EFFECTS OF CO_2 ON NITROUS OXIDE EMISSIONS

SPPI & CO2SCIENCE ORIGINAL PAPER ◆ June 12, 2013

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Citation: Center for the Study of Carbon Dioxide and Global Change. "Effects of CO_2 on Nitrous Oxide Emissions." Last modified June 12, 2013. http://www.co2science.org/subject/n/summaries/nitrousoxide.php.

In the words of Cantarel *et al*. (2011), nitrous oxide (N_2O) is "an influential greenhouse gas," with a per-molecule global warming potential "approximately 300 times that of CO_2 (IPCC, 2001)," and they say it "has shown linear increases of 0.2-0.3% per year over the last few decades, largely as a result of changes in agricultural practices and direct emissions from agricultural soils (IPCC, 2007)." As a result, understanding the factors that control the concentration of N_2O the atmosphere, and how the sources and sinks of N_2O vary with changes in climate and other factors, has long been an important concern among the scientific community. And in this Summary, therefore, we review important research that has been conducted on this topic, beginning with a discussion of studies examining how increases in atmospheric CO_2 might modify the release of N_2O into the atmosphere.

One of the main sources of nitrous oxide is agriculture, which accounts for almost half of its emissions in some countries (Pipatti, 1997). And with N_2O originating from microbial N cycling in soil -- mostly from aerobic nitrification or from anaerobic denitrification (Firestone and Davidson, 1989) -- there is a concern that CO_2-induced increases in carbon input to soil, together with increasing N input from other sources, will increase substrate availability for denitrifying bacteria and may result in higher N_2O emissions from agricultural soils as the air's CO_2 content continues to rise.

In a study designed to investigate this possibility, Kettunen *et al*. (2007a)[1] grew mixed stands of timothy (*Phleum pratense*) and red clover (*Trifolium pratense*) in sandy-loam-filled mesocosms at low and moderate soil nitrogen levels within greenhouses maintained at either 360 or 720 ppm CO_2, while measuring harvestable biomass production and N_2O evolution from the mesocosm soils over the course of three crop cuttings. This work revealed that the total harvestable biomass production of *P. pratense* was enhanced by the experimental doubling of the air's CO_2 concentration by 21 percent and 26 percent, respectively, in the low and

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[1] http://www.co2science.org/articles/V10/N42/B2.php.

moderate soil N treatments, while corresponding biomass enhancements for *T. pratense* were 22 percent and 18 percent. In addition, the researchers found that after emergence of the mixed stand and during vegetative growth before the first harvest and N fertilization, N_2O fluxes were higher under ambient CO_2 in both the low and moderate soil N treatments. In fact, it was not until the water table had been raised and extra fertilization given after the first harvest that the elevated CO_2 seemed to increase N_2O fluxes. The four Finnish researchers thus concluded that the mixed stand of *P. pratense* and *T. pratense* was "able to utilize the increased supply of atmospheric CO_2 for enhanced biomass production without a simultaneous increase in the N_2O fluxes," thereby raising "the possibility of maintaining N_2O emissions at their current level, while still enhancing the yield production [via the aerial fertilization effect of elevated CO_2] even under low N fertilizer additions."

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In a similar study, Kettunen *et al.* (2007b)[2] grew timothy (*Phleum pratense*) in monoculture within sandy-soil-filled mesocosms located within greenhouses maintained at atmospheric CO_2 concentrations of either 360 or 720 ppm for a period of 3.5 months at moderate (standard), low (half-standard), and high (1.5 times standard) soil N supply, while they measured the evolution of N_2O from the mesocosms, vegetative net CO_2 exchange, and final above- and below-ground biomass production over the course of three harvests. In this experiment the elevated CO_2 concentration increased the net CO_2 exchange of the ecosystems (which phenomenon was primarily driven by CO_2-induced increases in photosynthesis) by about 30 percent, 46 percent and 34 percent at the low, moderate, and high soil N levels, respectively, while it increased the above-ground biomass of the crop by about 8 percent, 14 percent, and 8 percent at the low, moderate and high soil N levels, and its below-ground biomass by 28 percent, 27 percent, and 41 percent at the same respective soil N levels. And once again, Kettunen *et al*. report that "an explicit increase in N_2O fluxes due to the elevated atmospheric CO_2 concentration was not found."

In another CO_2-enrichment study, while working at the Nevada Desert FACE Facility northwest of Las Vegas, Nevada (USA), McCalley *et al.* (2011)[3] measured soil fluxes of reactive N gases (NO, NO_x, NH_3) and N_2O in plots receiving long-term fumigation with ambient (380 ppm) and elevated (550 ppm) CO_2. These treatments were begun in April 1997; and reactive N gas flux measurements were made under these conditions several

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[2] http://www.co2science.org/articles/V10/N43/B2.php.

