Flux of carbon dioxide and nitrous oxide across scales of two tillage systems in a California agricultural system

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Abstract
Using eddy-covariance and closed chambers, we quantified the flux of carbon dioxide (CO₂) and nitrous oxide (N₂O) under minimum tillage (MT) and standard tillage (ST) systems in two 15-ha neighboring fields in California. The eddy-covariance data showed that field level CO₂ uptake in MT lagged behind that of ST for maize and sunflower, suggesting less photosynthesis in the MT crops compared to the ST crops. CO₂ flux at the soil surface as measured by chambers was not significantly different by tillage and position. The level of CO₂ flux rates varied annually depending on current crop type and soil carbon (C) inputs from a previous year. The CO₂ flux from eddy-covariance, automated chambers, and portable chambers compared reasonably well. No significant overall effect of tillage and position on N₂O emissions was observed. However, N₂O fluxes in the side dress position were significantly greater than fluxes from other bed positions. Peak N₂O emissions appear to match with the times of N fertilization and irrigation. Process-based models were successful at predicting CO₂ and N₂O emissions at our site. Simulations showed that annual differences in weather or management conditions contributed more to the variance in annual CO₂ and N₂O emissions than did soil variability.

Key Words
Mediterranean climate, conservation tillage, DAYCENT, SOILCO2

Introduction
Estimates of agricultural greenhouse gas (GHG) emissions are needed to develop economically efficient as well as effective policies in mitigating and reducing GHG emissions in farming systems. Despite the importance of agriculture in California’s Central Valley, the potential of alternative management practices to reduce soil GHG emissions has been poorly studied, and quantitative estimates across fields remain uncertain. Furthermore, the interactions between no or minimum tillage and irrigation practices have not been widely investigated. In addition, raised beds and furrows are typically formed for maintaining reasonable irrigation uniformity. Thus, soil properties controlling the rate of decomposition are expected to vary spatially across positions in the middle of the bed, the furrow, between plants, or across the fertilizer band. Accordingly, the spatial variability and intensity of CO₂ and N₂O emissions would likely be position-specific, but have not been investigated.

The objective of this field study were to (i) quantify CO₂ and N₂O emissions from an irrigated field under standard tillage (ST) and minimum tillage (MT), (ii) determine the temporal and spatial variations in CO₂ and N₂O across a seed bed and at the field scale, and (iii) to improve and validate existing models in predicting soil C and N across farmer’s fields following the implementation of MT.

Methods
Site description
The research site was a 30.8-ha irrigated field near Davis, CA (38°36’N, 11°50’E). The site has a Mediterranean climate with mean annual temperature of 16.1°C and mean annual precipitation of 564 mm, and irrigation is primarily by furrow irrigation. The site was managed under ST through Fall 2000 and then converted to no-till in Fall 2001. In October 2003 after harvest, the site was split into two fields, with the north half of the site under full tillage operations and the south half remaining under no-till. The standard tillage operations consisted of one pass each of deep ripping to 45 cm, stubble disk ing, disk ing to 15 cm, grading, and forming beds. In May 2005, stubble was chopped in both fields, with three shallow (7-10 cm), bed disc passes for ST and two passes for MT. Both fields also had one mulcher pass. From 2003 to 2006, the fields were planted to wheat, maize, and sunflower, respectively. At the initiation of the study in 2003, 30 sampling locations for gas samples were established in the field.
Greenhouse gas flux measurements

Three flux measurement methods were used. First, one eddy-covariance system was mounted on a mast in each treatment to measure field-scale CO₂ exchange. Measurements of vertical CO₂ fluxes were made using two 3-D sonic anemometers (CSAT-3) and two fast-response open path infrared gas analyzers (IRGAs). Secondly, two 0.62-m² auto-chambers were installed in the ST field with the capability of assessing the temporal pattern of CO₂ flux, and one auto-chamber was installed in the MT field. Lastly, the CO₂ and N₂O fluxes were measured at 30 locations with portable chambers (covered 0.012 m² of soil surface) approximately monthly during the fallow seasons and biweekly during the growing seasons. The CO₂ concentration inside the chambers was measured at 0, 30, 60, 120, 180, 240, and 300 seconds after placement of chambers over the soil surface with an IRGA. We sampled N₂O from the vented chambers in nylon syringes after 20 minutes and analyzed samples within 24 hours on a gas chromatograph.

At the position level, CO₂ and N₂O fluxes from the portable chambers were normalized for the time of day of sampling by applying a Q₁₀ function to the data. Based on 24-hr measurements of each flux, we used seasonal Q₁₀ values ranging from 1.3 to 3.1 for CO₂ and 1.68 for N₂O. A time-weighted average over a growing season was then computed. The effect of position on soil gas flux was determined by using the aggregated seasonal flux data. To extrapolate the flux at the position level to the whole field level, the Q₁₀-corrected flux was normalized by accounting for the percent of surface area each chamber position occupied in the field. The area-corrected data were used to determine the effect of tillage on soil gas flux at the field level.

