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Assessing carbon and water dynamics of no-till and conventional tillage cropping systems in the inland Pacific Northwest US using the eddy covariance method

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ABSTRACT

Analysis of carbon and water budgets in cropping systems is important for understanding the impacts of different management practices and meteorological conditions, in the context of climate change, on agriculture. We have established a pair of long-term eddy covariance flux towers at the R. J. Cook Agronomy Farm (CAF) near Pullman, Washington, US. The tower sites have similar crop rotation, weather conditions, and management practices except tillage. One site has been under no-till management (CAF-NT) since 1998, while the other site has used conventional tillage practice (CAF-CT) over the same time period. Measurements conducted above a garbanzo bean crop (*Cicer arietinum*) between October 2012 and September 2013 showed the CAF-NT site was close to CO_2 neutral with an annual cumulative net ecosystem exchange of CO_2 (NEE) of $-20 \pm 38\,g\,C\,m^{-2}$. By contrast, the CAF-CT site was a CO_2 source with an annual NEE of $117 \pm 39\,g\,C\,m^{-2}$ during the same time period. The annual NEE values at each site were significantly different ($p < 0.05$). When carbon losses via harvest export were taken into account, the net rates of carbon loss from each ecosystem to the atmosphere were 32 ± 50 and $178 \pm 48\,g\,C\,m^{-2}$ for CAF-NT and CAF-CT, respectively, indicating CAF-NT was close to carbon neutral and CAF-CT was a net carbon source during the measurement period. Partitioning of NEE into gross primary productivity (GPP) and total ecosystem respiration (R_{eco}) shows that the annual cumulative GPP of each site did not differ much, but CAF-NT had lower annual cumulative R_{eco} compared to CAF-CT during the period of October 2012–September 2013. Water budget analyses presented similar magnitudes of annual sums of evapotranspiration (ET), 425 and 416 mm for CAF-NT and CAF-CT, respectively. ET was partitioned into evaporation (E) and transpiration (T) for both sites, and CAF-CT had a larger fraction of annual E compared to CAF-NT during the measurement period. Relationships between carbon and water fluxes were investigated, and for the period of October 2012–September 2013, high correlations were found in GPP vs. T and NEE vs. ET at both sites. In summary, the site deploying no-till practices had lower total ecosystem respiration and evaporation throughout the measurement period, more net carbon uptake and a greater ratio of transpiration over evapotranspiration (T/ET) during the growing season.

1. Introduction

Global food demand is predicted to increase 100% by 2050 (Tilman et al., 2011), thereby increasing demands from ecosystem services including agricultural production and natural resources. Bondeau et al. (2007) assessed the role of agriculture for the global terrestrial carbon balance using a dynamic global vegetation model and estimated ~24% and ~10% reduction in global vegetation and soil carbon respectively due to agriculture for the 20th century. Agricultural activities contribute directly to greenhouse gas (GHG) emissions (CO_2, N_2O, CH_4) through a variety of processes, including ruminant livestock, rice cultivation, tillage practices, fertilization

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and field burning of biomass residues. However, croplands can also function as a carbon sink depending on crop species, soil types, meteorological conditions and management practices. Agriculture crops cycle large amounts of CO_2 by consuming CO_2 via photosynthesis to produce food, seed and fiber (Running et al., 2000; Snyder et al., 2009). Eventually all of the plant products convert back to CO_2 when consumed or decomposed. Smith et al. (2008) estimated that by 2030 the global GHG mitigation potential from agriculture will be approximately 5500–6000 Mt CO_2-eq. yr^{-1}. Therefore, a comprehensive understanding of carbon cycling in the agricultural ecosystems is crucial for mitigating GHG emissions from croplands.

No-till practices can reduce wind and water erosion, thus holding more soil organic carbon (SOC) and water in the soil to maintain and improve soil quality (Huggins and Reganold, 2008; Sauerbeck, 2001; West and Post, 2002). This is especially important in the inland Pacific Northwest (iPNW) region, because soils in the iPNW are vulnerable to wind erosion particularly in the low-precipitation areas and under intensive tillage conditions (Schillinger et al., 2007). For these areas, more than 50% of SOC has been lost after conversion of native sites to cultivation due to wind erosion and oxidation (Purakayastha et al., 2008). According to Schillinger et al. (2007), under no-till practices, SOC increased linearly each year at the soil surface and accumulated at a slower rate at deeper layers during an 8 year study in the iPNW region. By providing potential long-term carbon sequestration and protection against soil erosion by wind and water, the conversion from conventional tillage to no-till is predicted to increase SOC storage in the top 30 cm of soil in the iPNW region (Purakayastha et al., 2008) and has been accepted as one of the strategies to increase the soil carbon pool and therefore affect global climate change and food security (Lal, 2004).

