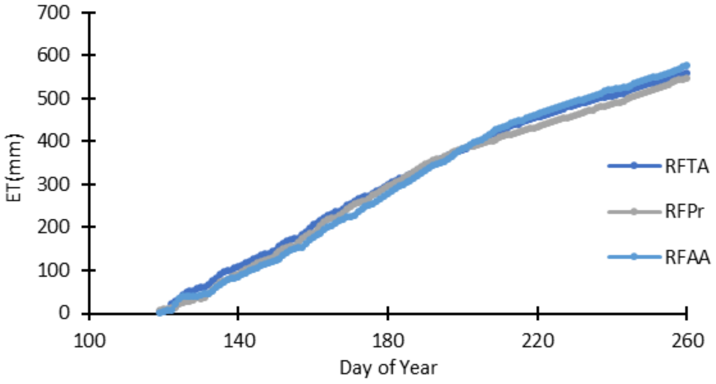


Figure 4 Cumulative evapotranspiration during the growing season

Table 1 Summary of the total carbon uptake, total et, and total corn productivity

	RFTA	RFAA	RFPr
Total ET (mm)	563	584	548
Total Carbon(g/m^2)	2166	1388	1062
Total Corn Yield(g/m^2)	782	482	
Growing Days	145	145	
WUE (kg/m^3/d)	6.3	3.5	6.7

3.2. Diurnal Patterns in Carbon, Water, and Energy Fluxes

3.2.1. Carbon Flux

Maximum diurnal carbon uptake in agricultural sites happened in the mid-period since this is when the crops are growing the fastest, which were -0.961 C mg/m^2/s for RFAA and -0.895 C mg/m^2/s for RFTA. The rates of carbon uptake for the native prairie in early and mid-periods were similar, which is up to -0.923 C mg/m^2/s. The comparison of diurnal carbon flux among three sites indicates that the capacity of carbon uptake was related to the sunlight and physiological stages of plants (Figure 3). The values of carbon flux during daytime were negative, indicating that the majority of the carbon was absorbed by the vegetation through photosynthesis as opposed to the carbon emission at night due to soil and plant respiration. Plant growth states influenced the daytime carbon flux. However, carbon fluxes at night were not influenced by the vegetation coverage; the values were nearly the same for the three sites, consistently around 0.3 mg/m^2/s (Figure 3).

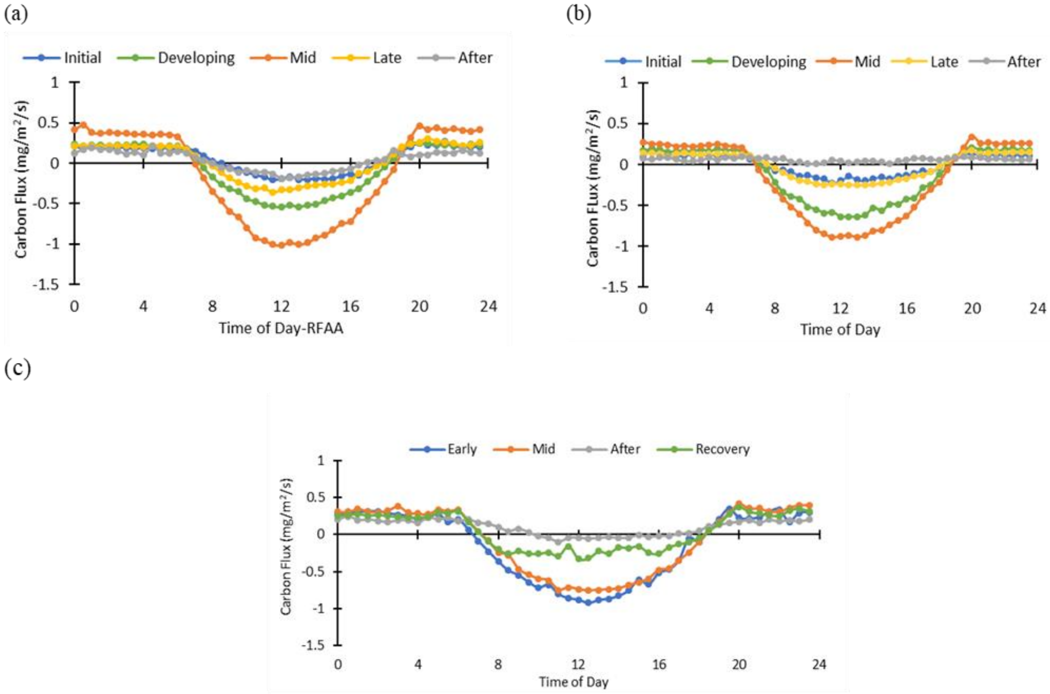


Figure 5 Diurnal average carbon fluxes at RFAA(a), RFTA(b), RFPr(c), segregated by season

Compared with RFAA, the carbon uptake of RFTA was significantly larger ($p<0.001$) in initial, developing, and late periods. Inversely, the carbon uptake of RFAA was significantly larger ($P<0.001$) than that of RFTA after harvest (Appendix A). But in mid-period the carbon uptake rates of two agriculture sites were not significantly different. In RFAA, the carbon uptake occurred during the developing and mid periods. However, in RFTA, the carbon uptake of plants only stopped after the harvest which is similar to the pattern of carbon flux change in native prairie within different biophysical stages (Figure 4). This suggested the carbon uptake in RFTA was influenced by the weeds. The duration of grass growing was longer than maize which made them have a higher capacity for carbon uptake in growing periods in RFTA.

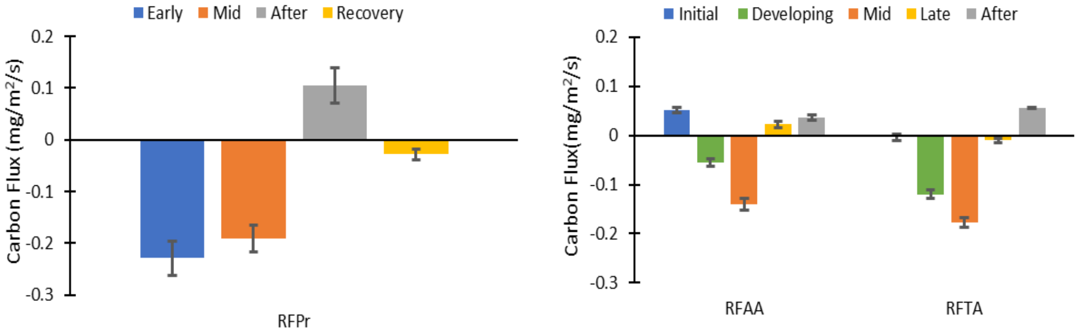


Figure 6 Average carbon flux of different biophysical periods at RFAA and RFTA

3.2.2. Energy Fluxes and Their Partitioning

The maximum diurnal net radiation of RFTA was 628 W/m^2 in the mid-period, while the maximum diurnal net radiation of RFPr was 589 W/m^2 (Figure 5). The average albedo in RFPr was 0.24, while it was slightly lower in RFTA at 0.21 (Figure 6).

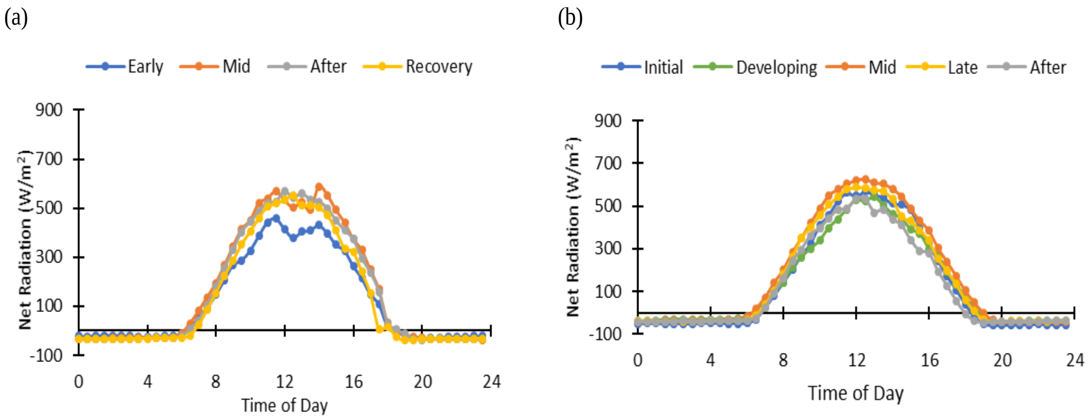


Figure 7 Diurnal average net radiation in RFPr(a), RFTA(b) segregated by season. Some monitoring and calculation errors happened in the data collection process at RFAA so the net radiation and albedo data were not available in this study.

