Greenhouse Gas Fluxes from Irrigated Sweet Corn (*Zea mays* L.) and Potato (*Solanum tuberosum* L.)

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Summary

Intensive agriculture and increased N-fertilizer use have contributed to elevated emissions of the greenhouse gases, CO_2, CH_4, and N_2O. In this study, the exchange of the greenhouse gases, CO_2, N_2O, and CH_4, between a Quincy fine sand (mixed, mesic Xeric Torripsamments) soil and atmosphere was measured in a sweet corn (*Zea mays* L.) - sweet corn - potato (*Solanum tuberosum* L.) rotation during the 2005 and 2006 growing seasons under irrigation in eastern Washington. Gas samples were collected using static chambers installed in the second year sweet corn and potato plots under conventional tillage (CT) or reduced tillage (RT). Total emissions of CO_2-C from sweet corn integrated over the season were 1887 and 1684 kg CO_2-C ha^{-1} for the 2005 and 2006 growing seasons, respectively. For the same period, CO_2 emission from potato plots was 1578 and 1290 kg of CO_2-C ha^{-1}. Cumulative CO_2 fluxes from sweet corn and potato fields were 15 times higher, than adjacent non-irrigated, native shrub steppe vegetation (NV) in 2005. Nitrous oxide losses accounted for 0.25% (0.55 kg N ha^{-1}) of the applied fertilizer (224 kg N ha^{-1}) in corn and 0.18% (0.59 kg N ha^{-1}) of the 336 kg N ha^{-1} applied fertilizer. Sweet corn and potato plots, on average, absorbed 1.7 g CH_4-C-ha^{-1} d^{-1} and 2.3 g CH_4-C-ha^{-1} d^{-1}, respectively. The global warming potential (GWP) contribution from NV, corn and potato fields were 448, 7175, and 6487 kg CO_2-equivalents ha^{-1}, respectively for the 2005 growing season and was 14% lower in 2006.

Introduction

Supporting an ever expanding human population has intensified demands on land and other natural resources. Conversion of forests and grasslands to intensive agriculture with biomass burning and increasing N-fertilizer use world wide have contributed to elevated emissions of greenhouse gases (GHG). Atmospheric concentrations of CO_2, CH_4, and N_2O are increasing at a rate of 0.4, 0.6, and 0.25% per year, respectively, (IPCC, 2006) and are projected to continue to do so. Carbon dioxide is the major greenhouse gas followed by CH_4 and N_2O. Agriculture is a minor emitter of anthropogenic CO_2, and a major emitter of anthropogenic CH_4 and N_2O to the atmosphere. Agriculture contributes about 20% of the world's global forcing from CO_2, CH_4, and N_2O. Agricultural practices contribute approximately 27% CH_4 and 70% of total anthropogenic N_2O emissions of these gases (USDA, 2004). As a consequence, increased concerns for global climate change necessitate agricultural mitigation strategies to reduce greenhouse gas emissions.

Agricultural management practices that include conservation tillage systems, soil erosion control measures, and improved nitrogen and irrigation management practices have the potential to sequester C and reduce GHG emissions (Lal, 2004; Lal et al., 2003; West and Marland, 2002; Follett, 2001; Paustian et al., 1997). Soil organic carbon (SOC) is the largest terrestrial pool and is two times greater than the atmospheric carbon pool, and three times larger than the amount of C stored in living plants (Follett, 2001; Jobbagy and Jackson, 2000; Schlesinger, 1990; 1995). Soils are the major global sources of CO_2 and sinks of CH_4, thus any drastic change in current land use and farm management practices might lead to a change in the size of the soil C pool and ultimately alter the concentration of GHG's in the atmosphere (Mooney et al., 1987; Wang et al., 1999). The exchange of greenhouse gases between the biosphere and the atmosphere is interrelated (Mosier, 1998), so any change in the dynamic equilibrium of the C cycle will lead to changes in other cycles such as the N cycle. Nitrous oxide and CH_4 are produced in the soil and their absolute quantities are small compared to CO_2, however, they have global warming potentials 296 and 23 times greater than CO_2, respectively, over a 100-year period (IPCC, 2001). These gases are produced or consumed from native and cultivated soils through microbial mediated processes.

Consumption of atmospheric CH_4 in aerobic soil depends upon the sink strength of soils under different land uses (Powlson et al., 1997; Ojima et al., 1993; Mosier et al., 1991), soil pH (Hutch et al., 1994), and application of ammonium fertilizer (Steudler et al., 1989; Powlson et al., 1997). Consumption of CH_4 in aerobic soils by microorganisms is ubiquitous in temperate, tropical, boreal, grasslands and forests; however, the importance of soil consumption in arid and semi-arid lands that cover 30% of the earth's surface has been underestimated (Potter et al., 1996).

Nitrous oxide is primarily emitted from ecosystems as a by-product of nitrification and denitrification. However, the size of fluxes produced as a result of microbial processes depends on agricultural management, climatic conditions, availability of N, and soil properties (Smith et al., 2003; Aulakh et al., 1992). Comparison of N_2O fluxes from different soils in Belgium indicated that land use rather than soil properties influenced emission (Goosens et al., 2001). Byrnes et al. (1990) indicated N_2O fluxes may be more closely related to soil properties than to the N fertilizer sources applied. Emissions of N_2O from N-fertilized agricultural fields varies considerably and have been found to range between 0.001% and 6.8% of the applied N fertilizer (Bowman, 1990; Eichner, 1990). Nitrous oxide emissions have been extensively studied within temperate agroecosystems (Eichner, 1990). However, only limited data are available under irrigation in semi-arid regions (Mosier et al., 1986; Bronson et al., 1992; Delgado and Mosier 1996; Delgado et al, 1996). The International Panel on Climate Change (IPCC) methodology for estimating direct N_2O emissions from fertilized agricultural soils assumes an N_2O emission factor of 1.25% ±1 of the fertilizer N applied (IPCC, 1997). This default value is applied uniformly to all regions with different agricultural management practices. Emissions from potato fields have been shown to be higher than reported previously and do not fit the relationship between N fertilization and N_2O emission adopted by IPCC (Bowman, 1994). Thus, there is a need to consider site specific environmental factors and management to quantify the emission rate of greenhouse gases from semiarid irrigated systems. The objectives of this research were to (i) describe cropping season patterns of greenhouse gas fluxes following fertigation practices in an irrigated sweet corn, sweet corn, potato rotation; (ii) estimate season losses of N_2O and amount of fertilizer losses as N_2O; and (iii) contrast field measured N_2O losses against predicted losses using IPCC methodology.

Materials and Methods

Field studies were conducted in 2005 and 2006 to characterize trace gas fluxes from a Quincy fine sand (mixed, mesic Xeric Torripsamments) soil. This study was conducted at the USDA-ARS Integrated Cropping Systems Research Field Station located near Paterson, Benton County, Washington (45°□56’ N, 119 29’ W; 114 m above sea level). The study area was previously in a native shrub-steppe plant community that had been converted to irrigated agricultural fields in 1990. The shrub-steppe is a portion of the semi-arid, shrub- and bunchgrass-dominated region in the western USA that stretches from British Columbia, Canada, to Mexico. The area is characterized by an annual precipitation of 178 mm, mostly occurring as rain/snow mix during winter months (Figure 21.1). The surface soil (0-10 cm) has a bulk density of 1.33 kg m^{-3} and 917 and 56 g kg^{-1} of sand and silt, respectively, with a pH of 6.6. Total soil organic C and N (analyzed by dry combustion on a LECO, CNS-2000 Elemental Analyzer, St. Joseph, MI) are 56 kg ha^{-1} and 16 kg ha^{-1}, respectively.

