TRACE GAS MANITOBA

The World's Longest Continuous Monitoring of N_2O and CO_2 Emissions from an Agricultural Field

TGAS-MAN Origins

When Dr. Mario Tenuta began his career at the University of Manitoba, he recognized that there was a lack of information on whole year budgets of nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions, especially together, from cropping systems in the prairies and elsewhere in Canada. This knowledge gap was of great significance as N_2O and CO_2 are the major greenhouse gasses emitted from agricultural soil.

Unfortunately, emissions are very episodic and therefore often missed or not fully captured using traditional sampling methods which are labor-intensive and conducted intermittently. Traditional methods, such as using static-vented chambers, are also challenging to deploy and execute during spring thaw, which is a particularly important time in Prairie Canada for N_2O emissions.

To further complicate the knowledge gap, about ten years of data collection is required to thoroughly quantify changes in soil organic matter levels resulting from farming practices. Short-term studies, while easier to conduct, are insufficient to determine the consequences of farming practices on carbon sequestration.

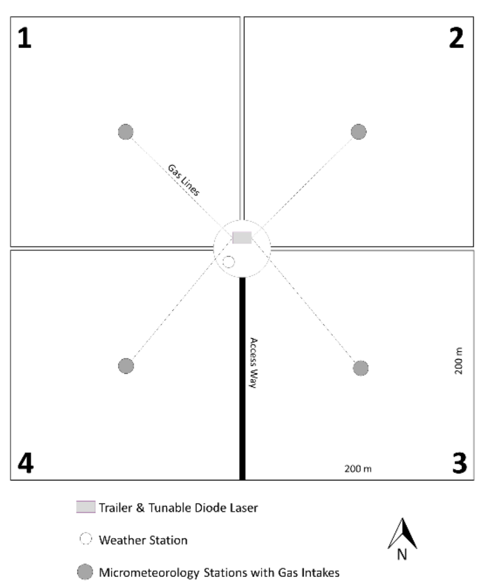
As a result of the knowledge gap and the underlying difficulties with addressing it, Dr. Tenuta realized that a micrometeorological system to monitor whole-field fluxes of N_2O and CO_2 was needed for Prairie Canada. In 2005, as part of the new National Centre for Livestock and the Environment (NCLE) initiative and with funding from the Canada Foundation for Innovation (CFI), under the leadership of Dr. Mario Tenuta and with technical assistance from Dr. Brian Amiro (University of Manitoba) and help from Applied Soil Ecology Lab technicians, Trace Gas Manitoba (TGAS-MAN) was established.

TGAS-MAN was envisioned to be a long-term site to test farming practices and their impact on greenhouse gas emissions, with the goal of providing empirical data to guide best management practices to lower emissions. Which farming practices are tested have changed over time to address current questions as technology and farming practices evolved.

Site & Infrastructure

TGAS-MAN is located in the Red River Valley approximately 16 km south of Winnipeg, MB, Canada. The area is a glaciolacustrine clay floodplain with near-level topography, extreme humid-continental climate, and soils predominantly of the Red River (Gleyed Humic Certisol) and Osborne (Gleysolic Humic Vertisol) soil series. The field is imperfectly drained and periodic flooding and excessive soil moisture, often around snow melt in spring or heavy early growing season rains, are not uncommon.

The TGAS-MAN field site is located in a 30-ha farmed field and consists of four 200m x 200m (4-ha) experimental plots arranged in a 2×2 grid.



At the epicenter of TGAS-MAN is the **Tunable Diode Laser** absorption spectrophotometer (Campbell TGAS100A) trace gas analyzer. Housed in an insulated trailer located at the junction of the four experimental plots, the trace gas analyzer continuously measures direct emissions from the TGAS-MAN plots for flux-gradient estimation of N_2O and CO_2 from soil.