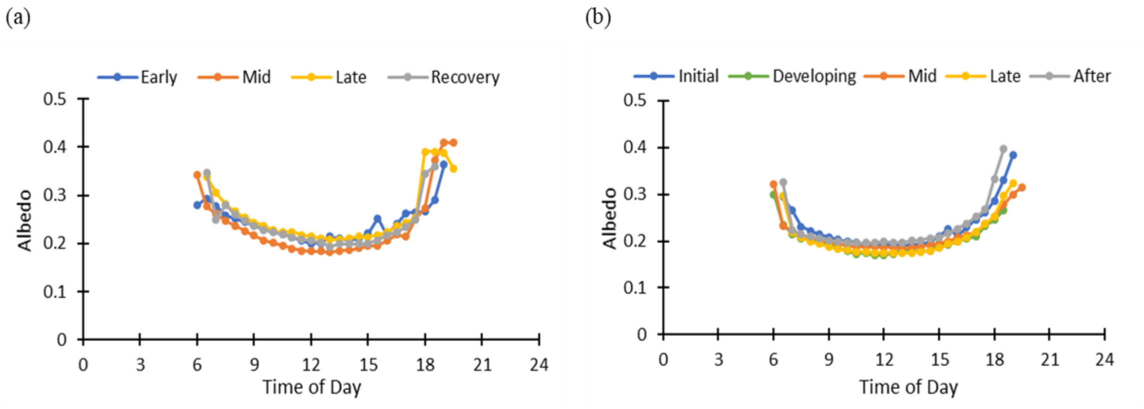


Figure 8 Diurnal average albedo in RFPr(a), RFTA(b) segregated by season

In RFPr, the net radiation during the mid-period was higher than other periods, which was identical to the lowest albedo value at mid-stage. Similarly, the net radiation was highest during the mid-period in RFTA (Figure 7). The net radiation might be linked to the green leaf density and structure of plant cover. The solar reflectivity may be altered by the leaf color shift or the plant community change.

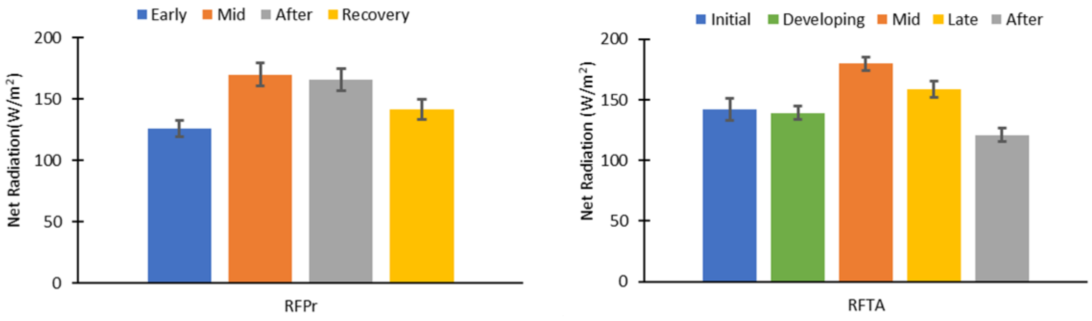


Figure 9 Average net radiation of different biophysical periods at RFPr and RFTA

The maximum diurnal latent heat of RFAA was 365 W/m^2 which was slightly larger than that of RFPr (340 W/m^2) in the early period. It was 289W/m^2 at RFTA in the mid-period (Figure 8). The average ET values over the growing season of three sites were 3.8mm, 4.4mm, and 4.8 mm in RFTA, RFAA, and RFPr, respectively. The latent heat is closely related to the canopy coverage. Comparing the agricultural sites, latent heat flux in mid-stage periods in RFTA was lower than that in RFAA. The difference between two agricultural sites in mid periods was caused by the weeds in RFTA which increased the canopy area. It indicates the high-density canopy could decrease the evaporation for the soil due to the native grass growing between the corn.

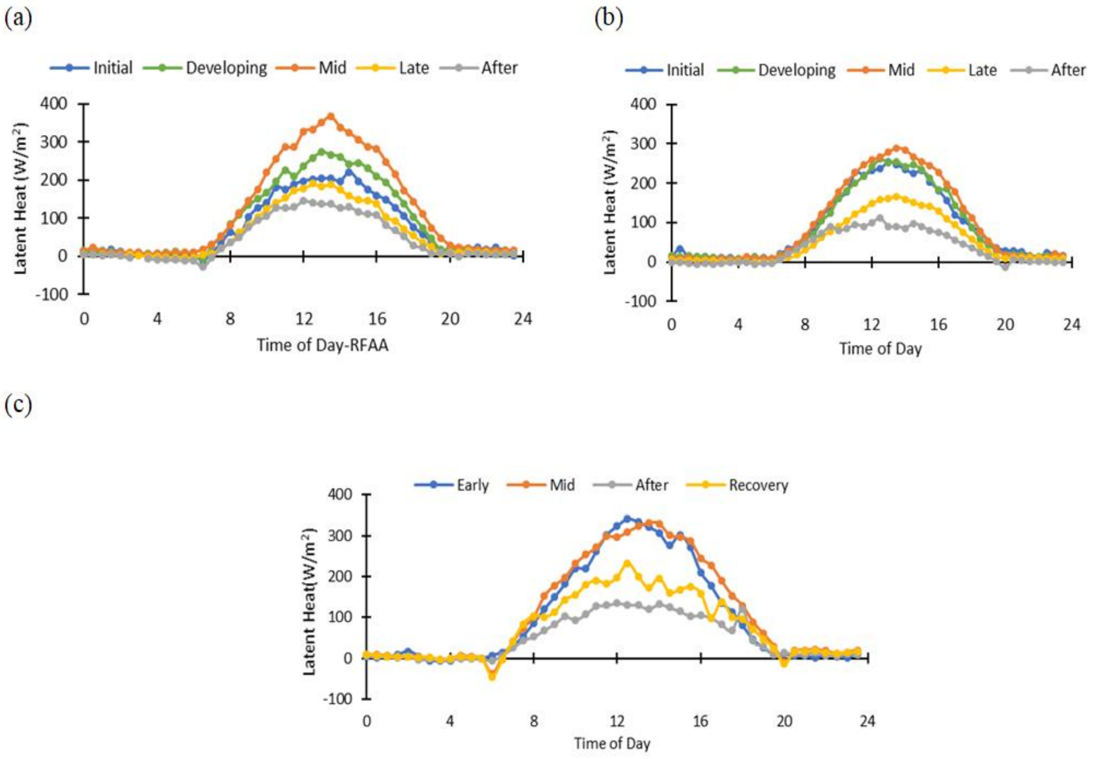


Figure 10 Diurnal average latent heat fluxes in RFAA (a), RFTA (b), RFPr (c), segregated by season

The latent heat of RFTA was significantly larger ($P<0.001$) compared with RFAA at the beginning of the growing season. However, the latent heat of RFAA became significantly larger ($P_{Mid}<0.001$, $P_{Late}< 0.001$, and $P_{After}<0.001$) than that of RFTA in mid, late, and post-harvest periods (Appendix A). Therefore, the cumulative ET over the growing season were similar. In the native prairie, the latent heat in the post-harvest period and the recovery period was lower than the early-period and mid-period. In the agricultural field, the evapotranspiration rates were higher before the corns withering because the photosynthesis rate of green leaves was higher. Also, within each site, the increase of green canopy led to an increase in the total evaporation so that the latent heat in the mid-period was highest during the whole growing season (Figure 9).