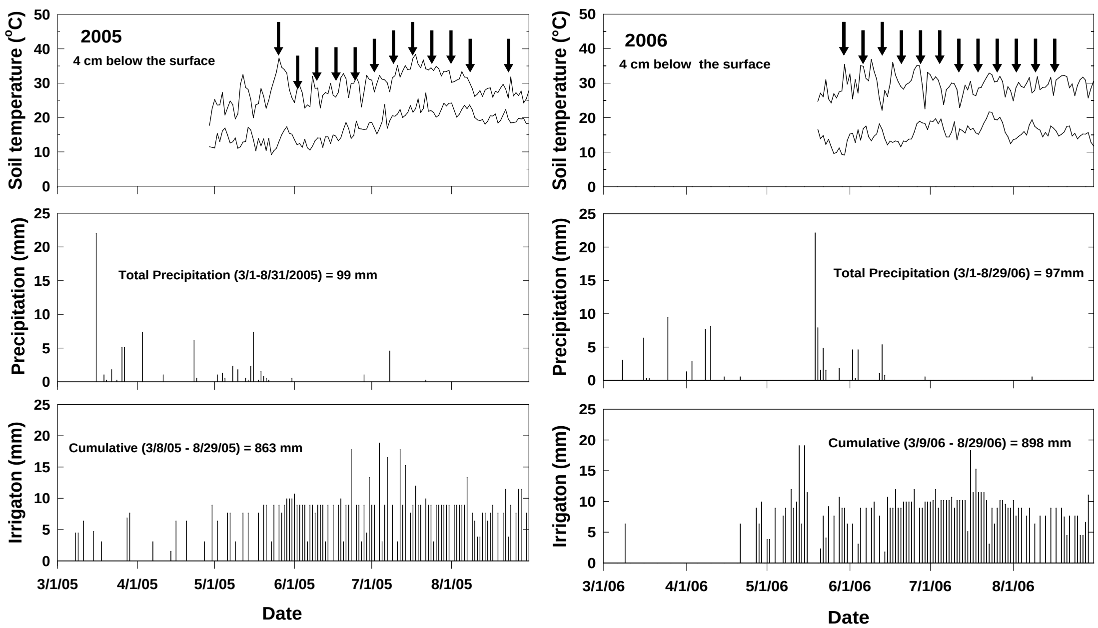

Figure 21.1. Growing season daily maximum and minimum soil temperature (-4 cm), precipitation, and irrigation for the 2005 and 2006 crop seasons. Soil temperature was measured every 30 min using thermocouples. Arrows identify fertigation events and sampling of trace gas fluxes.

Experimental Design

The experimental design was a strip split block with four replications within a three year sweet corn-sweet corn-potato rotation managed under center pivot irrigation. Treatments were stripped by tillage/crop (N-S) and split for N fertilizer (E-W). Crop and tillage were main plots and positions (locations) and fertilizer as subplots. Each replicate plot was 12 x 10 m. Within this design we sampled only the 100 kg N ha^{-1} pre-plant and 224 kg N ha^{-1} in season application, which represented a common fertilization schedule in the Columbia

Basin of eastern Washington. In both years, we sampled the potato and second-year sweet corn plots. Prior to tillage operations and planting a blended fertilizer containing 112 kg N ha^{-1} (as ammonium nitrate), 78 kg P_2O_5 ha^{-1}, 213 kg K_2O ha^{-1}, 4 kg S ha^{-1}, and 1.1 B kg ha^{-1} was applied to all treatments with a tractor using a Valmor™ spreader.

Equipment used in the setting up the tillage treatments included a Sunflower™- chisel-chopper-packer, a 13-shank bed splitter for potato hill formation, a six-row rod weeder, damer diker, six-row Harriston™ pick potato planter, and a twelve-row John Deere/Orthmann™ minimum tillage corn planter. Field preparation under the conventional tillage treatment for both corn and potato consisted of two passes with the chisel-chopper-packer to incorporate the previous year's crop residue, pre-plant fertilizer and create a smooth seedbed. Corn was planted at a seeding rate of 67,000 seeds ha^{-1} on 76-cm row spacing. For potato, after the primary tillage, hills were formed with the bed splitter on 81-cm centers, flatted with the rod weeder and planted. Potato seed pieces were planted to a depth of 15 cm at 25-cm spacing within the hill. The area between hills was damer diked prior to potato emergence. The damer diker creates depressions at approximately 30 cm intervals to improve water infiltration and reduced irrigation runoff. For the reduced tillage sweet corn treatment, no primary tillage was preformed. Corn seed was directly planted into the previous year's residue with the twelve-row John Deere/Orthmann™ minimum tillage corn planter. For potato, hills were formed in the previous year's residue with the 13-shank bed splitter then directly seeded with the six-row planter. The flattening of the hills and damer diking operations were omitted. During the two-year study, potato was planted in mid-March and harvested at the end of August. Sweet corn was planted at the end of April and harvested at the end of July.

In-season (IS) N fertilizer was applied every other week at rate of 22.4 kg N ha^{-1} through the center-pivot irrigation system. Corn plots received 112 kg N ha^{-1} as urea ammonium nitrate solution (UAN, 32%N), with five IS applications of 22.4 kg N ha^{-1} through the center pivot. Potato plots received 224 kg N ha^{-1} as UAN during five IS applications. Approximately, 112 kg N ha^{-1} was applied through the center-pivot irrigation system when corn was fertilized and the rest using a tractor-mounted-sprayer applicator, receiving a total of 44.8 kg N ha^{-1}every other week. The tractor applications were needed since the pivot was not equipped with variable-rate fertilizer technology. In-season applications of fertilizer started 4 weeks after potato plant emergence.

A native vegetation (NV) site outside the center pivot circle was also sampled to provide a comparison to the fertilized/irrigated cropland treatments. This site was native shrub-steppe, and received neither irrigation nor fertilizer.

Soil Sampling and Analyses

Soil samples (0-30 cm depth) were collected at the time of each gas sampling within 1 m of each chamber (see below). Soil samples were used to determine gravimetric moisture content and mineral N (NH_4^+ and NO_3^-) concentrations by extracting sub samples with 1M KCl and analyzed colorimetrically using a flow-injection analyzer (QuikChem AE, Lachat Zellweger, Loveland, CO). The pH of the soil (soil: DI water ratio 1: 2) was measured at the beginning and end of each growing season. Water-filled pore space (WFPS; m^3 m^{-3}) was calculated using the mean soil bulk density (SBD; Mg m^{-3}), and gravimetric soil moisture content (GSM; g g^{-1}) measured. WFPS= [(GSM * SBD)/ total soil porosity] where soil porosity = [1 – (SBD/2.65)], and the soil particle density is 2.65 Mg m^{-3}. At the time of gas sampling, inside chamber temperature (beginning and end) and air temperature before and after measurements were recorded using a hand-held digital differential thermocouple thermometer (Omega HHM290 Supermeter, Omega Engineering Inc., Stamford, CT). Eight EnviroSCAN capacitance probes (Sentek, Pty Ltd, Adelaide, South Australia) were installed within both sweet corn and potato plots with soil moisture determined at four depths (10, 30, 60, and 90 cm), and recorded every half hour over the growing season. Soil temperature at six positions (i.e. soil surface, and 4, 16, 100, and 150 cm below the soil surface) and air temperature at 1.5 m above the soil surface were measured every 30 min using thermocouples installed at four locations in both sweet corn and potato plots. These data were recorded on a CR10X data logger (Campbell Scientific Inc., Logan, UT).

