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

Dennis E. Rolston[A], Juhwan Lee[B], Kyaw Tha Paw U[A] and Johan Six[B]

[A]Department of Land, Air and Water Resources, University of California, Davis, California, United States, Email: derolston@ucdavis.edu
[B]Department of Plant Sciences, University of California, Davis, California, United States

Abstract
Using eddy-covariance and closed chambers, we quantified the flux of carbon dioxide (CO_2) and nitrous oxide (N_2O) 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 CO_2 uptake in MT lagged behind that of ST for maize and sunflower, suggesting less photosynthesis in the MT crops compared to the ST crops. CO_2 flux at the soil surface as measured by chambers was not significantly different by tillage and position. The level of CO_2 flux rates varied annually depending on current crop type and soil carbon (C) inputs from a previous year. The CO_2 flux from eddy-covariance, automated chambers, and portable chambers compared reasonably well. No significant overall effect of tillage and position on N_2O emissions was observed. However, N_2O fluxes in the side dress position were significantly greater than fluxes from other bed positions. Peak N_2O emissions appear to match with the times of N fertilization and irrigation. Process-based models were successful at predicting CO_2 and N_2O emissions at our site. Simulations showed that annual differences in weather or management conditions contributed more to the variance in annual CO_2 and N_2O 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 CO_2 and N_2O emissions would likely be position-specific, but have not been investigated.

The objective of this field study were to (i) quantify CO_2 and N_2O emissions from an irrigated field under standard tillage (ST) and minimum tillage (MT), (ii) determine the temporal and spatial variations in CO_2 and N_2O 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, 91°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 disking, disking 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 CO_2 exchange. Measurements of vertical CO_2 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-m^2 auto-chambers were installed in the ST field with the capability of assessing the temporal pattern of CO_2 flux, and one auto-chamber was installed in the MT field. Lastly, the CO_2 and N_2O fluxes were measured at 30 locations with portable chambers (covered 0.012 m^2 of soil surface) approximately monthly during the fallow seasons and biweekly during the growing seasons. The CO_2 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 N_2O from the vented chambers in nylon syringes after 20 minutes and analyzed samples within 24 hours on a gas chromatograph.

At the position level, CO_2 and N_2O fluxes from the portable chambers were normalized for the time of day of sampling by applying a Q_{10} function to the data. Based on 24-hr measurements of each flux, we used seasonal Q_{10} values ranging from 1.3 to 3.1 for CO_2 and 1.68 for N_2O. 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 Q_{10}-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 N_2O soil fluxes from these fields. Model performance was checked against measured N_2O fluxes. A Monte-Carlo analysis was performed for uncertainty estimation. Field scale CO_2 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 CO_2 and N_2O 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 CO_2 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 CO_2 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 CO_2 emissions, although the ST released slightly more CO_2 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. CO_2 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 CO_2 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 CO_2 fluxes show a significant dependency on soil hydraulic properties (Buchner *et al.* 2008).

No significant overall effect of tillage and position on N_2O emissions was observed. However, N_2O 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_2O emissions appear to match with the times of N fertilization and irrigation in 2004 and 2005. Generally, the range in modeled average daily N_2O 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_2O flux peak measured on 22 May 2006 was not predicted by the model. In addition, the model underestimated N_2O emissions during May and June of 2004. The modeled variability around daily N_2O fluxes was in general smaller than the measured variability.