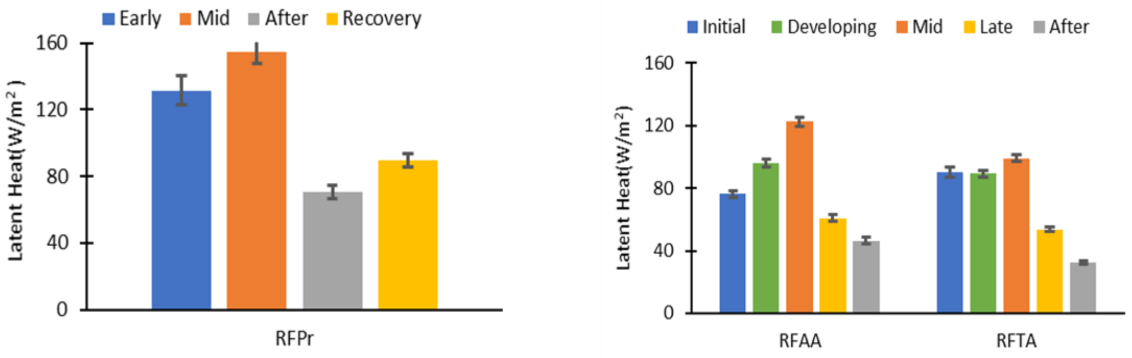


Figure 11 Average latent heat of different biophysical periods at RFPr, RFAA and RFTA

The maximum diurnal sensible heat of RFAA occurred in late period with 258 W/m^2, while it was 262 W/m^2 at RFTA after harvest. At RFPr, the maximum sensible heat was smaller than the other two sites with 248 W/m^2 after harvest (Figure 10).

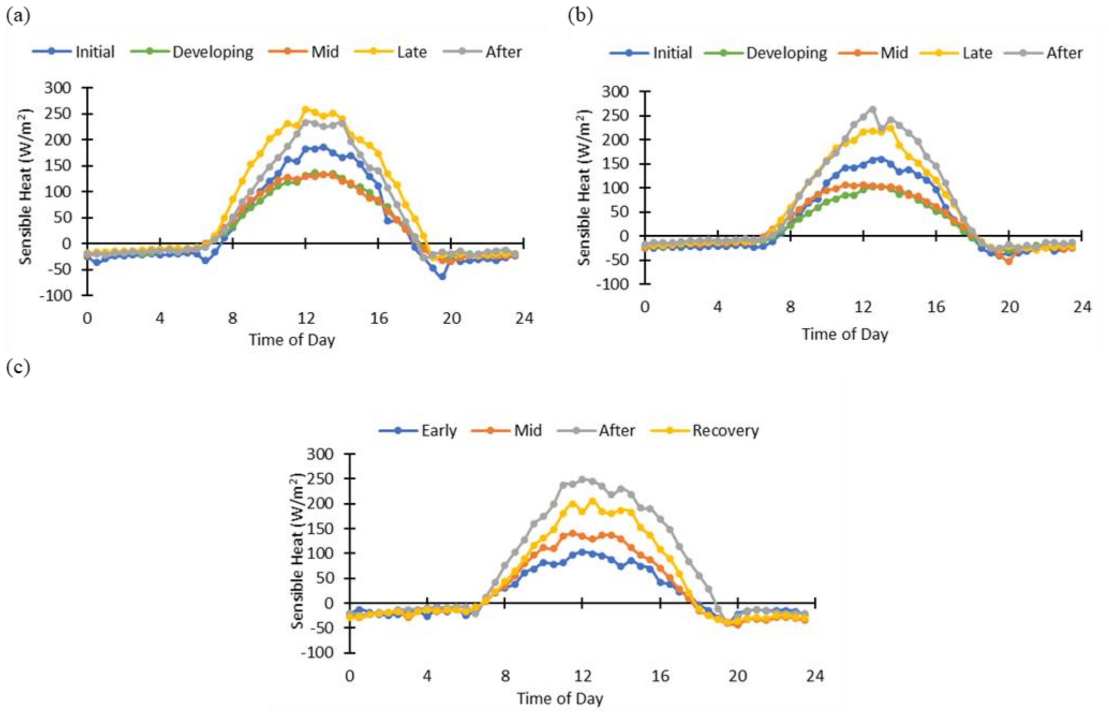


Figure 12 Diurnal sensible heat in RFAA(a), RFTA(b), and RFPr(c) segregated by season

The sensible heat of RFAA was significantly larger than that of RFTA during developing, mid, and late periods ($P_{Developing}<0.001$, $P_{Mid}<0.001$, and $P_{Late}<0.001$) (Appendix A). In the agricultural sites, the sensible heat fluxes during the senescent periods and post-harvest periods were similar and they were higher than the green-leaf periods. In the prairie site, the sensible heat fluxes during the germination period and post-harvest period were higher than the leaf-covered periods (Figure 11). This result is coherent with the latent heat. The increasing sensible heat during late periods and post-harvest reflected the climate shift from wet season to dry season. It is suggested that the color and shape change of leaves might be closely related to water availability. The wilting of corn may result from the decreasing soil moisture due to the dry season after mid of July.

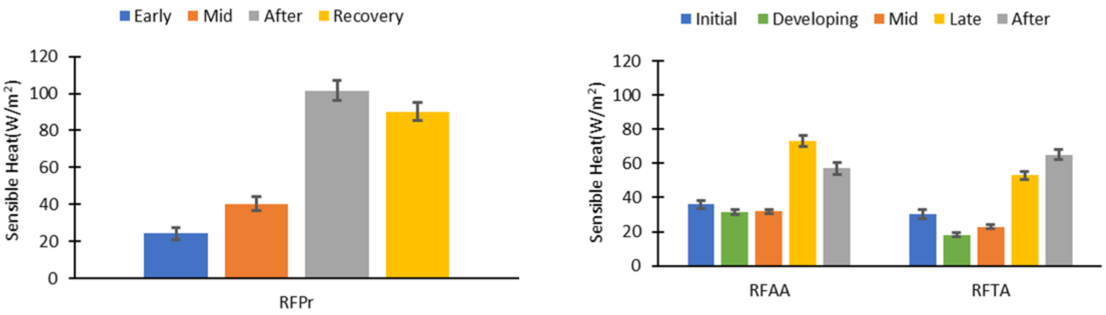


Figure 13 Average sensible heat of different biophysical periods at RFPr, RFAA, and RFTA

3.3. Soil Moisture

During the green-leaf period, the root average soil water content of the three sites was similar at around 0.6 cm^3/cm^3. However, the soil water content of three sites decreased at different rates in the second-half observation period. The soil in RFAA lost more water than the rest two sites. It ended up at 0.4 while the rest two sites ended up equally at about 0.5 (Figure 12; Figure 13). According to the latent heat results, the evapotranspiration rates at RFAA in mid period and late period was higher than rest two sites (Figure 9) which accelerated the decline of the soil moisture at RFAA later.