Gas Flux Measurements

In-situ trace gas fluxes were measured using the static closed chamber method (Hutchinson and Mosier, 1981; Hutchinson and Livingston, 1993). Thirty-two chambers were installed in both crops (sweet corn and potato) in CT and RT treatments. Chambers were installed in the crop row (R) and inter-row (IR) areas of each treatment and sampled according to USDA-ARS GRACEnet (**G**reenhouse gas **R**eduction through **A**gricultural **C**arbon **E**nhancement **net**work) protocols (www.GRACEnet.usda.gov). The flux of N_2O, CO_2, and CH_4 was measured weekly after irrigation during the growing season between May and September for the 2005 and 2006 crop years. Approximately 9 mm of water was applied during each irrigation before trace gas flux measurements were collected. Figure 21.2 provides the schedule of irrigation applications and amounts of water applied throughout the growing season.

Gas sampling was carried out at the same time each day, usually 1 to 2 h after fertigation and irrigation events that occurred between 1000 and 1500 h of the day. A base frame was inserted at each sample point at the beginning of each field season, allowed to stabilize for a week before measurements and remained in place until harvest operations necessitated their removal. The base frames were 30.5-cm diameter x 15-cm high PVC driven into the soil to a depth of 5 cm. Flux of trace gases (CO_2, N_2O, and CH_4) was measured weekly by fitting the chamber base frames with a vented PVC cap (30.5-cm i.d. by 7.5-cm high) that contained a sampling port. The caps also had a 2.54-cm hole to allow air to escape and minimize air turbulence when caps were placed on the base frame. The hole was sealed with a rubber stopper during the period of measurement. The change in concentration of gases within each chamber was determined by withdrawing 35 mL of air from the headspace using 60-mL polypropylene syringes every 20 minutes over a 1-hour period after placing the chamber cap. Gas samples were immediately transferred to evacuated 12 mL Labco Exetainer (Labco Limited, High Wycombe, Buckinghamshire, UK) vials and taken to the laboratory for determination of N_2O, CO_2, and CH_4 by gas chromatography (Mosier and Mack, 1980). Samples were stored in a temperature controlled chamber at 25ºC and analyzed within a week of sample collection. A Varian CP-3800 GC (Varian, Palo Alto,CA) equipped with a thermal conductivity, an electron capture, and a flame ionization detector, was used to measure CO_2, N_2O, and CH_4 concentrations, respectively. The trace gas flux rate was calculated using the slope of the gas concentration over time within the chamber as described by Hutchinson and Mosier (1981).

Statistical Treatment of Data

Flux rates of N_2O, CO_2, and CH_4 and soil NO_3^- N and NH_4-N were analyzed separately in 2005 and 2006. For the experiment under the center pivot irrigation, data were analyzed as a split block design with repeated measures over time (week). In addition to the block effect, the suite of factors examined in the experiment included crop (sweet corn vs. potato), tillage (CT vs. RT), chamber position (R vs. IR), and week. Since the study area was fertigated every other week, the effect of week in the analysis was used as a surrogate for fertilizer application. Of the 12 weeks during which chambers were monitored, fertigation occurred at 1, 3, 5, 7, and 9 weeks after potato emergence.

Statistical analyses were conducted using PROC GLM of SAS (SAS Institute Inc., 2004). Assumptions of normality and equal variances were checked using PROC UNIVARIATE and by examination of residual plots (Kuehl, 1994). When residual plots indicated that a transformation was appropriate, transformations were applied, and the best transformation was selected, as suggested by Kuehl (1994). Most responses required a transformation to stabilize the variances. Transformations that were tried included $\log_{10}$ + C (where C is a constant to ensure that the transformed data were greater than 1), square root, and inverse square root. When the data were transformed, the statistical analysis was based on the transformed data, but all means reported in tables and figures are presented in the original units.

When treatment effects were significant ($P \leq 0.05$), whether simple or interaction effects, the difference between pairs of means were assessed using the PDIFF option in the LSMEANS statement of PROC GLM. To control experiment-wise error rate, the number of pair-wise comparisons was limited to comparisons of the effects of one factor only within levels of the interacting factors. For example, when there was a significant crop by tillage interaction, the effect of crop was assessed within tillage level, and the effect of tillage was examined only within crop. When the effect of time (week) or its interaction was significant, and when we wished to compare fertilized-week vs. unfertilized-week responses, we constructed single-degree-of-freedom contrasts.

Cumulative seasonal fluxes for the three greenhouse gasses were calculated as the area under the curve of seasonal flux over time for each respective gas. The Systat software (Systat Software Inc., 2000) was used to perform these calculations.

The concept of GWP was devised by IPCC (2006) to allow comparisons of the total cumulative warming effects of different GHGs by integrating over a specified time period from the emission of a unit mass of gas relative to a reference gas. The contributions of the three primary GHGs, N_2O, CH_4, and CO_2, to GWP (kg CO_2-equivalents ha^{-1}) were estimated based on values of 298, 25, and 1, respectively, for a 100-year time horizon on a per molecule basis (IPCC, 2006).

Results

Temperature, Moisture, and pH

Average daily air temperatures from the date of potato emergence to harvest were 21.1 and 21.8 ºC for the first and second years, respectively. Daily maximum and minimum soil temperatures at -4 cm during the growing season are presented in Figure 21.1. Total precipitation and the amount of in-season irrigation during the growing period in 2005 and 2006 depicting the time of sample collection are also shown in Figure 21.1.

Average water-filled pore-space (WFPS) at the time of gas sampling for the NV site was 0.06 and 0.10 $m^3 m^{-3}$, during the 2005 and 2006 growing seasons, respectively. The average WFPS under irrigation at the time of gas sampling ranged from 0.50–0.63 $m^3 m^{-3}$ (Table 21.1). The pH of the soil showed no significant change between the beginning and end of the season, although a slight decrease was observed. Average soil pH at the beginning of the season for both years was 6.4 (±0.3) for both potato and corn and at the end of the season was 6.2 (±0.2). Soil pH of the NV site was 6.8 (±0.1), with no change at the end of the experiment.

Table 21.1. Average water field pore space (WFPS) at the time of gas sampling during the 2005 and 2006 cropping seasons under a sweet corn - sweet corn - potato rotation with center pivot irrigation.

Year	Crop	Reduced tillage		Conventional tillage	
		Row	Inter-Row	Row	Inter-row
		----------------- WFPS ($m^3 m^{-3}$) -------------------			
2005	Potato	0.53 (0.03)†	0.54 (0.03)	0.52 (0.04)	0.56 (0.04)
	Corn	0.63 (0.04)	0.60 (0.05)	0.60 (0.04)	0.57 (0.03)
2006	Potato	0.55 (0.06)	0.60 (0.05)	0.52 (0.06)	0.61 (0.07)
	Corn	0.59 (0.06)	0.50 (0.02)	0.58 (0.04)	0.54 (0.07)

† Numbers in parentheses are standard deviations.

Nitrate and Ammonium in Soil

The four-way interaction among crop, tillage, position, and fertilizer level had a significant effect on soil nitrate in both years ($P < 0.0001$, both years). Regardless of tillage, row position, or year, the potato plots had more nitrate in the fertilized weeks than in the unfertilized weeks (Table 21.2). The same was generally the case for corn, with the exception of the R position under CT in 2005 in which there was no significant difference.

Under CT in the IR position, corn plots had more nitrate – N than potato plots regardless of year or week of fertilizer application. Under RT in the IR position, there was generally little effect of crop on soil nitrate – N (Table 21.2). In 2005 in the R position, potato plots had more nitrate – N than corn plots regardless of tillage or week of fertilizer application. But in 2006 the reverse was the case, with the corn plots generally having significantly more

Table 21.2. Average soil nitrate concentrations during the 2005 and 2006 growing seasons in sweet corn and potato plots under center pivot irrigation.

