Assessment of water use efficiency of alfalfa using Eddy Covariance CO_2 and H_2O fluxes under hyper arid conditions of Saudi Arabia

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Abstract. *A field study was carried out to investigate the seasonal variations in alfalfa (Medicago sativa L.) water use efficiency (WUE) using Eddy Covariance (EC) measured CO_2 and H_2O fluxes, aiming at optimizing the use of irrigation water under hyper arid conditions of Saudi Arabia. The EC system used for this study was installed on a center pivot irrigated 50 ha alfalfa field in a farm located in the Eastern Province of Saudi Arabia. Results of the study showed EC estimated WUE values of 1.57 and 1.07 kg m^{-3} for winter (November 2013 to March 2014) and summer (June 2013 to October 2013 and April 2014) periods, respectively. However, the actual WUE values calculated for the harvested alfalfa crop were 0.70 and 0.71 kg m^{-3} for winter and summer periods, respectively. Attaining an actual crop WUE of 30-55% lower than the estimated one emphasizes the need for the application of precision irrigation systems to enhance water conservation practices.*

Keywords. *Center pivot irrigation, energy fluxes, water use efficiency, Eddy Covariance, hyper arid climate.*

Introduction

For efficient irrigation practices, investigation of the intra-annual variability of water use efficiency (WUE) of agricultural crops is of great importance. In Saudi Arabia, due to the limited water resources and the extremely fluctuating evapotranspiration patterns, there is a need for the application of efficient irrigation systems. The WUE, which is defined as the crop yield per unit of crop water use, provides vital information on irrigation efficiency. The rate of carbon uptake per unit of water lost, also referred to as WUE, integrates a suite of biotic and abiotic factors and quantifies how much water an ecosystem uses relative to the amount of carbon gained (Mo et al. 2005). In general, the WUE of agricultural crops differs significantly from each other according to their contribution to the CO_2 and H_2O fluxes (Gilmanov et al. 2013).

Eddy covariance (EC) technique, to measure CO_2, water and energy fluxes between the biosphere and the atmosphere, is widely used in various agricultural monitoring studies (Zaho et al. 2007). Growth dynamics of a crop depends mainly on the climatic conditions and the management practices, which ultimately influence the quality and quantity of crop yield. Therefore, this study was carried out, during the period from June 2013 to April 2014, to understand the net ecosystem exchange (NEE) of CO_2 and H_2O fluxes in alfalfa (*Medicago sativa* L.) field to investigate the seasonal variations in WUE of the crop, so as to optimize the use of irrigation water.

Materials and Methods

Study area

The study was carried out in a commercial farm that encompassed 47 fields under center pivot irrigation systems. The farm, which is located between Alkharj and Haradh cities in the Eastern Province of Saudi Arabia, lies within the latitudes of 24º10'22.77" and 24º12'37.25" N and the longitudes of 47º56'14.60" and 48º05'08.56" E.

Data Collection

For the determination of the NEE of CO_2 and H_2O fluxes, an EC system was installed on a center pivot irrigated 50 ha alfalfa field in the study farm. CO_2 and H_2O fluxes were measured by an open-path gas analyzer, where the wind vector was measured at a height of 3.8 m above the ground, using a 3-axis ultrasonic anemometer at a frequency of 10 Hz. The collected EC data (H_2O and CO_2 uptake, net radiation and energy fluxes) was analyzed using Eddypro software program (Ver. 5.1.1). The foot print of the EC system for the alfalfa field was assessed and the NEE was quantified. Subsequently, the Gross Primary Productivity (GPP) was estimated as a relationship between the residual ecosystem respiration (ER) and the NEE. Thereafter, the WUE was calculated using Equation 1 (Yu et al. 2008). The actual data of applied irrigation water and crop yield was obtained from the records of the study farm.

$$WUE = GPP/ET \quad (1)$$

Where GPP = Gross Primary Productivity and ET = evapotranspiration. Both, the GPP and the ET were calculated based on the EC recorded fluxes (CO_2 and H_2O).