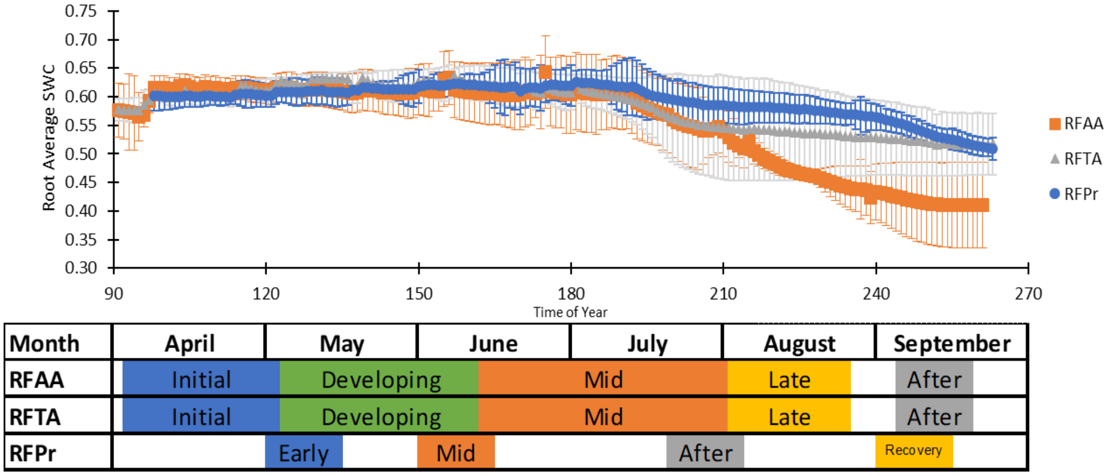


Figure 14 Daily average soil water content during the growing season

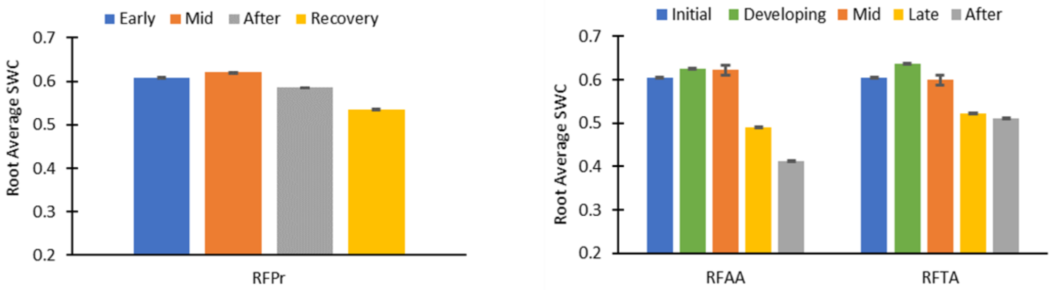
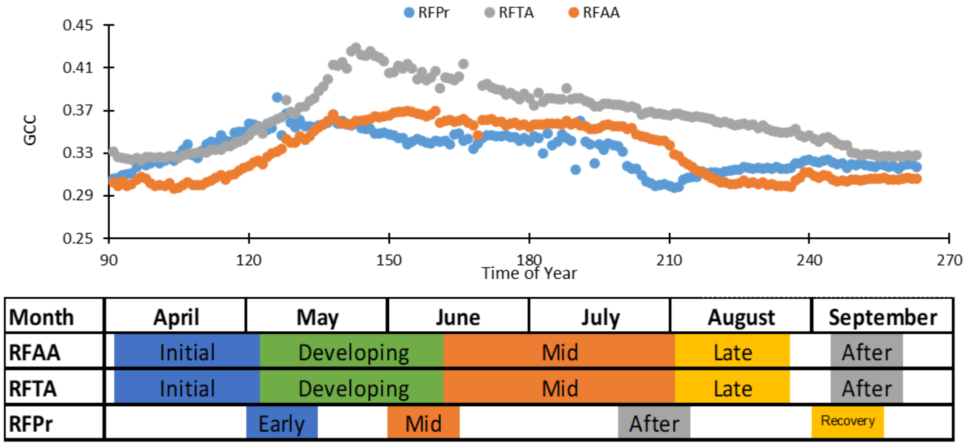


Figure 15 Average soil water content of different biophysical periods at RFPr, RFAA, and RFTA

3.4. Green Chromatic Coordinate (GCC)

Generally, the GCC of RFTA was higher than the other two sites. In the late growing season, the GCC of RFAA and RFPr experienced a sharp decrease because of the harvest and wilting, while the GCC still decreased steadily in RFTA (Figure 14). The average GCC of three sites over the whole growing season was 0.32, 0.33, and 0.35 in RFAA, RFPr, and RFTA respectively. It indicates that the green leaf density in RFTA was larger than RFAA and RFTA, and the duration of green-leaf plants was also longer. In agriculture sites, the GCC in the developing-period was highest among the five stages due to the faster growth speed. Likewise, the GCC in the early season of the native prairie was higher than that in other seasons (Figure 15). One possible explanation for the differences among the three sites would be the weed-control practice. The weeds growing between the cornrows in RFTA increased the canopy area and green leaf density.



Month	April	May	June	July	August	September
RFAA	Initial	Developing	Mid	Mid	Late	After
RFTA	Initial	Developing	Mid	Mid	Late	After
RFPr		Early	Mid	After		Recovery

Figure 16 Daily average GCC during the whole growing season

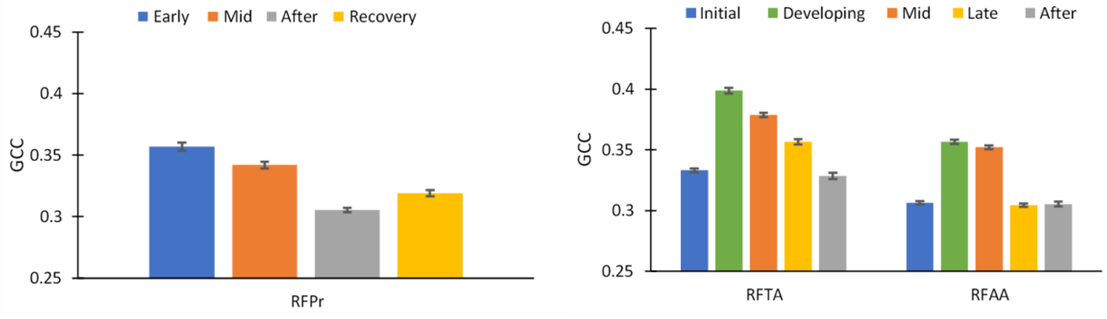


Figure 17 Average soil GCC of different biophysical periods at RFPr, RFAA, and RFTA

3.5. Comparison of Station Microclimates

3.5.1. Daily Average Climate over Growing Season

The soil temperature and air temperature increased through the growing season. The relative humidity, solar radiation, and wind speed showed larger fluctuation during the first half growing season. The frequency of precipitation decreased in the second half growing season (Figure 16). The fields experienced the transformation from wet season to dry season.