The flux (*F*) of N_2O and CO_2 between the crop system and lower atmosphere is determined as: $F = -K\frac{\Delta[C]}{\Delta z}$

Each plot is outfitted with its own micrometeorology station, which monitors environmental conditions such as wind speed and direction, air temperature, and soil moisture and temperature. The station's sonic anemometer-thermometer measures temperature and 3-D wind velocities, and these data are used to estimate the turbulent transfer coefficient, *K.*

Gas intakes separated by a vertical height difference (Δz) on each micrometeorological station alternately provide air samples to the analyzer, switching every 15 seconds. These data are used to determine the vertical concentration gradient (ΔC) of N_2O and CO_2. Only one plot is sampled at a time, for 30 minutes, yielding a maximum of 12 half-hourly flux-gradient estimates of N_2O and CO_2 from soil each day.

A fully equipped weather station is located 25m southwest of the trailer, which measures wind speed and direction, air temperature and relative humidity, precipitation, barometric pressure, snow depth, soil temperature and moisture content at various depths, incoming solar radiation, and photosynthetically active photon flux density.

PHASE 1: 2005-2018

Prior to establishment of TGAS-MAN, the field site was under a C_3 crop rotation (primarily cereals and oilseeds) and managed using conventional/intensive tillage techniques. Set-up and monitoring of the TGAS-MAN experimental plots began in the fall of 2005 following a Fallow Year during which no crop was planted or fertilizer used and weed management was by tillage and chemical means.

Over the next thirteen years, micrometeorological conditions and emissions were monitored multiple times daily, almost without interruption. Field conditions during the growing season were also monitored: soil samples were collected from all plots several times throughout each growing season and analyzed for gravimetric moisture content and nitrate (NO_3) and ammonium (NH_4) content; biomass samples were collected annually at harvest and analyzed for yield and total carbon and nitrogen content. Crop rotations during Phase 1 of TGAS-MAN included alfalfa + grass, barley, canola, corn, faba bean, soybean, and spring wheat.

During Phase 1, several short-term projects were conducted. These involved experimental manipulation of farming practices on the TGAS-MAN plots, such as using different tillage intensities, annual vs. perennial cropping systems, and timing of fertilizer application. Data collected during these experiments were also used to address other research objectives.

The table below summarizes the crops and experimental manipulation of each year, as well as the corresponding project number:

YEAR	PLOTS 1 & 4	PLOTS 2 & 3	EXPERIMENTAL MANIPULATION
2005	Fallow Year	Fallow Year	
2006	Corn	Corn	1) Tillage Intensity
2007	Faba Bean	Faba Bean	1) Tillage Intensity
2008	Alfalfa + Grass	Spring Wheat	1) Tillage Intensity 4) Annual vs Annual-Perennial
2009	Alfalfa + Grass	Canola	4) Annual vs Annual-Perennial
2010	Alfalfa + Grass	Barley	4) Annual vs Annual-Perennial
2011	Alfalfa + Grass	Spring Wheat	4) Annual vs Annual-Perennial 8) Fall vs Spring-Applied AA
2012	Corn	Corn	8) Fall vs Spring-Applied AA
2013	Soybean	Soybean	No manipulation
2014	Wheat	Wheat	" "
2015	Soybean	Soybean	" "
2016	Soybean	Soybean	" "
2017	Corn	Corn	" "
2018	Canola	Canola / Fall Rye Cover Crop	" "
2019	Oats / Fall Rye Cover Crop	Oats	11) Cover Crop
2020	Canola / Fall Rye Cover Crop	Canola	11) Cover Crop
2021	Hard Red Spring Wheat	Hard Red Spring Wheat	

PROJECT 1) AFFECT OF CONVENTIONAL VS. REDUCED TILLAGE ON CARBON DIOXIDE EXCHANGE (2006-2008)

A comparison of the effects of conventional/intensive tillage vs reduced tillage on CO_2 exchange was conducted during the 2006 through 2008 growing seasons. All plots were planted with corn and faba bean in 2006 and 2007, respectively. In 2008, plots 2 and 3 were planted with spring wheat while plots 1 and 4 were planted with a perennial forage crop and thus omitted from the study. To compare the two farming practices, plots 1 and 4 were managed using reduced tillage while plots 2 and 3 were managed with conventional/intensive tillage. The flux-gradient method was used to determine the net exchange of CO_2 between the soil-crop system and the lower atmosphere. It was found that tillage intensity did not affect CO_2 emissions, but possibly because of relatively large variability among the four experimental plots.