	Conventional Tillage				Reduced Tillage			
	Inter-row (IR)		Row (R)		Inter-row (IR)		Row (R)	
	Corn	Potato	Corn	Potato	Corn	Potato	Corn	Potato
2005	---------kg NO_3- N ha^{-1}---------							
Fertilizer	A 41.5 a†	A 19.8 b	A 12.3 b	A 16.1 a	A 18.3 a	A 19.3 a	A 12.4 b	A 30.3 a
No fertilizer	B 22.7 a	B 13.3 b	A 10.1 b	B 12.4 a	B 17.8 a	B 15.8 a	B 8.5 b	B 23.4 a
2006								
Fertilizer	A 46.8 a	A 24.2 b	A 23.5 a	A 14.7 b	A 38.0 a	A 26.6 a	A 26.3 a	A 20.8 b
No fertilizer	B 24.5 a	B 11.2 b	B 14.9 a	B 8.9 a	B 13.3 b	B 14.5 a	B 10.3 a	B 9.2 b

	Corn				Potato			
	Fertilizer		No fertilizer		Fertilizer		No fertilizer	
2005	IR	R	IR	R	IR	R	IR	R
	---------kg NO_3- N ha^{-1}---------							
Conventional till	A 41.5 a	A 12.3 b	A 22.7 a	A 10.1 b	A 19.8 a	B 16.1 b	B 13.3 a	B 12.4 a
Reduced till	B 18.3 a	A 12.4 b	A 17.8 a	A 8.5 b	A 19.3 b	A 30.3 a	A 15.8 b	A 23.4 a
2006								
Conventional till	A 46.8 a	A 23.5 b	A 24.5 a	A 14.9 b	B 24.2 a	B 14.7 b	B 11.2 a	A 8.9 a
Reduced till	B 38.0 a	A 26.3 a	B 13.3 a	B 10.3 b	A 26.6 a	A 20.8 b	A 14.5 a	A 9.2 a

The 4-way interaction was significant in both years ($P < 0.001$). †Upper case letters indicate significant differences between adjacent values within a column and within a given year. Lower case letters indicate significant differences between adjacent values within a row and within a given level of tillage and position (upper half of table) or within a given level of crop and fertilizer (lower half of table).

Table 21.3. Average soil ammonium concentrations during the 2005 and 2006 growing seasons in sweet corn and potato plots under center pivot irrigation.

	Conventional Tillage				Reduced Tillage			
	Inter-row (IR)		Row (R)		Inter-row (IR)		Row (R)	
	Corn	Potato	Corn	Potato	Corn	Potato	Corn	Potato
2005	kg NH_4- N ha^{-1}							
Fertilizer	A 10.7 b†	A 20.8 a	A 14.0 b	A 20.3 a	A 9.5 b	A 18.9 a	A 16.1 a	A 16.0 a
No fertilizer	B 4.4 b	B 6.0 a	B 4.0 b	B 7.6 a	B 3.9 b	B 6.3 a	B 3.7 b	B 6.3 a
2006								
Fertilizer	A 15.7 b	A 34.5 a	A 21.1 a	A 19.1 a	A 29.6 b	A 34.9 a	A 24.8 a	A 20.8 a
No fertilizer	B 3.5 b	B 11.1 a	B 4.0 b	B 6.0 a	B 6.2 b	B 7.3 a	B 7.2 a	B 6.5 b

	Corn				Potato			
	Fertilizer		No fertilizer		Fertilizer		No fertilizer	
	IR	R	IR	R	IR	R	IR	R
2005	kg NH_4- N ha^{-1}							
Conventional till	A 10.7 b	A 14.0 a	A 4.4 a	A 4.0 a	A 20.8 a	A 20.3 a	A 6.0 b	A 7.6 a
Reduced till	A 9.5 b	A 16.1 a	B 3.9 a	A 3.7 a	A 18.9 a	B 16.0 a	A 6.3 a	A 6.3 a
2006								
Conventional till	B 15.7 b	A 21.1 a	B 3.5 a	B 4.0 a	A 34.5 a	A 19.1 b	A 11.1 a	A 6.0 b
Reduced till	A 29.6 a	A 24.8 a	A 6.2 b	A 7.2 a	A 34.9 a	A 20.8 b	B 7.3 a	A 6.5 a

The 4-way interaction was significant in both years ($P < 0.001$, both years). †Upper case letters indicate significant differences between adjacent values within a column and within a given year. Lower case letters indicate significant differences between adjacent values within a row and within a given level of tillage and position (upper half of table) or within a given level of crop and fertilizer (lower half of table) nitrate – N regardless of tillage in the R position (Table 21.2). In corn plots, when there was a significant effect of tillage, the CT soils had more nitrate – N than the RT soils, but in potato plots when there was a significant difference, the RT soil had the higher concentration of nitrate – N, and this was the case regardless of whether the samples were taken during fertilized or unfertilized weeks (Table 21.2). Also in the corn plots, the IR position nearly always had significantly higher nitrate – N than the R position, again, regardless of the week of fertilizer application or year. But in the potato plots the effect of row position was mixed (Table 21.2).

As with nitrate, the four-way interaction among crop, tillage, position, and week of fertilizer application had a significant effect on soil ammonium in both years ($P < 0.0001$, both years). Regardless of crop, position, tillage, or year, soil ammonium was significantly higher in fertilized than unfertilized weeks (Table 21.3). Under CT, when there was an effect of crop on ammonium, the potato plots had the higher ammonium concentration regardless of year and position. The same was generally the case under RT (Table 21.3). The exception was in the R position during the unfertilized weeks in 2006. In the sweet corn plots when there was an effect of position, the R plots had the higher concentration regardless of week fertilized or year. But in the potato plots, when there was a difference, the IR position had the higher ammonium – N concentration except in the unfertilized weeks under CT in 2005 (Table 21.3).

The effect that tillage had on soil ammonium – N was mixed. In the sweet corn plots there was only one difference due to tillage in 2005, i.e., in the IR position in the unfertilized weeks (Table 21.4). But in 2006, RT plots generally had significantly more soil ammonium, particularly in the unfertilized weeks (Table 21.3). In the potato plots few differences in soil ammonium could be attributed to tillage, but when there was a significant difference, the CT plots had more ammonium – N (Table 21.3). The differences may be related to root distribution and plant uptake of soil nitrogen.

Carbon Dioxide Flux

Weekly CO_2 flux patterns in potato plots in 2005 showed that except for the first week of fertilization, CO_2 flux rates were generally greater during the week when fertilization occurred, with no significant differences between tillage (Figure 21.2). Flux rates ranged from 9.1 to 33.5 kg CO_2-C ha^{-1} d^{-1}. Corn plots exhibited a similar pattern except for unfertilized week six, where CO_2 flux rates were higher than some of the fertilized weeks. Emissions ranged from a high of 44.5 kg CO_2-C ha^{-1} d^{-1} in week seven to 8.6 kg CO_2-C ha^{-1} d^{-1} at the end of the season (Week 12). In 2005 there were significant interactions for the effects of crop x position ($P = 0.0005$), tillage x position ($P = 0.0017$), and crop x tillage x fertilizer level ($P < 0.0001$) on the average daily flux of CO_2. The effect of tillage in 2005 and 2006 depended upon row position. In the IR position, CT soils had the higher flux, but in the R position, the reverse was the case. In 2005, carbon dioxide flux was higher in fertilized than unfertilized weeks, regardless of tillage or crop. Sweet corn plots emitted more carbon dioxide than potato plots regardless of fertilizer status or tillage both years. In 2005, carbon dioxide flux in CT and RT potato plots was, on average, 18 kg CO_2-C ha^{-1} d^{-1} higher than NV (Figures 21.2 and 21.3). For sweet corn plots, CT and RT carbon dioxide fluxes were 24 kg CO_2-C ha^{-1} d^{-1} higher than the NV flux.