Modelling approach

The DAYCENT model was used to estimate N₂O soil fluxes from these fields. Model performance was checked against measured N₂O fluxes. A Monte-Carlo analysis was performed for uncertainty estimation. Field scale CO₂ fluxes were also evaluated using the one-dimensional process-based SOILCO2 module of the HYDRUS-1D software package.

Statistical analysis of data

We selected a mixed model ANOVA for a coarse analysis of tillage and position effects on CO₂ and N₂O fluxes, while accounting for confounding effects by changes in crops each year and the varying timing shifts of tillage, fertilizer, and irrigation management. The gas flux data were assumed to be independent each year at each plot. At each plot, gas flux measurements were considered as repeated over time and across positions within the plot.

At both position and field levels, data from November 2003 to February 2004 were not used in the mixed model ANOVA because flux measurements were made only on the bed positions during this period. Outliers were checked by visual inspection of the residual plot of the mixed model and then removed for a better model fit.

Results

Diurnal CO₂ patterns were evident in all months during the growing season, first related to a temperature dependence of soil respiration, and then later related to the light dependence of photosynthesis. Following the planting of maize in 2004, strong diurnal photosynthetic patterns (negative net ecosystem exchange) were observed by the young growing plants, with ST showing much more CO₂ uptake than in the MT treatment (Figure 1). It is notable that the maize plants in the ST tended to initially grow more vigorously than those in the MT during the early part of the growing season, although the photosynthetic C uptake rates subsequently became approximately equal. A similar difference persisted in 2005 under the sunflower crop, possibly due to poor crop growth in MT. In general, the eddy-covariance data suggest that tillage did not appear to increase soil CO₂ emissions, although the ST released slightly more CO₂ than the MT during the season in 2004 and 2005. Maximum mean, diurnal net ecosystem exchange (NEE) over the sampling period ranged from 16.3 to 111.7 for MT and 19.0 to 130.3 kg C/ha/d for ST. CO₂ emissions measured by chambers followed a similar trend of crop growth for the different years, ranging from 4.6 to 46.9 kg C/ha/d for ST and from 4.8 to 52.4 kg C/ha/d for MT (Lee et al. 2009). The flux from all three CO₂ flux measurement methods (eddy-covariance, automated chambers, and portable chambers) was compared. The flux values from these methods were all reasonably close to each other. Simulations showed that surface CO₂ fluxes show a significant dependency on soil hydraulic properties (Buchner et al. 2008).
No significant overall effect of tillage and position on N$_2$O emissions was observed. However, N$_2$O fluxes in the side dress position were significantly greater than fluxes from other seed bed positions, and were further accentuated by a significant tillage effect. Peak N$_2$O emissions appear to match with the times of N fertilization and irrigation in 2004 and 2005. Generally, the range in modeled average daily N$_2$O fluxes at the site was comparable to the range in measured daily fluxes (Figure 2) (De Gryze et al. in press). However, the solitary N$_2$O flux peak measured on 22 May 2006 was not predicted by the model. In addition, the model underestimated N$_2$O emissions during May and June of 2004. The modeled variability around daily N$_2$O fluxes was in general smaller than the measured variability.

![2004 Minimum Till Diurnal NEE](image1)

![2004 Standard Till Diurnal NEE](image2)

Figure 1. Mean net ecosystem exchange (NEE) on a diurnal basis in 2004 as measured by the eddy-covariance approach. Each plotted data point is the mean of data collected at 0.5 h intervals over the entire month.
Figure 2. Modeled and measured N$_2$O emissions versus time for the standard and minimum tillage treatments. The vertical bars associated with each mean measured value is ± 1 standard deviation. The gray area around model results shows ± 1 standard deviation around the average, as calculated by a Monte Carlo analysis. From De Gryze et al. (2010), in press.

Conclusion

The eddy-covariance results show that MT did not lead to a decrease in soil respiration compared to ST at the field scale. Similarly, there was no gross effect of tillage or position on CO$_2$ and N$_2$O flux measured by closed chambers. However, seasonal CO$_2$ and N$_2$O emissions were significant across the scales and tended to differ temporally at a specific bed position. A comparison between the three flux measurement methods shows that CO$_2$ fluxes were comparable across scales. The model showed that annual differences in weather or management conditions contributed more to the variance in annual GHG emissions than did soil variability. The SOILCO2 and DAYCENT models were successful at predicting CO$_2$ and N$_2$O emissions of different tillage systems in California.

References