Glenn, A.J., Amiro, B.D., Tenuta, M., Stewart, S.E., and Wagner-Riddle, C. (2010). Carbon dioxide exchange in a northern prairie cropping system over three years. Agricultural and Forest Meteorology. 150: 908-918.

PROJECT 2) CROP RESIDUE CARBON AND SOIL RESPIRATION (2006-2007)

To determine the relative contributions of crop residue carbon and soil organic carbon pools to respiration in a northern agroecosystem where the non-growing season is long, carbon dioxide flux-gradient data from all plots were examined during two non-growing periods: post-harvest to pre-freeze in the fall of 2006 and post snowmelt and pre-field operations in the spring of 2007. Non-growing period ecosystem respiration rates were found to be higher from intensive tillage than reduced tillage plots in Fall 2006 following the maize harvest. However, during the following spring, overall higher respiration fluxes resulted in similar cumulative CO_2 budgets over the non-growing periods for the two tillage treatments.

Glenn, A.J., Amiro, B.D., Tenuta, M., Wagner-Riddle, C., Drewitt, G., and Warland, J. (2011). Contribution of crop residue carbon to soil respiration at a northern Prairie site using stable isotope flux measurements. Agricultural and Forest Meteorology. 151: 1045-1054.

PROJECT 3) NITROUS OXIDE EMISSIONS FROM AN ANNUAL CROP ROTATION (2006-2008)

To address the lack of multi-year studies of N_2O emissions from poorly drained floodplain soil, emissions were monitored at TGAS-MAN from 2006 through to 2008, during which time all plots were planted with a corn, faba bean, and spring wheat rotation. Because of the concurrent tillage study, this project was also able to investigate the effects of different tillage practices on N_2O emissions. It was found that N_2O emissions from fertilizer N addition and soil thaw in spring in 2006 (corn/maize) and 2008 (spring wheat) accounted for nearly half of all emissions over the three crop years studied. The conversion from intensive tillage to reduced tillage practiced showed no difference in N_2O emissions; longer imposition of reduced tillage and more replicated plots may be needed to observe an impact.

Aaron Glenn – PhD Thesis (2006-2010) Greenhouse Gas Fluxes and Budget for an Annual Cropping System in the Red River Valley, Manitoba, Canada

Glenn, A.J., Tenuta, M., Amiro, B.D., Maas, S.E., and Wagner-Riddle, C. (2012). Nitrous oxide emissions from an annual crop rotation on poorly drained soil on the Canadian Prairies. Agricultural and Forest Meteorology. 166-167: 41-49.

PROJECT 4) SHORT-TERM EFFECTS OF ANNUAL VS. ANNUAL-PERENNIAL CROP ROTATION ON N_2O AND CARBON FLUX (2008-2011)

The short-term benefit of including perennial forage in an annual crop rotation on CO_2 and N_2O emissions was investigated from 2008 through to 2011. During this time, plots 1 and 4 were converted from annual crops to perennial forage composed of alfalfa and timothy grass while plots 2 and 3 continued with the annual crops wheat, canola, and barley. CO_2 and N_2O fluxes were measured continuously using the flux-gradient micrometeorological method. During the first two years, the newly established perennial forage alfalfa was nearly twice the sink for atmospheric CO_2 and emitted less than a quarter of the N_2O than annual crops.

Siobhan Maas – MSc Thesis (2009-2011) Perennial Legume Phase and Annual Crop Rotation Influences on CO_2 and N_2O Fluxes Over Two Years in the Red River Valley, Manitoba, Canada

Maas, S.E., Glenn, A.J., Tenuta, M., and Amiro, B.D. (2013). Net CO_2 and N_2O exchange during perennial forage establishment in an annual crop rotation in the Red River Valley, Manitoba. Canadian Journal of Soil Science. 93: 639-652.

PROJECT 5) CARBON DIOXIDE UPTAKE OF GRAIN CROPS (2006 & 2008)

Data from TGAS-MAN was included in a study of the carbon dioxide uptake and ecophysiological parameters of 13 maize and wheat fields across midcontinent North America, all of which were monitored using flux towers.

