ANNUAL CARBON BALANCE OF A SECOND-YEAR TALL FESCUE SEED CROP

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Introduction

Replacing annual with perennial species is widely recommended as a best practice to increase and maintain soil organic matter in crop and pasture systems. However, there are few data that describe rates of soil carbon accumulation under perennial grass seed production systems (Griffith et al., 2011). Changes in soil organic carbon are slow and can be difficult to detect following changes in cultural practices, in part because multiple factors can have opposing influences on soil organic carbon. Soil organic carbon change is determined by the balance between carbon taken up through photosynthesis and the carbon removed with harvest and lost through plant respiration, soil microbial respiration, and soil erosion. Routine measurements of plant biomass accumulation can describe the amount of carbon taken into a plant-soil system, but additional measurements are needed to fully describe the fluxes of carbon lost and to determine whether a plant-soil system is a net carbon sink or source.

Although it can take years of monitoring soil carbon changes to ascertain whether a plant-soil system is a carbon source or sink, carbon balance can be determined for a single year using the eddy covariance technique. This technique measures the exchange rate of CO_2 between the atmosphere and a plant canopy by means of wind speed and gas sensors affixed to a tower downwind of the study area. The covariance between fluctuations in vertical wind velocity and CO_2 concentration are measured to determine net fluxes of CO_2 entering and leaving the plant canopy. This technique provides nearly continuous measurements of photosynthesis and ecosystem respiration at a field scale. When combined with independent estimates of harvest carbon removal and soil erosional loss, eddy covariance measurements can be used to develop a complete, field-scale annual carbon budget.

In 2015, the eddy covariance technique was used to determine annual CO_2 exchanges for a 2-year-old tall fescue field as part of a regional study on the potential greenhouse gas impacts of bioenergy crops in Oregon (Schmidt et al., 2018). Here we report eddy covariance and ancillary data to evaluate the carbon budget of this second-year tall fescue field.

Materials and Methods

A 28-acre field in Marion County, OR, was planted with ‘Chipotle’ turf-type tall fescue in April 2013. Fall nitrogen (N) was applied at 40 lb N/acre and spring nitrogen at 160 lb N/acre. Trinexapac-ethyl plant growth regulator (Palisade) was applied at a rate of 2 pt/acre at the two-node growth stage. Rodenticide, slug bait, herbicide, and fungicide were also applied as needed. The crop was swathed June 25, 2015, and seed and straw were harvested on July 6 and 9, respectively.

Exchanges of CO_2 were measured with the eddy covariance method during the second harvest year, from January through December 2015. Primary instruments included a three-dimensional sonic anemometer (model CSAT3, Campbell Scientific Inc., Logan, UT) and a closed-path infrared gas analyzer (model LI-7200, LI-COR Inc., Lincoln, NE), both measuring at 8.2 feet above ground level. Ancillary meteorological measurements included air temperature and humidity, total solar radiation, and photosynthetically active radiation, ambient air pressure, and volumetric soil water content.

High-frequency (10 Hz) eddy covariance measurements were processed to 30-minute average fluxes following the procedure described by Thomas et al. (2009). Approximately 44% of the initial 30-minute flux data was removed because of limited turbulence development, a wind direction originating outside the tall fescue field, or unusually high CO_2 values reflective of vehicle emissions. After removing these data, the flux data were gap-filled using linear interpolation when data gaps were less than 2 hours. For gaps longer than 2 hours, a light-response model and temperature-response model were applied separately to the daytime and the nighttime data. Two longer data gaps occurred from May 5 to May 27 (due to power system failure) and from June 28 to July 6 (when equipment was removed for harvest). No meteorological data were available to model these gaps. Therefore, daily-average fluxes were estimated by linear interpolation for the May gap and by extrapolation of postharvest fluxes for the June-July gap.

Net CO_2 fluxes were also partitioned into estimated fluxes for photosynthesis and ecosystem respiration.

These calculations are based on the fact that no photosynthesis occurs at night; nighttime fluxes result from respiration alone. Daytime respiration was estimated by first computing regressions between nighttime fluxes and air temperature, which is the main environmental driver of respiration, and subsequently applying the regression coefficients to daytime air temperatures to estimate daytime respiration. Photosynthesis was computed as the difference between net CO_2 flux and daytime respiration. Uncertainty for annual net CO_2 exchange was estimated as ± 18%, based on a synthesis of error analysis across the AmeriFlux network (Schmidt et al., 2012).

The amount of carbon exported with harvest was computed from grower-reported seed yield and tons of grass straw removed. A carbon content of 42% was assumed for both straw and seed based on typical values from previous studies (T. Chastain, personal communication). Carbon losses due to soil erosion were not measured, but, based on previous studies showing very low erosion rates for second-year tall fescue (Steiner et al., 2006), these losses were expected to be small.

To provide environmental context, long-term average annual precipitation and temperature for the site were retrieved from the Oregon State University PRISM Climate group. Long-term average production statistics for Marion County were also retrieved from Oregon State University Extension.