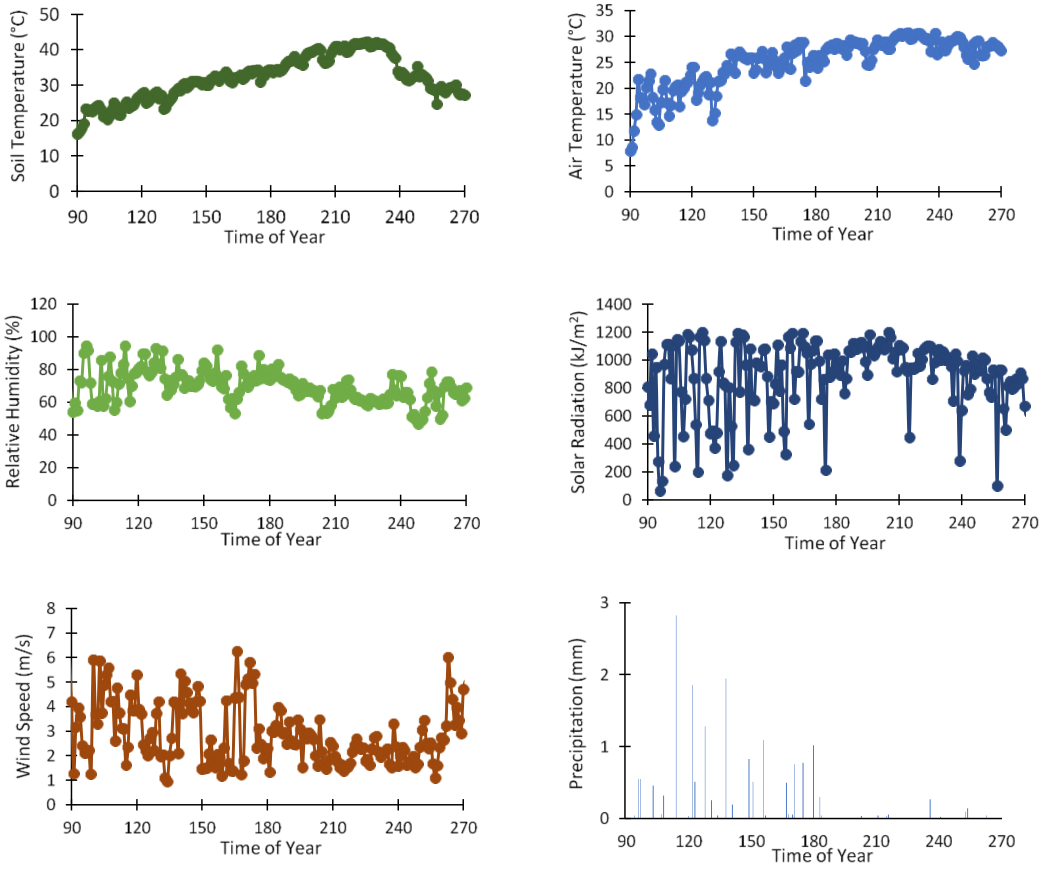


Figure 18 The daily soil temperature, air temperature, relative humidity, solar radiation, wind speed and precipitation over the growing season collected from RFWS

3.5.2. Solar Radiation

The standardized solar radiation (SSR) at RFPr was significantly larger (P<0.001) than agriculture sites (Appendix B). The mean SSR of RFPr was 9.93 W/m^2. The mean SSR of RFAA was the lowest with 7.11 W/m^2, while the mean SSR of RFTA was 8.71 W/m^2. The overall higher SSR in the morning at RFPr might contribute to the largest average value. The range of diurnal SSR was smaller in RFAA than other sites (Figure 17). The differences among the three sites might be related to the different shading effects in the locations among RFWS and TWO sites.

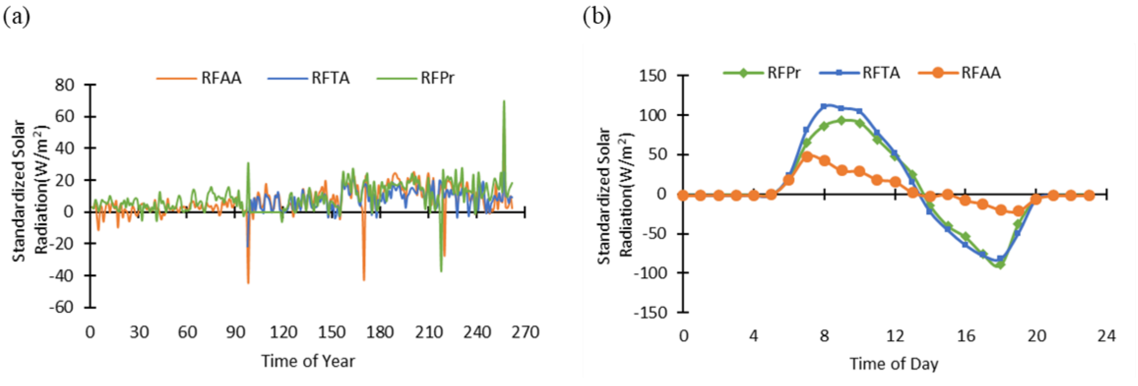


Figure 19 Daily average (a) and diurnal average (b) standardized solar radiation

3.5.3. Air Temperature

The standardized air temperature (SAT) of RFAA was significantly higher (P<0.001) in the late of the growing season (Appendix B). The mean SAT of RFAA during the whole season was 0.43 °C, while the SATs of RFTA and RFPr were 0.29 °C and 0.16 °C respectively. The highest air temperature at RFAA was consistent with the higher sensible heat at RFAA during almost the whole growing season. The diurnal SAT of RFAA showed a smaller range than the other two sites (Figure 18). This was identical to the comparison of diurnal average SSR. Because the diurnal variation of SSR in RFAA was smaller, the SAT was less fluctuated.

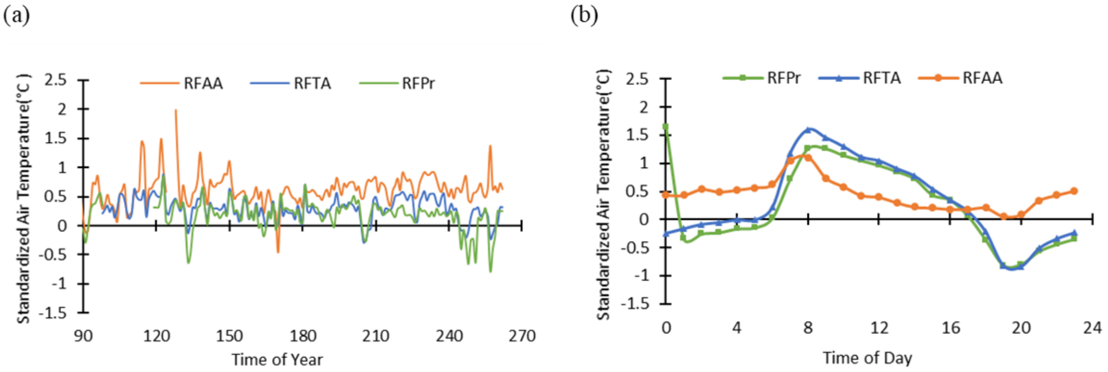


Figure 20 Daily average (a) and diurnal average (b) standardized air temperature

3.5.4. Relative Humidity

The standardized relative humidity (SRH) of RFAA was significantly lower (P<0.001) than that of RFTA and RFAA during the growing season (Appendix B). The mean SRH of RFTA during the whole season reached the highest at -7%. The mean SRH of RFPr was slightly lower at -8%, but the mean SRH of RFAA was twice as much as that of RFTA (Figure 19). This is consistent with the air temperature differences among the three sites, as the air temperature of RFAA was the highest.

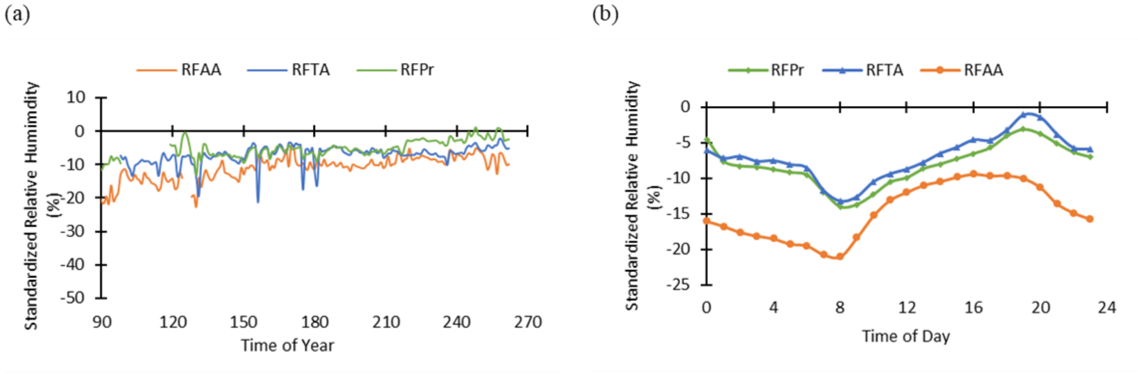


Figure 21 Daily average (a) and diurnal average (b) standardized relative humidity

3.5.5. Wind Speed

The mean standardized wind speeds (SWS) during the whole season were 0.3 m/s, -0.1 m/s, and -0.5 m/s at RFAA, RFTA, and RFPr, respectively. The diurnal average SWS was positive in RFAA, while it was negative in RFPr (Figure 20). The SWS of RFAA was significantly larger (P<0.001) than that of RFTA and RFPr (Appendix B), which represents that plant coverage had lower frictional resistance at RFAA. The frictional resistance is closely linked to the plant's density. The weeds growing between the corns at RFTA increased the plant density leading to similar air friction as RFPr.