Results and Discussion

The seasonal variations of EC measured GPP and ET of alfalfa crop are shown in Fig. 1. The peak GPP value (4.46 g C m^{-2} s^{-1}) was observed in April 2014 and the lowest value (0.27 g C m^{-2} s^{-1}) was noted in January 2014. However, the highest ET (0.37 g H_2O m^{-2} s^{-1}) was observed in August 2013. As depicted in Table 1, results of the study revealed that the net CO_2 uptake ranged from 650 g C m^{-2} (6,500 kg ha^{-1}) to 2,150 g C m^{-2} (21,500 kg ha^{-1}) for winter (November 2013 to March 2014) and summer (June 2013 to October 2013 and April 2014) periods, respectively. On the other hand, the EC recoded net uptake of water (H_2O flux) was calculated at 4,147 and 20,157 m^3 ha^{-1} for winter and summer seasons, respectively. These results were converted to EC estimated WUE values of 1.57 and 1.07 kg m^{-3} for winter and summer seasons, respectively. The actual amount of applied irrigation

water, however, was determined at 5,520 and 25,780 m^3 ha^{-1} producing an actual alfalfa hay yield of 3,852 and 18,271 kg ha^{-1} for winter and summer periods, respectively. Hence, the actual WUE of alfalfa was calculated at 0.70 and 0.71 kg m^{-3} for winter and summer periods, respectively. The WUE of the harvested alfalfa crop was observed to be lower than that estimated using EC measurements by 55% and 33% for winter and summer periods, respectively.

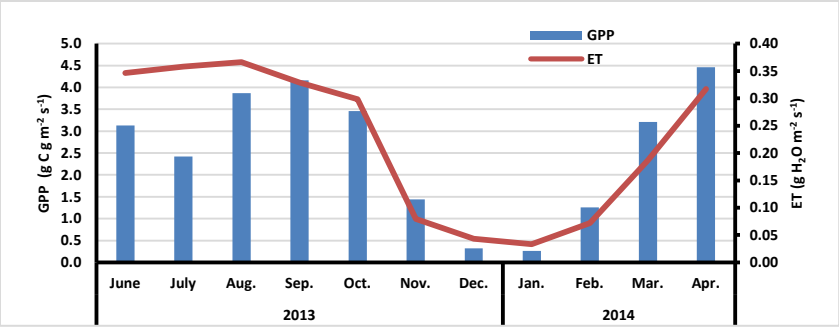

Fig 1. The seasonal variations of the GPP and the ET over alfalfa field.

Table 1. Results of the EC estimated and actual alfalfa WUE for winter and summer periods.

Eddy Covariance Estimated			Actual		
	Winter Period	**Summer Period**		**Winter Period**	**Summer Period**
CO_2 uptake (kg ha^{-1})	6,500	21,500	Crop Yield (kg ha^{-1})	3,852	18,271
H_2O uptake (m^3 ha^{-1})	4,147	20,157	Applied Water (m^3 ha^{-1})	5,520	25,780
WUE (kg m^{-3})	1.57	1.07	WUE (kg m^{-3})	0.7	0.71

Conclusion

A field study was conducted to investigate the water use efficiency (WUE), using the EC recorded fluxes (CO_2 and H_2O), of the alfalfa crop cultivated under the hyper arid conditions of Saudi Arabia. The specific conclusions can be summarized as follows:

- The actual alfalfa WUE of 0.70 and 0.71 kg m^{-3} was recorded for winter and summer periods, respectively. However, the values of EC estimated WUE were 1.57 and 1.07 kg m^{-3} for winter and summer periods, respectively.
- The actual alfalfa crop WUE was found to be 30-55% lower than the estimated WUE. Therefore, a potential for increasing the actual WUE exists. The increase of the actual WUE can be achieved by employing the technology of precision irrigation.

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