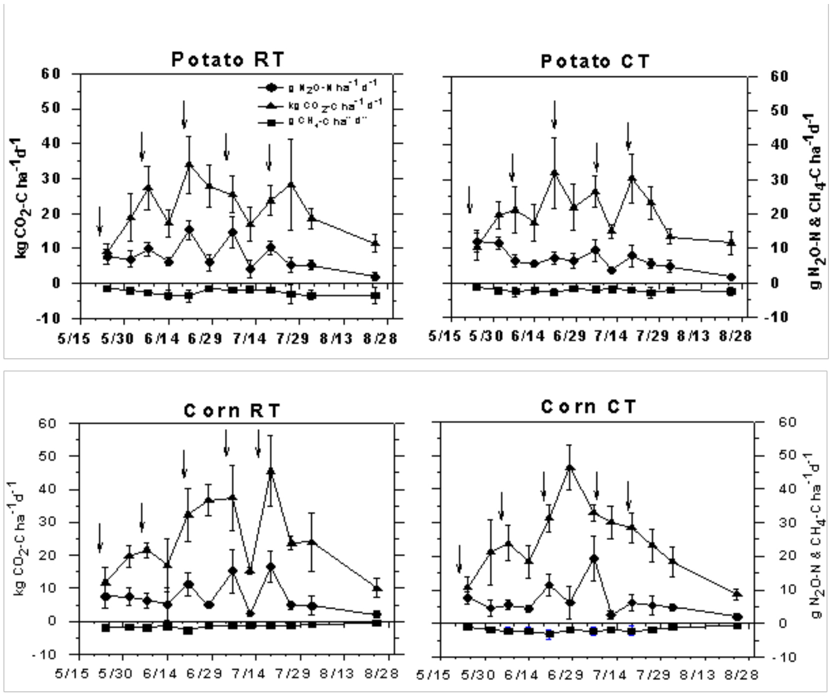

Figure 21.2. CO_2-C, N_2O-N and CH_4-C flux rates during the 2005 growing season for the potato and corn under reduced (RT) and conventional (CT) tillage. Arrows identify dates of fertilization. Data was plotted as the average of the row and inter-row sample locations. Error bars @ p=0.05.

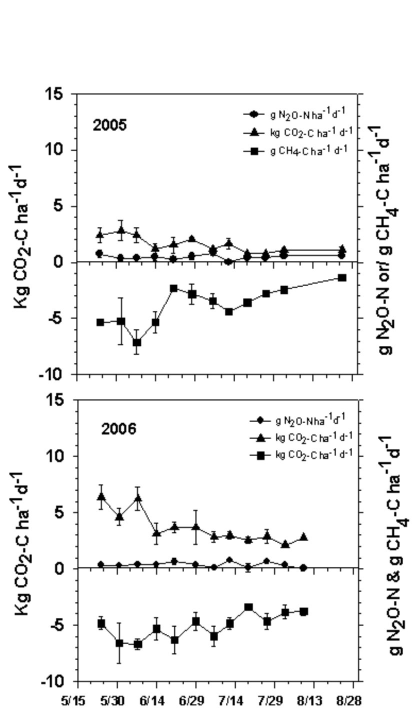

Figure 21.3. Seasonal CO_2, N_2O, and CH_4 flux rates from the native site during 2005 and 2006. Error bars @ p=0.05.

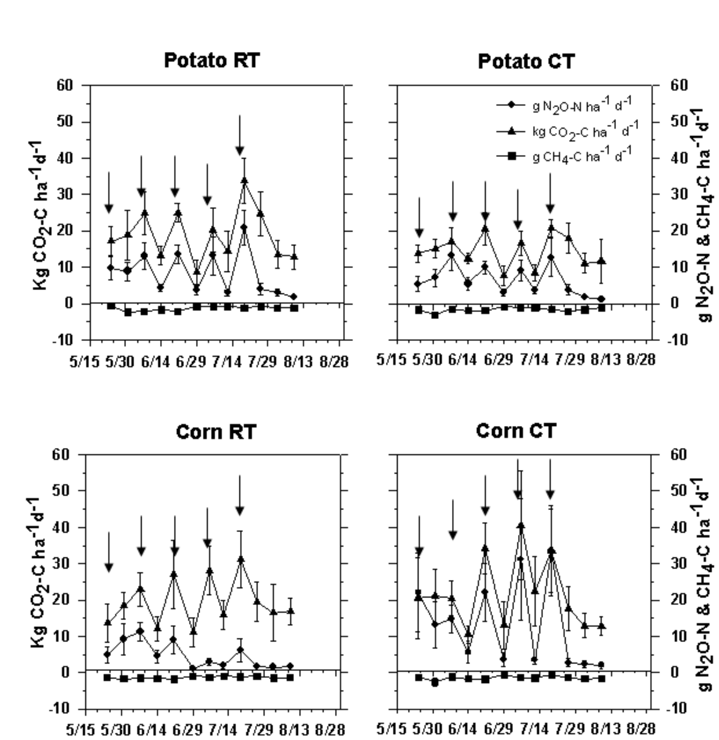

Figure 21.4. CO_2-C, N_2O-N, and CH_4-C flux rates during the 2006 growing season for potato and corn under reduced (RT) and conventional (CT) tillage. Arrows identify dates of fertilization.

Over the 2005 growing season (12 weeks) cumulative CO_2-C emissions were 1887 and 1695 kg CO_2-C ha^{-1} from sweet corn and potato plots, respectively. During the 2006 crop year, the patterns of seasonal CO_2-C emissions were similar to 2005 but with greater differences between fertilized and unfertilized weeks (Figure 21.4). Cumulative emissions in 2006 were slightly lower than 2005, averaging 1578 and 1290 kg CO_2-C ha^{-1} in corn and potato plots, respectively.

Methane Uptake

In 2005, several interactions had a significant effect on methane flux, i.e., crop x tillage ($P = 0.0145$), crop x fertilizer x position ($P = 0.0034$), and tillage x fertilizer x position ($P < 0.0001$). Potato plots took up more methane than corn plots regardless of tillage (Table 21.4). Reduced tillage plots took up more methane than CT only in potato plots (Table 21.4). In general, there was more methane flux into potato plots than into sweet corn plots, and more methane uptake in fertilized weeks than in unfertilized weeks. But row position had a mixed influence on methane flux, being significantly higher in R than in IR only in unfertilized weeks in the potato plots (Table 21.4). In the unfertilized weeks in 2005, the effect of row position was reversed in CT relative to RT. Tillage had no effect on methane flux in fertilized weeks. In unfertilized weeks, though, CT had higher flux than RT in the IR position, but CT had lower flux in the R position.

In 2006, the four-way interaction among crop, tillage, fertilizer treatment, and position had a significant ($P < 0.0001$) effect on methane flux. Generally, when there was an effect of crop, potato plots absorbed more methane than sweet corn plots, the exception being under reduced tillage in the row position. In 2006, fertilizer treatment had no effect on methane flux except in the R position of sweet corn plots under RT where the soil absorbed more methane in the fertilized weeks than in the unfertilized weeks.