No-till practices can reduce soil CO_2 emissions and evaporation in agricultural ecosystems (e.g. Feiziene et al., 2011; Gajri et al., 1992; Hu et al., 2013; Jabro et al., 2008; Kocyigit and Rice, 2011; Liu et al., 2013; Rastogi et al., 2002; Ward et al., 2012). The reduced soil CO_2 emissions under no-till conditions are primarily due to several biological and physical factors: the less disturbed soil keeps SOC unexposed (Rastogi et al., 2002), improves aggregate structure and microbial carbon source utilization efficiency (Aziz et al., 2013; Hu et al., 2013), and limits the gas diffusion from the soil to the atmosphere due to high bulk density (Ball et al., 1999; Regina and Alakukku, 2010). In addition, the undisturbed crop residue layer under no-till conditions serves as a barrier to reduce both soil respiration and evaporation (e.g. Al-Kaisi and Yin, 2005; Regina and Alakukku, 2010; Salado-Navarro and Sinclair, 2009; Van Wie et al., 2013).

Tillage effects on soil CO_2 emissions have been quantified through chamber-based field measurements as reported in the above studies. However, other carbon and water fluxes, such as total ecosystem respiration (including both field-scale soil and plant respiration), can be affected by different soil conditions, and these fluxes cannot be characterized by chamber measurements. In the study reported herein, we used the eddy covariance technique to make field-scale measurements of net ecosystem exchange of CO_2 and evapotranspiration, coupled with partitioned estimates of total ecosystem respiration, gross primary productivity, evaporation, and transpiration in order to assess the overall impacts of tillage practices on carbon and water dynamics at two cropping systems in the iPNW region.

During the past decade, EC measurements of GHG emissions have been reported for winter wheat by Gilmanov et al. (2003), Anthoni et al. (2004), Moureaux et al. (2008), Dufranne et al. (2011), Schmidt et al. (2012), and Billesbach et al. (2014), as well as for some other crops by Gilmanov et al. (2014), Saito et al. (2005), Lohila et al. (2004), Verma et al. (2005), and Hollinger et al. (2005). These studies were carried out in the Southern Great Plains, the North Central Region, and areas of the Midwest of the US, Germany, Belgium, Finland, and Japan, where the climate conditions are very different from the iPNW region. In addition, there is a lack of carbon and water budget measurements using EC over spring garbanzo beans, based on the reviews by Gilmanov et al. (2014) and Ceschia et al. (2010). Also based on Baldocchi (2014), the use of paired eddy covariance flux towers has been identified as powerful tools and will be in great need for investigating the impacts of different agricultural management practices (no-till vs. conventional tillage in this paper) at field scale in the future. To our knowledge, this paper and its companion (Waldo et al., 2016) are the first EC studies over a wheat-based cropping system (wheat rotated with other crops, e.g. spring garbanzo in this study) in the iPNW region, and this paper is the first comparison study of tillage vs. no-till practices using EC measurements to assess carbon and water budgets. This paper addresses the following objectives using EC techniques: 1) to quantify carbon and water fluxes for two agricultural sites (one no-till and one conventional tillage) with spring-garbanzo beans (*Cicer arietinum*) planted during 2013; 2) to compare carbon and water budgets between no-till and conventional tillage sites; 3) to investigate relationships between carbon and water fluxes in these two cropping systems; and 4) to consider the implications of annual carbon budgets for long-term carbon storage.

2. Methods

2.1. Site description

The Washington State University Cook Agronomy Farm (CAF, 46.78°N, 117.09°W, 800 m above sea level) was established in 1998 as a long-term, precision farming research site located near Pullman, Washington, in the iPNW region of the United States. This site was zonal xeric grassland or steppe (Kovar-Eder et al., 2008) before conversion to agriculture. The climate type of CAF is a Mediterranean climate with a mean annual temperature of 9 °C and annual precipitation of 550 mm (averaged based on the historical records from 1981 to 2010, Palouse Conservation Field Station, National Climatic Data Center, NOAA). CAF is in the high rainfall zone of the iPNW region and the soil type is classified as Mollisols with the soil texture of silt loam (Naff, Thatuna and Palouse Series) (Soil Survey Staff, 1999; Web Soil Survey, 2013). Continuous dryland crops have been farmed at CAF. CAF is a wheat-based cropping system where crop rotation consists of winter wheat and spring crops (spring garbanzo beans in this study) such that spring crops are planted into winter wheat residue.

Two EC flux tower systems were deployed at CAF as shown in Fig. 1 as part of the Regional Approaches to Climate Change (REACCH) USDA-supported research program (https://www.reacchpna.org/). Both sites had the same crop rotation, winter wheat (*Triticum aestivum*), spring garbanzos (*Cicer arietinum*), during the growing periods of 2012 and 2013; but one site has been in continuous no-till management (CAF-NT) since 1998 while the other site has been in conventional tillage practices (CAF-CT) for the same time-period. After harvesting of winter wheat in August 2012, the crop residues were retained in the field at both sites and CAF-CT was tilled with chisel plow to a depth of about 0.15–0.2 m in the fall of 2012. Both the CAF-NT and CAF-CT were seeded for garbanzos (rate: 168 kg/ha) on May 2, 2013, reached full senescence around August 22 and were harvested on September 15, 2013. Before seeding, CAF-CT was cultivated with harrow to a depth of 0.05–0.08 m while CAF-NT was no-till planted. No fertilizers were applied at either site during the garbanzo growing season of 2013.

2.2. Meteorological and eddy covariance measurements

Meteorological variables averaged over 5- and 30-min intervals are simultaneously recorded at both sites, including air