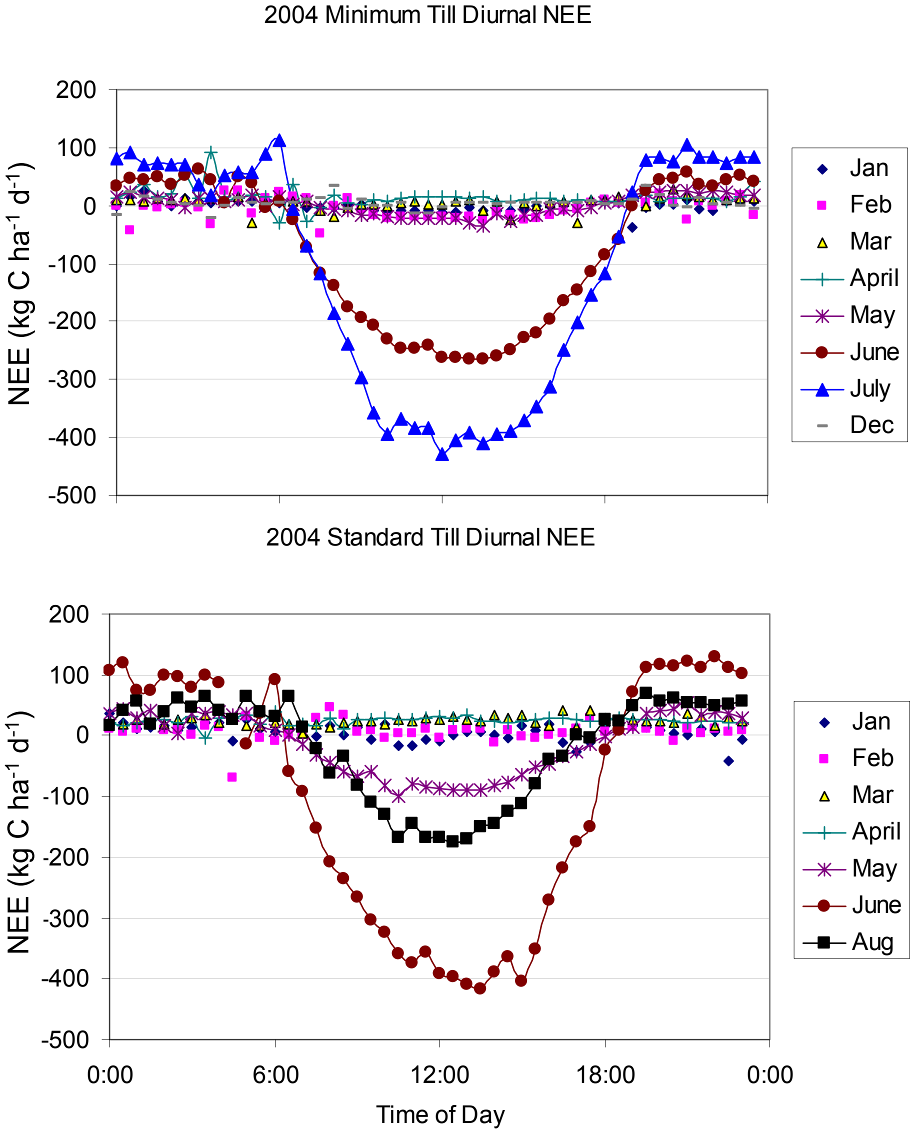

Figure 1. Mean net ecosystem exchange (NEE) on a diurnal basis in 2004 as measured by the eddy-covariance approach. Each plotted data point is the mean of data collected at 0.5 h intervals over the entire month.

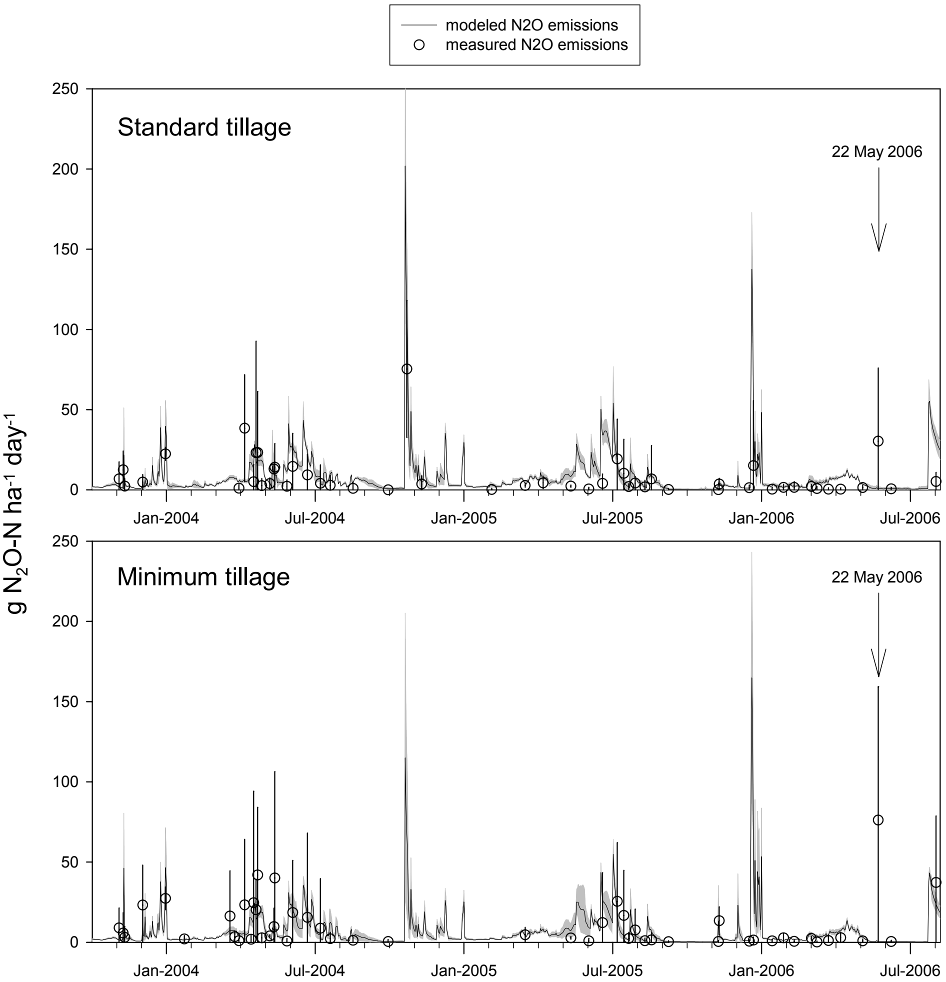

Figure 2. Modeled and measured N_2O emissions versus time for the standard and minimum tillage treatments. The vertical bars associated with each mean measured value is ± 1 standard deviation. The gray area around model results shows ± 1 standard deviation around the average, as calculated by a Monte 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_2O flux measured by closed chambers. However, seasonal CO_2 and N_2O 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_2O emissions of different tillage systems in California.

References

Buchner JS, Ŝimůnek J, Lee J, Rolston DE, Hopmans JW, King AP, Six J (2008) Evaluation of CO_2 fluxes from an agricultural field using a process-based numerical model. *Journal of Hydrology* **361**, 131–143.

De Gryze S., Wolf A, Kaffka SR, Mitchell J, Rolston DE, Temple SR, Lee J, Six J. (2010) Simulating greenhouse gas budgets of four California cropping systems under conventional and alternative management. *Ecological Applications*, in press.

Lee J, Hopmans JW, van Kessel C, King AP, Evatt KJ, Louie D, Rolston DE, Six J (2009) Tillage and seasonal emissions of CO_2, N_2O and NO across a seed bed and at the field scale in a Mediterranean climate. *Agriculture, Ecosystems & Environment* **129**, 378–390.