In sweet corn plots, tillage had a significant effect on methane flux only in the R position during fertilized weeks, with the greater flux under RT. In potato, CT had higher flux than RT in the R position regardless of fertilizer treatment, but in the IR position the higher flux was in RT during fertilized weeks. In corn plots, row position significantly affected methane flux only under RT in fertilized weeks. In RT potato plots, the IR position had higher methane fluxes than R regardless of fertilizer treatment. In CT potato plots, the effect of row position was significant only during unfertilized weeks, being greater in the R position.

Soil absorption of methane in NV was higher than in the cropped plots. In 2005, the sweet corn plots on average absorbed 2.28 g CH_4-C-ha^{-1} d^{-1} less than the NV site, while potato plots absorbed 1.7 g CH_4-C-ha^{-1} d^{-1} less than the NV site. Tillage had little effect on how much less the cropped areas absorbed compared with the NV site in 2005. Treatments in 2006 had relatively little effect on how much methane was absorbed by the agricultural fields relative to the NV site, but the difference between the cultivated plots and NV was greater in 2006 than in 2005. Overall, the cultivated plots absorbed 3.7 g CH_4-C-ha^{-1} d^{-1} less than the NV site in 2006.

Table 21.4. Methane flux into the soil during the 2005 and 2006 growing season in sweet corn and potato plots under center pivot irrigation.

	Inter-row (IR)		Row (R)		Inter-row (IR)		Row (R)	
2005	Corn	Potato	Corn	Potato	CT	RT	CT	RT
	g CH_4 - C ha^{-1} d^{-1}				g CH_4 - C ha^{-1} d^{-1}			
Fertilizer	A -1.8 b†	A -2.2 a	A -2.0 a	A -2.2 a	†A -1.8 b	A -2.2 a	A -2.1 a	A -2.0 a
No fertilizer	B -1.5 b	B -2.0 a	B -1.3 b	A -2.5 a	A -2.0 a	B -1.5 b	B -1.6 b	A -2.2 a
	Conventional Tillage				**Reduced Tillage**			
2006	Inter-row (IR)		Row (R)		Inter-row (IR)		Row (R)	
	Corn	Potato	Corn	Potato	Corn	Potato	Corn	Potato
	g CH_4 - C ha^{-1} d^{-1}							
Fertilizer	A -1.2 a	A -1.6 a	A -1.1 b	A -1.6 a	A -1.3 b	A -1.9 a	A -1.6 a	A -0.9 b
No fertilizer	A -1.5 a	A -1.4 a	A -1.3 b	A -1.8 a	A -1.2 b	A -1.6 a	B -1.2 a	A -1.0 a

The three-way interaction among crop, fertilizer and position was significant ($P = 0.0034$). †Upper case letters indicate significant differences between adjacent values within a column. The three-way interaction among tillage, fertilizer and position was significant ($P < 0.0001$). Lower case letters indicate significant differences between adjacent values within a row and within a given level of crop and position.

The four-way interaction in 2006 was significant ($P < 0.0001$). Upper case letters indicate significant differences between adjacent values within a column. Lower case letters indicate significant differences between adjacent values within a row and within a given level of tillage and position (upper half of table) or within a given level of crop and fertilizer (lower half of table).

Uptake of CH_4 by the soil was greater during the 2005 study period for both crops. Total cumulative CH_4 uptake by sweet corn plots was 140 and 113 g CH_4-C ha^{-1} for 2005 and 2006, respectively. For potato plots the uptake was 179 and 123 g CH_4-C ha^{-1}, respectively, for the same study period. In the NV site cumulative uptake was 298 and 396 g CH_4-C ha^{-1} for 2005 and 2006, respectively. Methane uptake in the NV site was 3 and 4 times higher than potato and sweet corn sites, respectively, during 2006 growing season and the trend was the same in 2005 but with a lower ratio.

Nitrous Oxide Flux

Seasonal changes in nitrous oxide flux in 2006 as influenced by crop, tillage, and fertilizer are apparent in Figure 21.4 compared to analyses in 2005 (Figure 21.2). In sweet corn plots, the effect of tillage was much larger during fertilized weeks than unfertilized weeks. Regardless of fertilizer treatment, there was a consistent tendency for higher nitrous oxide fluxes under CT than RT (Figure 21.2, 21.4). In potato the trend was toward higher seasonal nitrous oxide fluxes in RT, but in spite of the reversal, the effect of tillage was apparently weaker in potato than in sweet corn. By the third week of the experiment, nitrous oxide fluxes in potato plots were consistently higher during fertilized weeks than unfertilized weeks in both years.

The four-way interaction among crop, tillage, position, and fertilizer level had a significant effect on nitrous oxide flux in 2005 ($P = 0.0005$). In 2006 the significant interaction was among crop, tillage, and fertilizer level ($P = 0.0006$) with position no longer contributing to the effect on nitrous oxide emission. In both years, fertilized weeks had higher nitrous oxide fluxes than unfertilized weeks, regardless of other interacting factors (Tables 21.5 and 21.6). In 2005, the effect of crop on nitrous oxide emission was generally mixed relative to tillage, position, and fertilizer effects. The effect of crop was consistent, however, within the R position regardless of tillage treatment; in the fertilized weeks, nitrous oxide emission from the sweet corn and potato plots was the same, but in the unfertilized weeks, flux in the potato plots was higher than in sweet corn plots (Table 21.5). In 2006, emission from corn plots was consistently higher than from potato plots under CT, regardless of fertilizer treatment. But under RT in the fertilized weeks, potato plots had higher nitrous oxide flux (Table 21.6).

In 2005 when there was also a significant effect of row position, chambers in the R position had higher flux rates than chambers in the IR position (Table 21.5). Also in 2005, the only significant effect of tillage occurred in the fertilized weeks in the IR position; in sweet corn plots, CT emitted more nitrous oxide than RT, but the reverse was the case in potato plots. This same reversal occurred in 2006, i.e., CT corn plots had higher fluxes than RT corn plots, but in the fertilized weeks, RT potato plots had higher fluxes than CT potato plots (Table 21.6).

Total N_2O-N emission from corn plots were 555 and 668 g N_2O-N ha^{-1} for the 12 week period during 2005 and 2006, respectively. During the same period, total N_2O emission from potato plots were 591 and 579 g N_2O-N ha^{-1}. Nitrogen lost as nitrous oxide-N, as a percentage of N applied to sweet corn plots was 0.25% and 0.3% in 2005 and 2006, respectively. For potato plots, in both years, 0.18% of N applied was lost in nitrous oxide.

Table 21.5. Average daily nitrous oxide flux from soil cropped to sweet corn and potato under center pivot irrigation, during the 2005 growing season.