Results and Discussion

The tall fescue field had net daily gains of CO_2 (indicated as a positive flux value, Figure 1A) during the spring growing season and net daily CO_2 emissions during much of the rest of the year. The plant-soil system began the 2015 calendar year losing CO_2 to the atmosphere, until daily fluxes began to exceed parity (i.e., photosynthesis exceeded respiration) in mid-February. CO_2 uptake increased until mid-May and returned to parity by the time the crop was swathed in late June. Following harvest, the field lost CO_2 on most days. Partitioned fluxes indicate that respiration was relatively consistent throughout the year, and therefore seasonal patterns in photosynthesis dominated CO_2 exchange rates over the year (Figures 1B and 1C).

High rates of spring CO_2 uptake more than offset emissions during the rest of the year; therefore, the field had a net positive carbon uptake of 1.4 tons C/acre/year (3.2 megagrams (Mg) C/ha/year) when fluxes were summed for the whole year (Figure 2). Individual fluxes for photosynthesis and ecosystem respiration were estimated to be 8.2 and -6.8 tons C/acre/year (18.4 and –15.3 Mg C/ha/year), respectively.

Grower-reported seed yield for 2015 was 0.9 ton/acre (2.0 Mg/ha), which is within the 15-year range reported for the county but was approximately 35% higher than the county average for 2015 (Figure 3). Unusually warm temperatures in 2015 reduced yields for many of the region's producers, as demonstrated by long-term climate and yield data (Figure 3).

The grower reported 2 tons/acre (4.4 Mg/ha) of straw biomass harvested. Assuming a 42% carbon content in harvested seed and straw provided an estimated carbon removal of 1.25 ton/C/acre (2.8 Mg C/ha, Figure 2). Subtracting harvested carbon from net annual CO_2 exchange provided an estimated carbon balance of 0.19 ton C/acre/year (0.4 Mg C/ha/year, Figure 2). Assuming uncertainties of ± 18% for net annual CO_2 exchange and ± 20% for harvested biomass provided an uncertainty range of ± 0.35 ton C/acre/year (0.8 Mg C/ha/year) for the annual carbon balance. The field was therefore estimated to be carbon neutral to a small

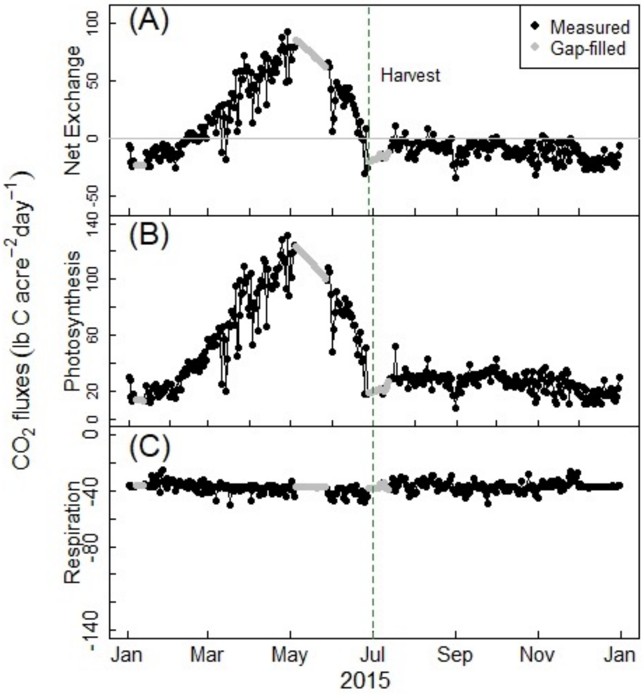

Figure 1. Time series for (A) daily net CO_2 exchange and partitioned estimates for (B) daily photosynthesis and (C) daily ecosystem respiration. Black points show direct measurements, and gray points show fluxes estimated by gap-filling procedures.

carbon sink. Any incremental carbon gain likely took the form of additional root or shoot biomass, as tall fescue plants increase in size over the first several years of stand establishment (Steiner et al., 2006).

The annual carbon balance of tall fescue and other perennial grass stands can be expected to increase with stand age over the first several years following establishment. This is expected because soil tillage in the establishment year causes microbial respiration of soil carbon and because root and shoot biomass growth over time reduces soil erosion (Steiner et al., 2006). These factors should contribute to lower carbon losses and greater carbon uptake through time. The eddy covariance measurements presented here showed that a tall fescue stand had reached parity between establishment-related emissions and plant CO_2 uptake by the second harvest year. The magnitude of ecosystem respiration that occurs with stand replacement and seedbed preparation has not been examined for perennial grass seed systems, to our knowledge. Several years of plant growth may be needed to compensate for the emissions occurring during the establishment year, and additional research would be needed to assess the carbon balance of a complete 4- to 5-year tall fescue rotation.

