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Assessing carbon dynamics at high and low rainfall agricultural sites in the inland Pacific Northwest US using the eddy covariance method

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ABSTRACT

Agricultural soils have the potential to be an important carbon (C) sink with proper management. The main goal of this study was to characterize C dynamics and net C exchange over two full crop years at two sites in the inland Pacific Northwest (iPNW). The iPNW is a highly productive dryland wheat growing region. The two measurement sites represent the low- and high-end of the regional precipitation gradient (250 and 550 mm year^{-1}, respectively). The low rainfall site is in a winter wheat-fallow rotation, while the high rainfall site is under continuous cropping with a rotation that includes winter wheat and pulse crops. The net ecosystem exchange of CO_2 (NEE) was monitored using the eddy covariance method. The winter wheat cropping years were strong CO_2 sinks, with net uptake of 517 ± 26 and 524 ± 29 g C m^{-2} year^{-1} at the high- and low-rainfall sites, respectively. The fallow and pulse-crop years were close to neutral with respect to NEE, with a net uptake of 20 ± 38 g C m^{-2} year^{-1} for garbanzo beans at the high rainfall site, and a net loss of 3 ± 19 g C m^{-2} year^{-1} for the fallow season at the low rainfall site. Combining NEE with other carbon exchange terms, most importantly carbon import and export via seeding and harvest, gives the net ecosystem carbon balance (NECB). We found that even when harvest export was taken into account, both sites acted as net carbon sinks over the two year period: the NECB at the continuous cropping site was 202 ± 60 g C m^{-2}, and the crop-fallow site had a NECB of 444 ± 34 g C m^{-2}. These results present useful insights to field-scale C dynamics on finely resolved timescales. To understand the potential of soils as a long term C sink however, longer-term monitoring over multiple complete crop rotation cycles in combination with other field measurements or process-based models will be necessary.

1. Introduction

Agriculture's role in the global carbon budget is important but inadequately understood. The disturbance to the soil associated with cultivation has resulted in a 25–50% decrease in soil carbon (C), most of which has been lost to the atmosphere (Beniston et al., 2014; Kucharik et al., 2001; Mann, 1986). This deficit can be thought of as a reservoir to be filled via changes in agricultural management (Baker et al., 2007). Cultivated soils are a potentially important sink for C, estimated to be 40 Mt C yr^{-1} in the United States (Lal, 2003; Lal et al., 2003), or between 5% and 14% of annual US greenhouse gas emissions (Murray et al., 2005; Paustian et al., 2006). Reducing tillage, incorporating cover crops, diversifying crop rotations, and reducing fallow periods are some of the management changes that have the potential to increase carbon storage in agroecosystems (Eagle et al., 2011; Lal et al., 1998; Purakayastha et al., 2008; Smith et al., 2007).

There is a high degree of variability in carbon dynamics between the same crop in different locations and/or from year to year. Scores of studies have looked at the C dynamics of different agroecosystems using the eddy covariance (EC) method (reviewed in e.g. Ceschia et al., 2010; Gilmanov et al., 2010, 2013, 2014; Kutsch et al., 2010). There is a wide range in the C balance for the agroecosystems included in these reviews: from a net sink of 690 g C m^{-2} yr^{-1} to a net source of 275 g C m^{-2} yr^{-1} (Ceschia et al., 2010). This range is due to the variability in C dynamics in agroecosystems as a

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function of cultivar, soil type, climate, and management. Furthermore, as Schmidt et al. (2012) point out, the carbon budget of the preceding crops has an important impact on that of subsequent cropping years. This site-to-site and year-to-year variability makes it difficult to prescribe management practices based on measurements from a single crop year. A few recent EC publications have characterized a crop's carbon budget over multiple crop years/full crop rotations to address this issue (Aubinet et al., 2009; Beziat et al., 2009; Glenn et al., 2010; Schmidt et al., 2012).

This study reports the results of the first multi-year EC measurements of CO_2 over the unique and highly productive dryland wheat cropping systems in the inland Pacific Northwest (iPNW). Thus, this work presents new C dynamics data for an important agricultural region and our results contribute to understanding the bridge from short-term carbon flux measurements to long-term changes in soil organic carbon. We analyze measured carbon fluxes over two sequential crop years at two sites with very different rainfall regimes in the iPNW. This region differs from other dryland regions with wheat-based cropping systems in several important ways. European systems tend to use organic fertilizer and harvest the straw along with the grain, while in the iPNW most growers use only synthetic fertilizer and the straw residue is retained. In mid-continent North America, most of the precipitation occurs during the growing season, while in the iPNW the crops rely on stored soil moisture built up from winter and spring precipitation. The latter factor has critical implications for the effects of climate change in this region where warmer temperatures are projected to be accompanied by significant changes in seasonal precipitation (Abatzoglou et al., 2014).