	Conventional Tillage				Reduced Tillage			
	Inter-row (IR)		Row (R)		Inter-row (IR)		Row (R)	
	Corn	Potato	Corn	Potato	Corn	Potato	Corn	Potato
	------g N_2O- N ha^{-1} d^{-1} ------							
Fertilizer	A 11.1 a†	A 7.1 b	A 11.1 a	A 12.0 a	A 8.8 b	A 10.4 a	A 11.0 a	A 12.5 a
No fertilizer	B 4.5 a	B 4.2 a	B 3.7 b	B 6.0 a	B 6.2 a	B 4.4 b	B 3.5 b	B 6.6 a
	Corn				**Potato**			
	Fertilizer		No fertilizer		Fertilizer		No fertilizer	
	IR	R	IR	R	IR	R	IR	R
	------g N_2O- N ha^{-1} d^{-1} ------							
Conventional till	A 11.1 a	A 11.1 a	A 4.5 a	A 3.7 a	B 7.1 b	A 12.0 a	A 4.2 b	A 6.0 a
Reduced till	B 8.8 b	A 11.0 a	A 6.2 a	A 3.5 a	A 10.4 b	A 12.5 a	A 4.4 b	A 6.6 a

The 4-way interaction was significant (P = 0.0005). †Upper case letters indicate significant differences between adjacent values within a column. Lower case letters indicate significant differences between adjacent values within a row and within a given level of tillage and position (upper half of table) or within a given level of crop and fertilizer (lower half of table)

Table 21.6. Average daily nitrous oxide flux from soil cropped to sweet corn and potato under center pivot irrigation, during the 2006 growing season

	Conventional tillage		**Reduced tillage**	
	Corn	Potato	Corn	Potato
	-------------- g N_2O - N ha^{-1} d^{-1} -----------------			
Fertilizer	A 19.6 a †	A 9.8 b	A 7.9 b	A 12.8 a
No fertilizer	B 6.6 a	B 4.4 b	B 2.9 a	B 4.5 a

	Corn		**Potato**	
	CT	RT	CT	RT
	-------------- g N_2O - N ha^{-1} d^{-1} -----------------			
Fertilizer	19.6 a	7.9 b	9.8 b	12.8 a
No fertilizer	6.6 a	2.9 b	4.4 a	4.5 a

The three-way interaction among crop, tillage and fertilizer was significant (P = 0.0006). †Upper case letters indicate significant differences between adjacent values within a column. Lower case letters indicate significant differences between adjacent values within a row and within a given level of tillage and crop.

The difference in nitrous oxide flux between sweet corn plots and NV was relatively constant in 2005, averaging 6.8 g N_2O-N ha^{-1} d^{-1} among CT and RT (Figures 21.4 and 21.5). There was a wider range of differences in potato plots with 8.6 g N_2O-N ha^{-1} d^{-1} in the R position under CT and RT, respectively, and 4.9 and 6.4 g N_2O-N ha^{-1} d^{-1} in the IR position under CT and RT, respectively (data not shown). In 2006, sweet corn plots had the higher range of differences, with 11.7 and 4.6 g N_2O-N ha^{-1} d^{-1} under CT and RT, respectively. In potato plots CT and RT had 6.3 and 7.6 g N_2O-N ha^{-1} d^{-1} higher fluxes, respectively, than NV (Figures 21.5 and 21.6).

Global Warming Potential

The contributions of the three primary GHGs, N_2O, CH_4, and CO_2, to GWP (kg CO_2-equivalents ha^{-1}) were estimated based on values of 298, 25, and 1, respectively, for a 100-year time horizon on a per molecule basis (IPCC, 2007). Total CH_4 uptake by the soil expressed in terms of GWP was 11.7, 3.9, and 4.9 kg CO_2-equivalents ha^{-1} in the NV, corn, and potato fields, respectively, averaged over both years. We found that the native shrub-steppe sites in the semi-arid Pacific Northwest oxidize three times more CH_4 than the fertilized corn and potato sites and therefore may help to mitigate global warming. The total GWP contribution from the NV, sweet corn and potato fields after subtracting CH_4 uptake by the soil were 448, 7175, and 6487 kg CO_2-equivalents ha^{-1} for 2005 and 1015, 6100, and 4870 kg CO_2-equivalents ha^{-1} for 2006**.** The total GWP of 2006 was 14% lower than 2005 because of lower CO_2 flux rates from cropped fields. The GHGs, CO_2, N_2O, and CH_4, contributed on average 96.6%, 4.3%, and -0.14% of the total GWP, respectively. The CO_2 uptake by plants and the release from soil are considered to be in balance. We routinely eliminate the contribution of CO_2 emissions from soil when calculating GWP. Therefore, N_20 and CH_4 are considered the primary gases contributing to the GWP from agricultural systems. Within this rotation 100% of the GWP can be attributed to N_20 emissions.

Table 21.7. Estimated growing season (May 15 through August 28) fluxes and global warming potential (GWP) of nitrous oxide, carbon dioxide, and methane measured in native vegetation (NV), sweet corn, and potato plots at the USDA-ARS Integrated Cropping Systems Research Field Station located near Paterson, Benton County, Washington in 2005 and 2006 on a Quincy sand soil type. Average of conventional and reduced till treatments.

	2005		2006	
Vegetation	Field flux†	GWP CO_2 E‡	Field flux	GWP CO_2 E
	kg ha^{-1} season^{-1}		kg ha^{-1} season^{-1}	
N_2O				
NV	0.05	15	0.05	15
Sweet corn	0.87	260	1.05	313
Potato	0.93	277	0.91	271
CO_2				
NV	443	443	1,013	1,013
Sweet corn	6,920	6,920	5,787	5,787
Potato	6,216	6,216	4,730	4,730
CH_4				
NV	-0.40	-10.0	-0.53	-13.3
Sweet corn	-0.17	- 4.3	-0.14	- 3.5
Potato	-0.23	- 5.8	-0.16	- 4.0

†Field fluxes were calculated from static chamber measurements integrated over the season.
‡CO_2 E = CO_2 equivalents based on the global warming potential of greenhouse gasses, relative to CO_2; CO_2 equivalents of N_2O and CH_4 are 298 and 25 times that of CO_2, respectively (IPCC, 2007).

Discussion

The most limiting factors for crop production in the semi-arid Quincy sand soil series in the Columbia Basin are water and nutrients. Growers irrigate frequently to replace water lost by evapotranspiration during periods of hot dry weather. Growers fertigate frequently with low concentrations of nutrients to decrease leaching of nutrients, which results from the high sand content and very low CEC of this soil type. During the growing seasons in our study, aerobic soil conditions dominated with soil moisture remaining around field capacity (0.50–0.63 m^{3}m^{-3} WFPS) following 9-mm irrigations applied before gas sampling (Table 21.2). Soil and air temperatures were favorable for microbial activity with air temperatures reaching 36 ºC at 1.5 m above the soil surface and 14ºC 1.5 m below the soil surface during the growing season.

When there were significant differences in nitrate concentrations between tillage treatments, CT corn was higher than RT corn, suggesting the possible adsorption of N by surface residues in RT and immobilization by microbial populations involved in residue decomposition. The reverse was true for potato (RT>CT). Plant canopy architecture most likely contributed to higher nitrate concentrations in the inter-row position, resulting from interception of fertilizer by the canopy and deflection into the inter-row position and/or was due to lower plant uptake of N in the inter-row.

Carbon dioxide emissions from these plots represented both microbial and plant root respiration. The relatively high emissions of CO_2 from sweet corn plots were most likely due to a greater density of roots that supported a greater soil microbial activity than potato. Soil CO_2 emissions increased as crops matured (max. 47.5 kg of CO_2-C ha^{-1} d^{-1}) and declined (min. 5.56 CO_2 -C ha^{-1} d^{-1}) as irrigation decreased and roots senesced following maturity and harvest. The amount of CO_2 produced from cropped sites indicated that the C supply did not limit the activity of denitrifying organisms during the growing season. Fertilized weeks produced more CO_2 than unfertilized weeks suggesting decomposition of previously incorporated crop residues was accelerated by in-season N fertilizer additions. That IR positions produced more CO_2 than the R positions in sweet corn may be attributed to extensive lateral root growth that extended into the IR position. However, the effect was different in potato where the R produced more CO_2 than the IR position. The hilling practice in potato production concentrates roots in the hill localizing root growth and root respiration. In addition, soil loosening by hilling may result in well-aerated and relatively un-compacted soil resulting in higher diffusivity of CO_2 compared to the direct-seeded corn crop.