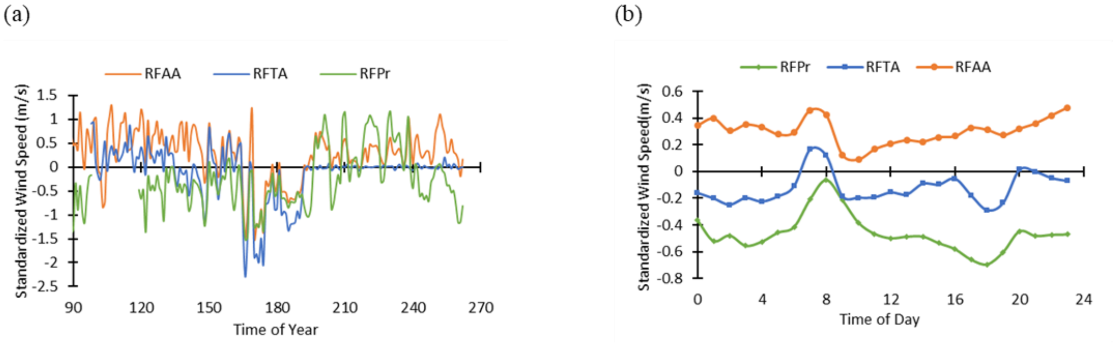


Figure 22 Daily average (a) and diurnal average (b) standardized wind speed

3.5.6. Soil Temperature

The standardized soil temperature (SST) at RFPr was significantly lower (P<0.001) than the other two sites (Appendix B). The mean SST was -7.13 °C in RFPr. It was -5.17 °C in RFAA and -4.94°C in RFTA. The diurnal SST values in agriculture sites were similar, which were larger than that in RFPr (Figure 21). This indicates that the canopy of native grass had better ability to prevent the thermal convection between the soil and the atmosphere due to the high plant density at RFPr that increased the aerodynamic resistance.

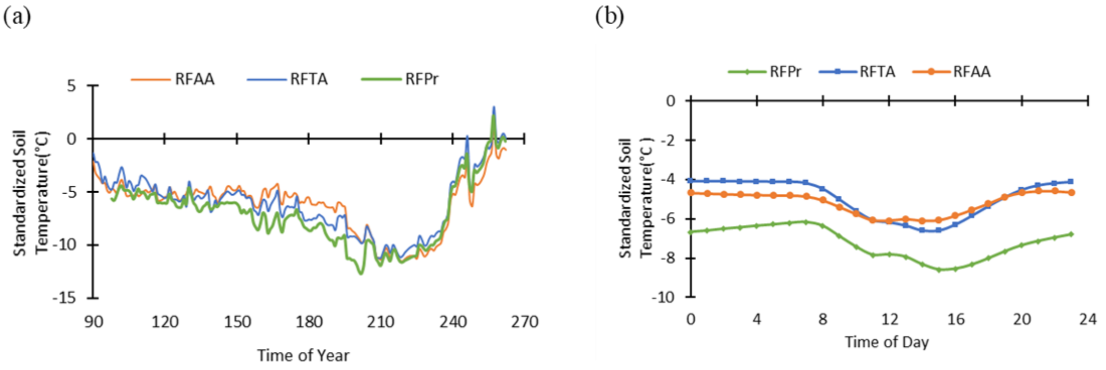


Figure 23 Daily average (a) and diurnal average (b) standardized soil temperature

4. DISCUSSION

4.1. Land Use Change Effect

As the plant community altered with the land-use change, we expected that the interactions between the soil and the atmosphere to vary in gas fluxes and energy fluxes. The variations could be reflected through total yield, water use efficiency, and energy partitioning.

The water use efficiency slightly decreased after the land-use change under the no-till system without weed control practice after planting, while it was much smaller in the aspirational field compared with the other two sites. However, the total ET of agriculture fields increased slightly compared with the native prairie, while the total carbon uptake largely increased. The total carbon consumption of native prairie was much lower than that of agriculture fields due to the harvest in July. The harvest greatly impaired the sequestration process. Although the prairie recovered in the late growing season, the capability of carbon assimilation was weaker than in the mid-stage.

The differences in water use efficiency among three sites indicate agriculture practices that caused strong disturbances to the ecosystems had a significant impact on the WUE such as weed control and harvest. The conversion of grassland to agriculture fields without additional agriculture practices could have little effect on the water use efficiency in Blackland prairie. The proportions of C3 and C4 plants in native prairie and RFTA might be similar because the volunteer species included both C3 and C4 grass and the weeds could introduce C3 plants into the cornfield, lessening the overall advantage of corn (C4) plants on water use efficiency.

Responses of SWC to the land-use change were similar to the WUE. There were few differences between the soil moisture change trend of RFTA and RFPr. In the green-leaf periods, the average soil moisture was almost the same for all sites, around 0.6. In the second half growing season, the frequency and intensity of precipitation largely decreased, which led to the reduction of SWC. Therefore, the corn died and leaves wilted. However, the soil moisture of aspirational fields decreased significantly to 0.4 by the end of the growing season, while the SWC in RFTA ended up at 0.5 similar to RFPr. The differences between two agriculture sites and the similarity between RFTA and RFPr suggested that the effects of land-use change on SWC were likely due to the adoption of herbicides during the growing season. The water loss from soil after the harvest could be mostly attributed to the evaporation since the corn stopped growing. It seems that the weed prevented soil water loss from evaporation efficiently (will discuss in 4.2.). If the land change happened without weed-control practice, the influence of land cover change on soil moisture would not show significant differences. However, the capacity of soil water content might be more related to the soil structure. As briefly introduced in site information (2.1), both agriculture sites experienced long-term agriculture management. The soil structure of three sites might be different due to historical agriculture management practices. Some practices in the aspirational agriculture site might impair the soil structure. Thus, more soil water loss from evapotranspiration. This hypothesis of the soil structure difference needs to be tested in future research.

The net radiation in RFPr was slightly lower than that in RFTA. The net radiation differences among two sites reflected the albedo change caused by land-use change. The land surface reflectivity was decreased after the shift of the plant community from volunteer species to corn. The plant growing density or canopy structure directly influenced the surface albedo. Traditionally, conversion from native prairie to the cornfield would increase the albedo due to the reduction of green leaf density (Monson et al., 2014). However, in this research, the results indicated that the canopy density of RFTA was higher than that of RFPr. The weeds growing between corn increased the canopy density of the conventional field which may be even larger than native prairie.

4.2. Effect of Management Practices

The difference in weed-control practice demonstrated huge influences on the ecosystem and the soil-atmosphere interactions. The nuisance species growing in the fields without weed control practice would change the components and structure of plant communities.

The average WUE in RFAA was 3.5 kg/m^3/d which was less than 6.3 kg/m^3/d in the conventional field. Although the total ETs of two agriculture sites were close, the total carbon uptake of the aspirational field was about 60% of the conventional field. The low carbon assimilation led to a low corn yield in RFAA as 482 g/m^2, while the corn yield in RFTA was 782 g/m^2. Weed management is likely to be an important factor that influenced the WUE. According to the comparison of native prairie and agriculture fields, the WUE of corn was lower than the WUE of volunteer species. The plant community of RFTA contained not only the corn but also the nuisance species, which could increase the average WUE in RFTA. Lack of supplemental phosphorus in RFAA may also enhance the difference. Therefore, the agriculture field without weed control (RFTA) showed a higher WUE than the weed-controlled field (RFAA). The large GCC value indicated that the canopy density of RFTA was also higher, which could reduce the evaporation during the green leaf periods. Most of the water consumption might contribute to the growth of plants in RFTA.

The SWC decreased significantly after the harvest in RFAA. At the same time, ET of the aspirational field was higher. It might be caused by the adoption of herbicides during the growing season. Without weed-control practice, the weed was an effective layer to protect soil water. It increased plant density. After harvest, the high density of stalks remained above the ground in RFTA still could reduce evaporation.