Gilmanov, T.G., Wylie, B.K., Tieszen, L.L., Tilden, P.M., Baron, V.S., Bernacchi, C.J., Billesbach, D.P., Burba, G.G., Fischer, M.L.,Glenn A.J., Hanan, N.P., Hatfield, J.L., Heuer, M.W., Hollinger, S.E., Howard, D.M., Matamala, R., Prueger, J.H., Tenuta, M., and Young, D.G. (2013). CO_2 uptake and ecophysiological parameters of the grain crops of mid-continent North America: Estimates from flux tower measurements. Agriculture, Ecosystems and Environment. 164: 162-175.

PROJECT 6) PRODUCTIVITY AND CARBON DIOXIDE EXCHANGE OF LEGUMINOUS CROPS (2007)

TGAS-MAN data from 2007, when all experimental fields were planted with faba bean, were included in a study of the carbon dioxide exchange of legume crops at 17 flux tower sites in North America and 3 in Europe.

Gilmanov, T.G., Baker, J.M., Bernacchi, C.J., Billesbach, D.P., Burba, G.G., Castro, S., Eugster, W., Fischer, M.L., Gamon, J.A., Gebremedhin, M.T., Glenn, A.J., Griffis, T.J., Hatfield, J.L., Heuer, W.L., Howard, D.M., Leclerc, M.Y., Loescher, H.W., Matamala, R., Meyers, T.P., Phillips, R.L., Prueger, J.H., Suyker, A.E., Tenuta, M., and Wylie, B.K. (2014). Productivity and carbon dioxide exchange of leguminous crops: Estimates from flux tower measurements. Agronomy Journal. 106: 545-559.

PROJECT 7) VALIDATION OF THE DENITRIFICATION DECOMPOSITION (DNDC) MODEL (2006-2012)

The TGAS-MAN dataset is a rare case of continuous N_2O emissions measured over multiple years along with a robust set of accompanying parameters, including weather conditions, soil conditions, and biomass/yield observations. These data were used to assess the ability of the DeNitrification DeComposition (DNDC) Model to estimate N_2O emissions and soil mineral N under varying crop-management regimes and environmental conditions, including wet vs dry years, annual vs annual-perennial cropping systems, and fall vs spring-applied anhydrous ammonia.

Uzoma, K.C., Smith, W.N., Grant, B.B., Desjardins, R.L., Gao, X., Hanis, K., Tenuta, M., Goglio, P., and Li, C. (2015). Assessing the effects of agricultural management on nitrous oxide emissions using flux measurements and the CAN-DNDC model. Agriculture, Ecosystems and Environment. 206: 71-83.

PROJECT 8) FALL VS. SPRING-APPLIED ANHYDROUS AMMONIA (2011-2012)

In 2011 and 2012, Plots 2 and 3 were used to compare the effects of late fall and pre-plant application of anhydrous ammonia on N_2O emissions. Spring wheat and corn were planted in 2011 and 2012, respectively, and field-scale flux of N_2O was measured using each plot's micrometeorological station. It was found that late fall application of anhydrous ammonia before freeze-up increased N_2O emissions at thaw and decreased emissions for the early growing season compared to spring pre-plant application

Tenuta, M., Gao, X., Flaten, D.N., and Amiro, B.D. (2016). Lower nitrous oxide emissions from anhydrous ammonia application prior to soil freezing in late fall than spring pre-plant application. Journal of Environmental Quality. 45(4): 1135-1143.

PROJECT 9) FREEZE-THAW CYCLES AND NITROUS OXIDE EMISSIONS (2006-2014)

Data collected at TGAS-MAN from 2006 to 2014 and at a similar micrometeorological experimental site in Elora, Ontario from 2000 to 2014, was used to investigate the contribution of seasonal freezing to N_2O emissions from croplands. It was found that these are episodic, usually occurring at spring thaw and following fertilizer application and precipitation events.

Wagner-Riddle, C., Congreves, K.A., Abalos, D., Berg, A.A., Brown, S.E., Ambadan, J.T., Gao, X., and Tenuta, M. (2017). Globally important nitrous oxide emissions from croplands induced by freeze-thaw cycles. Nature Geoscience. 10: 279–283.