[3] http://www.co2science.org/articles/V14/N46/B2.php.

years later in April 2005, July 2005, July 2006, January 2007 and March 2007, as well as after the termination of CO_2 fumigation in July 2007, October 2007, January 2008 and April 2008.

In discussing the flux measurements, the five researchers report that "long-term exposure to elevated CO_2 decreased reactive N gas emissions from Mojave Desert soils," and that it did so primarily "in islands of fertility created by the dominant shrub *Larrea tridentata*," and especially "in the spring and fall when recent precipitation, either natural or artificial, created soil conditions that are optimal for biological activity." Emissions of N_2O, on the other hand, were "a very small component" of gaseous N loss and were "largely insensitive to elevated CO_2." In addition, the five researchers state that the greater-than-60% reductions in reactive N gas fluxes during periods of peak N demand imply that elevated CO_2 is "increasing the retention of biologically available N during critical growth periods," which is a major benefit for desert ecosystems.

Writing as background for their work, Livesley *et al*. (2009)[4] state that "soils provide the largest terrestrial carbon store, the largest atmospheric CO_2 source, the largest terrestrial N_2O source and the largest terrestrial CH_4 sink, as mediated through root and soil microbial process," and that "a change in land use or management can alter these soil processes such that net greenhouse gas exchange may increase or decrease." Seeking to determine how the emission and absorption of these three greenhouse gases differ between forests and pastures, the authors "measured soil-atmosphere exchange of CO_2, N_2O and CH_4 in four adjacent land-use systems (native eucalypt woodland, clover-grass pasture, *Pinus radiata* and *Eucalyptus globulus* plantation) for short, but continuous, periods between October 2005 and June 2006 using an automated trace gas measurement system near Albany in southwest Western Australia."

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With respect to nitrous oxide, the six scientists discovered that soil N_2O *emissions* were more than an order of magnitude greater in the pasture than in the natural and managed forests," and given the authors' findings with respect to CO_2 and CH_4, it was concluded that "there is a triple greenhouse-gas benefit from afforestation of pasture systems," where in addition to carbon sequestration via tree biomass, "there is a decrease in N_2O emissions because of lower nitrogen inputs and a tighter nutrient cycling, and an increase in CH_4 uptake by forest soils." Such findings demonstrate the important role of land use change and land management in the release of nitrous oxide to the atmosphere.

In a different type of study -- driven by the possibility that the climate of the Amazon Basin may gradually become drier due to a warming-induced increase in the frequency and/or intensity of El Niño events that have historically brought severe drought to the region -- Davidson *et al.*

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[4] http://www.co2science.org/articles/V12/N17/B2.php.

(2004)[5] devised an experiment to determine the consequences of the drying of the soil of an Amazonian moist tropical forest for the net surface-to-air fluxes of both N_2O and methane (CH_4). This they did in the Tapajos National Forest near Santarem, Brazil, by modifying a one-hectare plot of land covered by mature evergreen trees so as to dramatically reduce the amount of rain that reached the forest floor (throughfall), while maintaining an otherwise similar one-hectare plot of land as a control for comparison.

Prior to making this modification, the three researchers measured the gas exchange characteristics of the two plots for a period of 18 months; then, after initiating the throughfall-exclusion treatment, they continued their measurements for an additional three years. This work revealed that the "drier soil conditions caused by throughfall exclusion inhibited N_2O and CH_4 production and promoted CH_4 consumption." In fact, they report that "the exclusion manipulation lowered annual N_2O emissions by >40 percent and increased rates of consumption of atmospheric CH_4 by a factor of >4," which results they attributed to the "direct effect of soil aeration on denitrification, methanogenesis, and methanotrophy."

Consequently, if global warming would indeed increase the frequency and/or intensity of El Niño events as some claim it will, the results of this study suggest that the anticipated drying of the Amazon Basin would initiate a strong negative feedback via (1) large drying-induced reductions in the evolution of both N_2O and CH_4 from its soils, and (2) a huge drying-induced increase in the consumption of CH_4 by its soils. Although Davidson *et al*. envisage a more extreme second phase response "in which drought-induced plant mortality is followed by increased mineralization of C and N substrates from dead fine roots and by increased foraging of termites on dead coarse roots" (an extreme response that would be expected to increase N_2O and CH_4 emissions), it should also be noted that the projected rise in the air's CO_2 content would likely prohibit such a thing from ever occurring, due to the documented tendency for atmospheric CO_2 enrichment to greatly increase the water use efficiency of essentially all plants, which would enable the forest to continue to flourish under significantly drier conditions than those of the present.