Our findings were different from recent studies in an irrigated silt loam soil in Nebraska, where CO_2 production from maize fields was higher in the R position (Amos et al., 2005). Unlike the higher WFPS reported by Amos et al. (2005) in the IR position (WFPS 0.60 m^3m^{-3}) than R (0.48 m^3m^{-3}), the R position in our corn plots had relatively higher WFPS than the IR positions (Table 21.2). Reports indicate that tilled soils emit more CO_2 (Linn and Doran, 1984a; Kessavalou et al., 1998; Lupwayi et al., 1999; Schlesinger and Andrews, 2000) than no till (conservation tillage) soils, where tillage creates favorable soil microbial activity for decomposition of residues. In our study, tillage did not affect CO_2 emissions. This could be due to the shorter period (3 years) that our plots were under RT, which may not have allowed enough time to develop significant differences in physical and chemical characteristics. This finding suggests that short-term implementation of conservation tillage in potato production systems does not reduce CO_2 emissions compared to that observed in long-term continuous no-till corn production of the Midwest.

Peak N_2O fluxes occurred during mid-season (June 20 to July 20) fertigations and ranged on average from 16 to 28 g N_2O-N ha^{-1} d^{-1}, and were about 25 times greater than peak fluxes from NV site. Soil in fertilized weeks emitted more N_2O than in unfertilized weeks. In 2005, as with CO_2, higher N_2O fluxes were measured from the R position in potato, suggesting greater concentrations of available C around potato roots, which may stimulate nitrification and denitrification activities at these locations (Kessavalou et al., 1998).

In sweet corn regardless of fertilization, no significant difference between chamber positions was found in nitrous oxide flux except under RT in fertilized weeks, where the R produced significantly more N_2O. In fertilized weeks, CT produced more N_2O than RT in the IR position of corn but not for potato (RT>CT). This could be due to less compaction in the

RT than CT in potato plots resulting in an increase in the diffusivity of gases. Yamulki and Jarvis (2002) reported 3.5 times more N_2O emission in compacted plots compared to un-compacted plots, while tillage did not affect N_2O emission. Tillage differences may not be the only factor controlling N_2O emission in the soil (Linn and Doran, 1984b; Mosier et al., 1998). Liu, et al. (2005) found emissions of N_2O were similar between no till and conventional tillage in irrigated corn fields. Nitrous oxide flux was not affected by position in 2006. As in 2005, RT in potato produced more N_2O than CT during 2006. The influence of tillage treatment on N_2O fluxes in potato is not clear and is difficult to explain.

During 2005, total fluxes of N_2O from sweet corn and potato fields were 16 and 17 times greater than NV plots, respectively. In 2006, N_2O flux from corn and potato fields were 22 and 19 times higher than the NV plots, respectively. Nitrous oxide-N losses accounted for 0.25% (0.55 kg N ha^{-1}) of the applied fertilizer (224 kg N ha^{-1}) in corn and 0.18% (0.59 kg N ha^{-1}) of the 336 kg N ha^{-1} applied fertilizer in potato during 2005. In 2006, N_2O losses from potato plots were similar. In sweet corn the 2006 loss increased to 0.3% of the applied fertilizer.

Split applications (bi-weekly) of N fertilizer in this sandy soil during the growing season might have helped reduce the nitrate concentrations in soil for denitrification and as a result increased the production of mineral nitrogen relative to N_2O (lower N_2O to N_2 ratio). In our study we did not distinguish between the microbial activities of nitrification or denitrification responsible for the production of N_2O. Both processes can occur simultaneously in this sandy soil when the WFPS is greater than 0.60 m^3m^{-3}. However, the moisture data, the soil pH around 6, and the sandy texture throughout the profile with 15-50 cm h^{-1} permeability suggests that aerobic microbial activity (nitrification) rather than anaerobic microbial activity (denitrification) is the dominant microbial source of N_2O.

In a short grass steppe of Colorado (Parton et al., 1988), in a seasonally dry tropical forest of Mexico (Davidson et al., 1993), and in an irrigated maize-based agroecosystem in Nebraska (Amos et al., 2005) nitrification appeared to be the dominant source of N_2O. Our data collected at each sampling time ranged from 0.50–0.60 m^3m^{-3} WFPS, suggesting predominantly aerobic soil conditions. This soil water content range (0.50–0.60 m^3m^{-3} WFPS) remained for a period of less than 4 hours after irrigation (data not shown) due to excessive hydraulic conductivity of these sandy soils. As others report, nitrous oxide emissions through nitrification occurred when the WFPS was less than or equal to 60 m^3m^{-3} x100 and by denitrification when WFPS exceeds 0.60 m^3m^{-3} (Freney et al., 1979; Linn and Doran, 1984, Davidson, 1991).

Methane flux was small relative to carbon dioxide and nitrous oxide, but the direction of the flux was consistently negative, i.e., into the soil. In 2005, the cultivated soil generally absorbed more methane during weeks when fertilizer was applied than during the other weeks. But this difference largely disappeared inn 2006. This effect of fertilizer in 2005 is hard to explain. We expected lower flux of methane into the soil when the soil had higher concentrations of ammonium since the ammonium would compete for methane binding sites of the methane monooxygenase (Steudler et al., 1989). Although application of ammonium inhibited uptake of methane in one study, the same study showed a slight increase in soil consumption of methane when fertilized with nitrate, so we may be seeing a complex interaction among methane, ammonium, and nitrate influenced by the UAN fertilizer additions.

During both years, the effect of crop was fairly consistent. When there was a significant effect of crop, potato plots absorbed more methane then sweet corn plots, with the only exception being in the R position under RT during fertilized weeks in 2006. The greater flux of methane into potato plots may have been due to generally better aeration and less compaction in the hilled soils of the potato plots.

The higher methane flux into the NV soil than the farmed plots was unexpected, but the fluxes we measured in the NV site were comparable to those measured by others working in dry, native habitats (Striegl et al., 1992; McLain and Martens, 2006a). McLain and Martens (2006a) noted that methanotroph activity moved deeper into the soil profile as the soil dried, and this may have occurred in the NV site. The dry, sandy soil would probably have allowed adequate diffusion of gases to and from the sites of microbial activity, even relatively deep in the profile. Other alternatives exist. The methanotrophs in the NV site may have been obtaining their moisture from hydraulic lift due to the dominant shrub, *Artemisia tridentata*, which is known to redistribute water from depth to the surface (Caldwell, et al., 1998). There is also evidence that nitrification by soil fungi is responsible for nitrous oxide production in some systems (Laughlin and Stevens, 2002; McLain and Martens, 2006b), and this could have been occurring on our NV site.

Conclusions

Cropping systems, which optimize rotational crops in irrigated sandy soils, are needed to maximize yield and crop quality and minimize potential adverse impacts to the environment. Although the total amount of uptake is small, the results of this study suggest that semi-arid native shrub steppe soils in the Columbia Basin act as a terrestrial sink for methane during the growing season. Native sites were able to consume CH_4 three times higher than the cropped land. Contributions of N_2O and CO_2 to the GWP from the irrigated sandy soil under corn and potato cropping systems were lower compared to other studies. Approximately 0.18% of the applied fertilizer was lost from sandy irrigated potato fields. This lower value may be due to split applications of fertilizer through the irrigation system during the growing season. Considering the amount of fertilizer applied to each crop, sweet corn, because of greater acreage, contributes much more to the GWP. Potato fields on the other hand oxidize more CH_4 than sweet corn, which may be due to the better aerated soil environment. Reducing tillage did not show any significant effect in reducing emissions of greenhouse gas fluxes from the irrigated sandy soils under the vegetable cropping system studied.

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