The overall goal of this research is to increase our understanding of the relationship between management, climate, and the C budget in iPNW agroecosystems as part of the USDA-supported Regional Approaches to Climate Change (REACCH) program (https://www.reacchpna.org/). The work represented herein is a first step in a plan to develop a long term record of C dynamics for wheat systems in this region, as part of a USDA Long-Term Agroecosystem Research (LTAR) site. We report here on two locations which are both dryland, wheat-based cropping systems in eastern Washington, but they represent two extremes within the region in terms of rainfall (550 vs. 250 mm annually) and management practices. Though soil carbon has been extensively studied in agroecosystems in this region (e.g. Stockle et al., 2012; Brown and Huggins, 2012), this work, along with results presented in the companion paper (Chi et al., 2015) constitute the first use of the EC method and auxiliary biotic measurements to provide highly time-resolved information on carbon dynamics and related water and energy fluxes at multiple sites over more than one consecutive growing season. The data are used to address the following science questions:

1. How do net CO_2 fluxes (NEE) and C budgets (NECB) compare between these two low and high rainfall measurement sites?
   - What are the seasonal differences in carbon dynamics?
   - How sensitive are the measured C fluxes to variations in precipitation amount and timing?
2. What are the implications of these two-year budgets for long term C storage?
   - How does this budget compare to other approaches and in other agricultural systems?

Through answering these questions we will improve the understanding of C dynamics in iPNW agroecosystems, which will help to identify best management practices for climate mitigation. The analysis also sheds light on how EC compares to other C measurement techniques.

Table 1
Summary of key characteristics of the high and low rainfall study sites.

Characteristic	CAF-NT	LIND
Avg annual precipitation	550 mm	247 mm
Location	46.78°N, 117.09°W	46.99°N, 118.60°W
Elevation	800 masl	475 masl
Soil type and order	Silt loam, Mollisol	Silt loam, Mollisol
% SOM in top 5 cm	2–5%	1–2%
Avg annual temp	9 °C	10 °C
Tillage type	Direct drill (no-tillage)	Chisel plow and cultivate (reduced tillage)
Crop rotation type	Continuous cropping	Crop-fallow

2. Materials and methods

2.1. Site description

Comparison of key characteristics of the two study sites is summarized in Table 1. The high-rainfall study site is located 10 km northeast of Pullman, WA at the Washington State University Cook Agronomy Farm (CAF) (46.78°N, 117.09°W, 800 m above sea level). Both this site and the low-rainfall site are located in the Columbia Basin, and were zonal xeric grassland or steppe (Franklin and Dyrness, 1973; Kovar-Eder et al., 2008) before conversion to agriculture. The region has a Mediterranean, semi-arid climate, with the majority of precipitation falling between October and April. The average annual precipitation at the study site is 550 mm. The soils are silt loam (Naff, Thatuna, and Palouse Series) of the Mollisol order (Soil Survey Staff, N.R.C.S. and United States Department of Agriculture, 1999, 2013) with 2–5% organic matter in the top 20 cm (Purakayastha et al., 2008). The average high temperature is 26 °C in the summer and the low is −4 °C in the winter, with an overall average annual temperature of 9 °C from 1981–2010 (NOAA, 2015). The prevailing wind directions in the region are from the southwest and east, but at the site local flows are from the east and east by southeast, with occasional winds from the west and west by southwest (Fig. 1). The site is currently under a rotation that includes winter wheat (*Triticum aestivum*, "WW"), spring wheat, and pulse crops, including garbanzo beans (*Cicer arietinum*, "GB") and has been under no-tillage (aka no-till or direct drill) management since 1998. The no-till site is hereafter referred to as CAF-NT. The site was under WW during the 2012 crop year and GB in 2013 (see Table 2), deviating from the normal rotation in order to address biological pathogens. Approximately

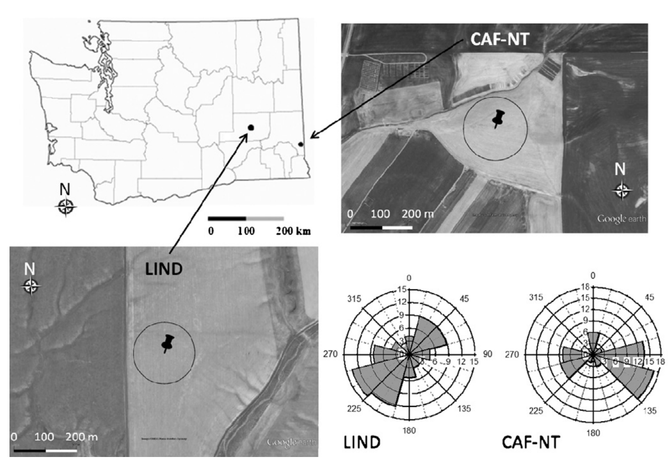

Fig. 1. Locations of study sites. The daytime fetch of each flux tower site is ~100 m (gray ring). The wind roses show wind direction frequency for the two-year study period at each site.