In conclusion, a 2-year-old tall fescue stand with straw removal was shown to be carbon neutral or a small carbon sink in 2015. However, the present study did not evaluate carbon balance over a full tall fescue rotation, and it should be stressed that carbon accrued during the rotation may be lost during stand replacement. This study examined only a single tall fescue field for 1 year and did not assess the impacts of management (e.g., postharvest residue management or tillage method) on carbon accrual. However, this study did

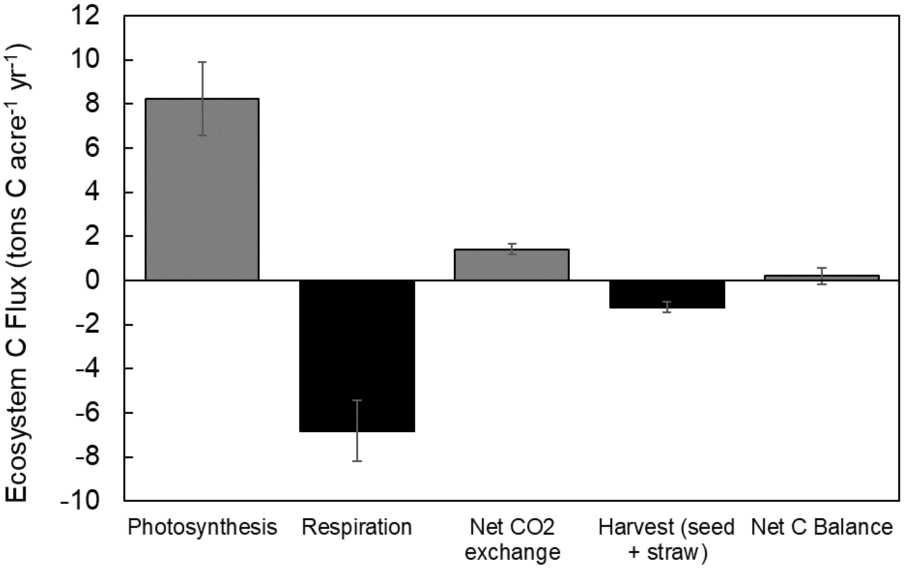

Figure 2. Fluxes contributing to annual carbon (C) balance for a second-year tall fescue stand in Marion County, OR.

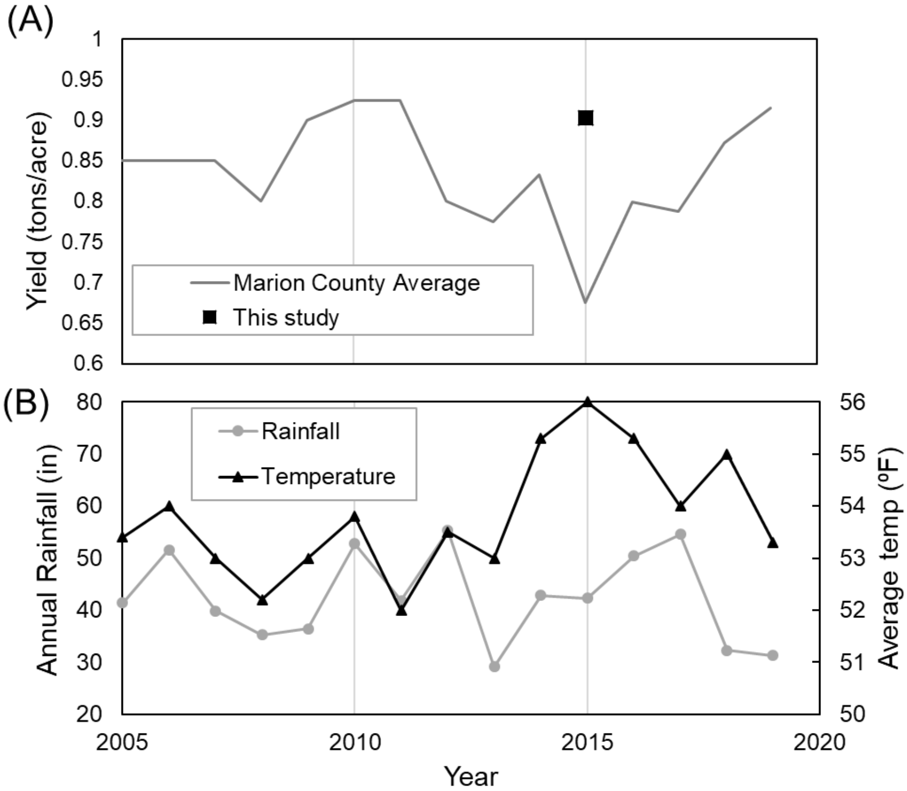

Figure 3. (A) Average grower-reported seed yield in Marion County, OR, compiled by Oregon State University Extension (solid line) and grower-reported seed yield at the study site in 2015 (closed square). (B) Annual cumulative rainfall and average air temperature at the study site.

show that baling straw did not lead to carbon losses for a second-year stand. The near-neutral carbon balance shown here and the lack of change in soil organic carbon shown over time by previous research (Griffith et al., 2011) suggest that tall fescue grown for seed may have a low carbon footprint. This information is useful for establishing the climate and soil health impacts of tall fescue seed production.

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