Additionally, the weeds influenced the change of sensible heat when the leaves of corn turned yellow. The sensible heat in RFTA at the late stage was lower than post-harvest, while it was relatively higher in RFAA at the late stage compared with the post-harvest stage. The GCC value at the late stage showed that after the corn leaves turned yellow, the weeds remained green. It is indicated that the green canopy worked like a barrier to prevent the energy transformation between sensible heat and latent heat. Therefore, weed control was important for the energy partitioning especially in the late period of the corn.

4.3. Limitations and Future Research

The research time was focused on 2019 with annual precipitation at 652 mm, which was less than the average annual precipitation at 890 mm. Therefore, the responses of carbon, water, and energy fluxes to the land-use change in 2019 represented the influence of a dry year. But the responses in wet years (when the annual precipitation is larger than average value) might be different from dry years because of the increasing water availability. The water deficit becomes the most dominant factor that controlled the evapotranspiration and plant growth under some conditions when the water availability is limited. The WUE was also limited by the water availability since the photosynthesis process was impaired by water deficit and reduced the carbon sequestration.

It would be valuable to keep tracking the water, carbon, and energy fluxes change over a long temporal scale in the future. First, the long-term observation will provide a comprehensive understanding of the gas fluxes and energy fluxes under various climate conditions that may have an important influence on the plant community development. The results of dry years and wet years should be compared to estimate if the precipitation can alter some differences caused by land-use change and agriculture practices. Second, this research concentrated on the annual response of the ecosystem to the land-use change and agricultural practice change, but some subtle differences may not be captured. Some effects may only appear after the accumulation of many years, such as residue and mineral soil C content change. The gas fluxes, energy fluxes, and micrometeorology may show different responses to land-use change and agricultural management change in a long temporal scale. Thus, the investigation and prediction of the long-term effects of land-use change, especially the agriculture practices would be the future direction for the next step in this study.

5. CONCLUSIONS

The conversion from the native vegetation ecosystem to the crop ecosystem could change the interaction of the biosphere and atmosphere, which may lead to some environmental issues such as greenhouse effect, soil erosion, etc. Some agricultural land management strategies might enhance the effect of land-use change. Many studies monitored the ET, carbon flux, and energy fluxes in native prairie and cornfields to investigate the influence of land-use change. However, not all the studies observed a difference between the plant communities of native species and corns. Previous research indicated that the influence of land-use change varied with the location and season. Therefore, we compared the water, energy, and carbon in native prairie and cornfields change in USDA-ARS Riesel Station during the growing season in 2019 to determine the influence of land-use in Blackland Prairie.

We monitored the gas fluxes and energy fluxes through the Eddy Covariance system coordinated with the time-domain reflectometers which measured the soil moisture and soil water content. The PhenoCam system was adopted to analyze the plant growth status. We compared the data collected from the devices above to test our hypothesis: (1) the carbon flux, water flux, and energy fluxes are influenced by the land-use and agriculture management, (2) water use efficiency, total crop yield, and soil water content are various with plant communities and agriculture practice, (3) land-use change can influence the micrometeorology.

In this study, the ET, carbon flux, and energy fluxes were similar between RFPr and RFTA compared with the differences between the two agriculture fields. Land-use change did not significantly impact the WUE and soil water content without additional agriculture management strategies (weed control). The ecosystem communities of the conventional agriculture field and native prairie were similar because the proportions of C3 and C4 plants were close in RFTA and RFPr. The ecosystem transpiration rates and plant respiration rates of two systems would be similar under the same environmental conditions.

The larger differences between RFTA and RFAA in SWC and WUE reflected the large variations in carbon uptake, energy partitioning, and evapotranspiration between two sites. It is suggested that weed control practice might play an important role in the land-use change. The difference in plant canopy area was likely to be enlarged under weed control practice. The weed growing in RFTA increased green leaf density. The low leaf density in RFAA may not be able to prevent the soil water loss from evaporation efficiently. Therefore, a larger ratio of the water was consumed by the evaporation process so that WUE was reduced in RFAA. However, the differences between the two agriculture sites might be more related to historical agriculture practices. The effects of long-term practices may not fade away since the RFAA was managed under aspirational strategies for a short-term.

The microclimate of RFAA was different from that of RFTA and RFPr. This may be more related to the locations of the three sites. The shading effect may occur so that the solar radiation altered in RFAA, which further influenced the air temperature and relative humidity. However, the soil temperature and wind speed might be related to the plant cover because the canopy could increase the air resistance roughness and isolated the thermal exchange between soil and atmosphere.

This study investigated the immediate response of the gas fluxes, energy fluxes, and micrometeorology in a dry year. However, some changes in these variables might have not been observed without long-term accumulation. The results of this research may also shift with climate change. A long-term study on land-use change can provide a comprehensive understanding of the response of the water, carbon, and energy under different climate conditions. Therefore, the long-term observation of the ET, carbon flux and energy fluxes in USDA-ARS Riesel Station is necessary for future study.

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APPENDIX A

Table 2 ANOVA test results of carbon flux, energy fluxes, and soil moisture between RFTA and RFAA in each biophysical stage

		Initial Period		Developing Period		Mid Period		Late Period		After Harvest	
		RFAA	RFTA	RFAA	RFTA	RFAA	RFTA	RFAA	RFTA	RFAA	RFTA
Carbon Flux (mg/m^2/s)	Mean	0.051724	-0.00388	-0.05504	-0.1199	-0.13945	-0.17708	0.022612	-0.00987	0.036209	0.056375
	STE	0.004923	0.00608	0.007604	0.008657	0.012185	0.009822	0.007174	0.004619	0.005084	0.001542
	T-test	<0.0001		<0.0001		0.0159		<0.0001		<0.0001	
Latent Heat (W/m^2)	Mean	76.25812	90.19686	95.7647	89.38824	122.5086	99.29172	60.98918	53.70709	46.48653	32.44722
	STE	2.451425	3.397522	2.480212	2.32147	2.789972	2.188298	2.126297	1.637314	2.251839	1.080168
	T-test	0.0007		0.0606		<0.0001		0.0058		<0.0001	
Sensible Heat (W/m^2)	Mean	35.92048	30.12929	31.6753	18.09928	31.92248	22.9986	73.3252	52.9674	57.16273	65.11995
	STE	2.460836	2.6481	1.445976	1.131721	1.334394	1.138206	3.303257	2.409266	3.591899	2.748556
	T-test	0.1262		<0.0001		<0.0001		<0.0001		0.2047	
Net Radiation (W/m^2)	Mean		142.0976		139.2069		179.7436		158.8901		121.0855
	STE		8.728298		5.366436		5.433374		6.623328		5.548735
	T-test										
Soil Moisture (W/m^2)	Mean	0.604415	0.605095	0.625687	0.636774	0.622151	0.599192	0.490151	0.521973	0.412793	0.510255
	STE	0.000586	0.000786	9.26E-05	0.00064	0.000483	0.000786	0.001094	0.000571	0.000461	0.00084
	T-test	0.4789		<0.0001		<0.0001		<0.0001		<0.0001	

APPENDIX B

Table 3 ANOVA test of climate variables among RFAA, RFTA and RFPr

		Mean	Std Error	P-value
Air Temperature(°C)	RFAA	-14.946	0.3866	<.0001
	RFPr	-8.387	0.40078	
	RFTA	-7.05	0.48436	
Wind Speed (m/s)	RFAA	0.30005	0.03445	<.0001
	RFPr	-0.47098	0.03584	
	RFTA	-0.12257	0.04341	
Relative Humidity (%)	RFAA	-14.946	0.3866	<.0001
	RFPr	-8.387	0.40078	
	RFTA	-7.05	0.48436	
Incoming Solar Radiation(W/m^2)	RFAA	7.11026	0.5193	0.0009
	RFPr	9.92625	0.5393	
	RFTA	8.71325	0.65313	
Soil Temperature(°C)	RFAA	-5.1693	0.17476	<.0001
	RFPr	-7.1322	0.22022	
	RFTA	-4.9393	0.17476	