PROJECT 10) LONG-TERM EFFECTS OF ANNUAL VS. ANNUAL-PERENNIAL CROP ROTATION ON NITROUS OXIDE AND CARBON FLUX (2006-2016)

Nitrous oxide and carbon flux data collected from 2006-2016 showed that there was no significant difference in emissions from the annual and annual-perennial crop rotations, because of large emissions following termination of the perennial crop in 2011. It was also found that N application rate and time integrated concentration (nitrate exposure) were more important than environmental factors, such as soil nitrate exposure or soil ammonium concentrations, to N_2O emissions.

Tenuta, M., Amiro, B., Gao, X., Wagner-Riddle, C., and Gervais, M. (2019) Agricultural management practices and environmental drivers of nitrous oxide emissions over a decade for an annual and an annual-perennial crop rotation. Agricultural and Forest Meteorology. 267-277: 107636.

Amiro, B., Tenuta, M., Gervais, M., Glenn, A., and Gao, X. (2017). A decade of carbon flux measurements with annual and perennial crop rotations on the Canadian Prairies. Agricultural and Forest Meteorology. 247: 491-502.

CONTINUED MONITORING UNDER CONVENTIONAL FARMING PRACTICES (2013-2018)

No experimental manipulations were conducted at TGAS-MAN from 2013 through to 2018, though monitoring of emissions and field conditions continued. This period allowed the plots time to recover from manipulations that had taken place during the previous seven growing seasons, in preparation for Phase 2 of TGAS-MAN.

PHASE 2: 2018-2021

On August 29, 2018, a cover crop of Fall Rye was applied without fertilizer and only to the east plots (Plot 2 and 3) of TGAS-MAN, marking the beginning of Phase 2 and a new project investigating the effects of cover cropping on greenhouse gas emissions. On the evening of May 13, 2019, all plots were seeded with oats. The following morning, glyphosate was applied to Plots 2 and 3 to terminate the fall rye. Most recently, on August 19, 2019, all four plots were desiccated with glyphosate in anticipation of harvest.

PROJECT 11) EFFECTS OF COVER CROPS ON NITROUS OXIDE EMISSIONS AND SOIL CARBON STORAGE

This project aims to resolve significant gaps in understanding N_2O emissions from the increasingly popular practice of cover cropping. Past studies focused on warmer climates where thaw emissions are less important. On the

Prairies and in Eastern Canada, thaw can contribute to 20-50% of emissions for conventional systems and, as we recently discovered, > 80% of emissions for organic systems.

The studies here will discover if covers cause reduced thaw emissions by lowering soil NO_3^- and will determine how low levels need to be to limit emissions. Alternatively, covers may increase C availability to denitrifiers increasing emissions at thaw, particularly with termination before planting. We will learn how soil moisture determines relative N_2O and N_2 emissions to increased C availability and lower NO_3^- with covers. Knowing how covers affect soil emissions allows for better forecasting of the national GHG inventory.

The research will also help in reducing the environmental footprint (N_2O and CO_2 emissions) of oat production in the Red River Valley, an area that General Mills sources most of the oats for its products.

TGAS-MAN Support and Funding Sources

Past and present support and funding for TGAS-MAN and research conducted at the field site has come from a variety of sources:

- AAFC Agriculture Greenhouse Gas Program (AGGP)
- AAFC Canadian Agricultural Adaptation Program (CAAP)
- Bell-MTS Innovations in Agriculture Program
- BIOCAP Canada
- Canada Research Chair in Applied Soil Ecology
- Canadian Fertilizer Institute
- Canadian Foundation for Innovation grant to NCLE
- Fertilizer Canada
- General Mills
- Manitoba Sustainable Agriculture Practices Program (Government of Manitoba)
- National Centre for Livestock and the Environment (NCLE)
- NSERC Discovery Grant Program
- NSERC Industrial Research Chair
- NSERC Strategic Grant
- Prairie Improvement Network (formerly Manitoba Rural Adaptation Council)
- Western Grains Research Foundation

Contact Us

Dr. Mario Tenuta

Department of Soil Science, University of Manitoba
Room 309 Ellis Building, 13 Freedman Crescent
Winnipeg MB R3T 2N2 Canada
Phone: (+001) 204-474-7827
Email: Mario.Tenuta@umanitoba.ca