APPENDIX C

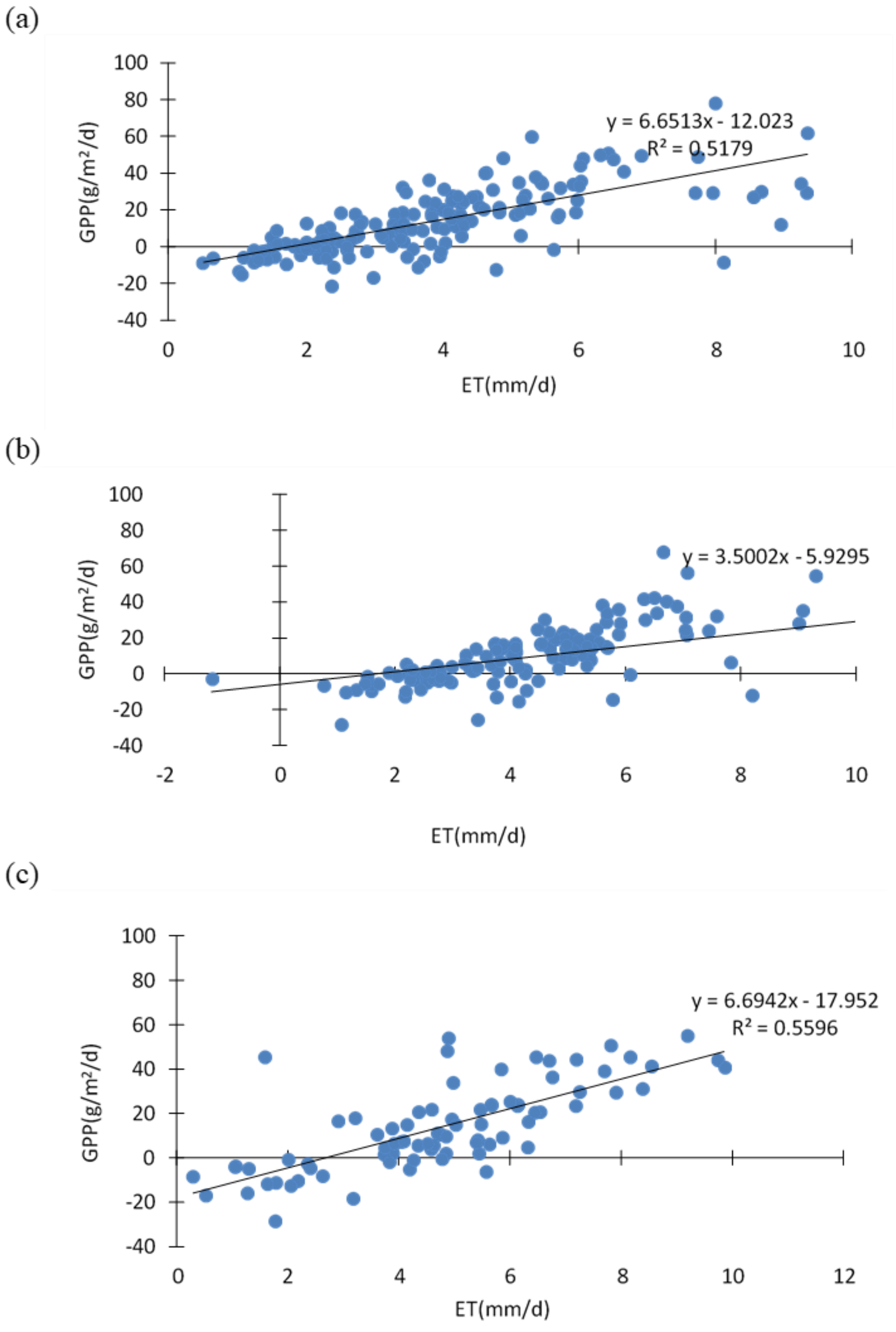

Figure 24 Daily water use efficiency for RFTA(a), RFAA(b), and RFPr(c) over the growing season

APPENDIX D

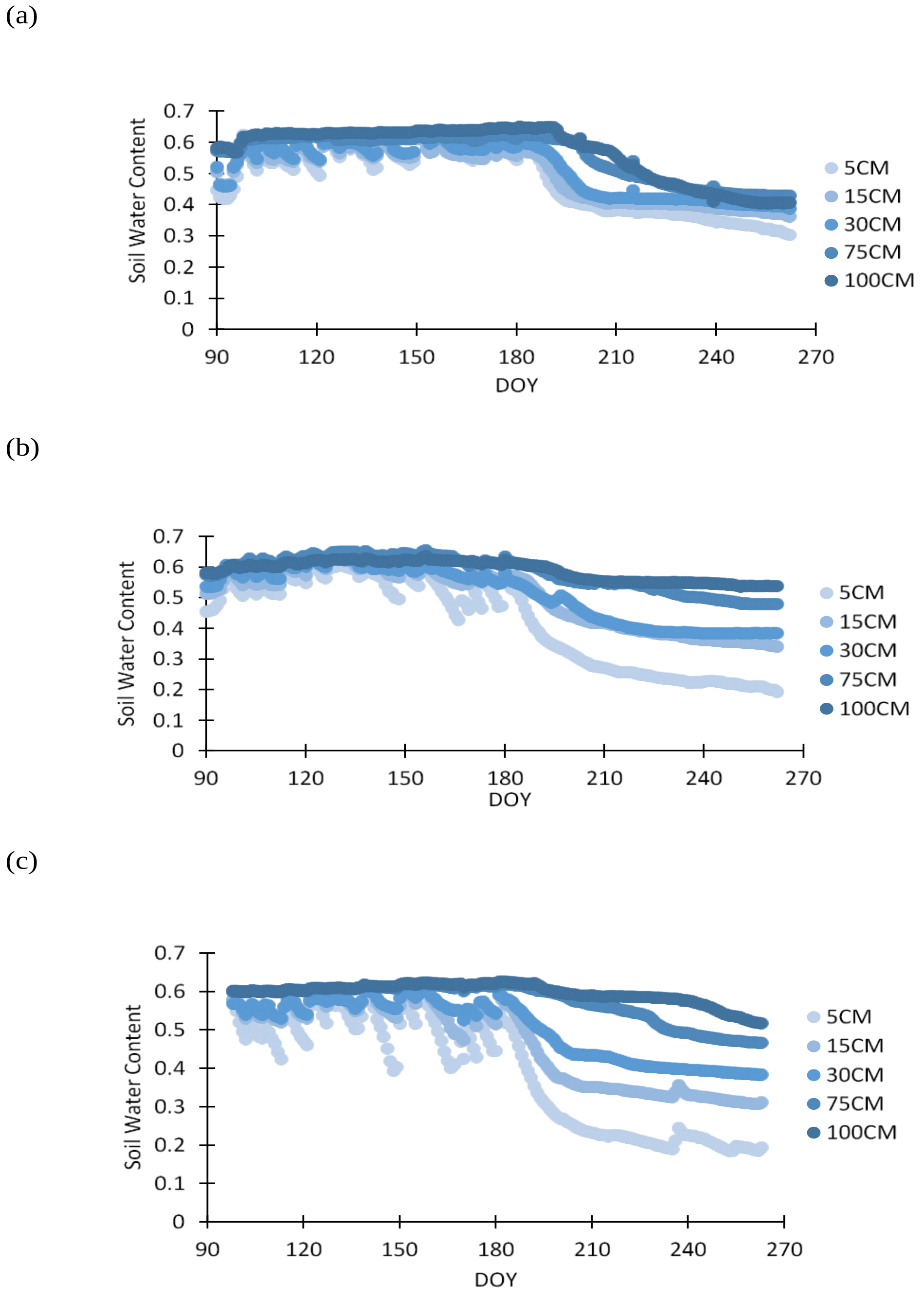

Figure 25 Daily average soil water content of five depths at RFAA (a), RFTA(b) and RFPr(c)