Other researchers have also examined the relationship between nitrous oxide emissions and soil water status. Goldberg and Gebauer (2009)[6], for example, investigated the influence of drying and rewetting events on N_2O emissions from the soil of a mature Norway spruce forest in Northeast Bavaria, Germany. Writing as background for their work they state that "the only sink for N_2O considered in global models is the destruction of atmospheric N_2O in the stratosphere through photolysis and photooxidation (IPCC, 2007)," and also citing the 2007 IPCC report, they say that "soils have been identified as the main sources for atmospheric N_2O."

In conducting their analysis to learn more about the emission of N_2O from wet vs. dry soils, Goldberg and Gebauer induced an artificial summer drought of 46 days duration (which was accompanied by a natural drought) via *throughfall exclusion* (TE) that was provided by special roof installations, which they followed with an experimental rewetting of 66 mm over two days,

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[5] http://www.co2science.org/articles/V7/N31/C3.php.

[6] http://www.co2science.org/articles/V12/N28/B3.php.

during which periods (and before and after them) they closely monitored N_2O fluxes from the soils of the TE and unaltered control (C) plots that were exposed to the elements.

According to the two researchers, their results indicated that "before the drought, both the C and TE plots showed slightly positive N_2O fluxes from the soil to the atmosphere," in harmony with the sentiment of the IPCC. *During* the drought, on the other hand, they report that "the soil of both the throughfall exclusion and control plots served as an N_2O sink," *contrary* to what might have been expected in light of IPPC statements; and they say that "the sink strength of the throughfall exclusion plots was *doubled* [italics added] compared with the control plots." Rewetting, however, "turned the soil into a source for atmospheric N_2O again," but they found that "it took almost *four months* [italics added] to turn the cumulative soil N_2O fluxes from negative (sink) to positive (source) values." Thus, on the basis of their observations, Goldberg and Gebauer concluded that "long drought periods can lead to drastic decreases of N_2O fluxes from soils to the atmosphere or *may even turn forest soils temporarily to N_2O sinks* [italics added]," which situation may in some places persist for years at a time. It is also entirely possible, however, that over the *entire* terrestrial surface of the planet, the net result is indeed that "soils are the main sources for atmospheric N_2O," as stated by the IPCC. Nevertheless, the two scientists conclude that the *fact* that there is what they call an *unbalanced global N_2O budget* "underlines the likelihood of a hitherto unconsidered sink function of soils."

If climate change proceeded as predicted for this particular part of the world, it would likely not be magnified to any significant degree by climate-change-induced increases in ecosystem N_2O emissions.

In combining the effects of soil water status *and* atmospheric CO_2 on N_2O emissions, Welzmiller *et al.* (2008)[7] measured N_2O and denitrification emission rates in a C_4 sorghum [*Sorghum bicolor* (L.) Moench] production system with ample and limited flood irrigation rates under Free-Air CO_2 Enrichment (seasonal mean = 579 ppm) and control (seasonal mean = 396 ppm) conditions during the 1998 and 1999 summer growing seasons at the experimental FACE site near Maricopa, Arizona (USA). In doing so, they found that "elevated CO_2 did not result in increased N_2O or N-gas emissions with either ample or limited irrigation," which findings they describe as being "consistent with findings for unirrigated western U.S. ecosystems reported by Billings *et al*. (2002) for Mojave Desert soils and by Mosier *et al*. (2002) for Colorado shortgrass steppe." Discussing the implications of their findings, Welzmiller *et al*. say their results suggest that "as CO_2 concentrations increase, there will not be major increases in denitrification in C4 cropping environments such as irrigated sorghum in the desert southwestern United States," which further suggests there will not be an increased impetus for global warming due to this phenomenon.

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[7] http://www.co2science.org/articles/V11/N23/B2.php.

Adding *temperature* to the mix, Cantarel *et al.* (2011)[8] monitored N_2O fluxes in an *in situ* ecosystem manipulation experiment simulating the climate predicted for the study area (an upland temperate grassland in the French Massif Central region), making use of the Clermont Climate Change Experiment facility, where Bloor *et al*. (2010) were conducting "a long-term grassland study of multiple climate changes applied in an additive experimental design." Thus, over a two-year period, they monitored N_2O fluxes under conditions "simulating the climate predicted for the study area in 2080 (3.5°C temperature increase, 20% reduction in summer rainfall and atmospheric CO_2 levels of 600 ppm)."

"Overall," as the four researchers described the results of their study, "experimental warming had a positive effect on the annual N_2O emissions." *However*, and "contrary to expectations," as they put it, "combined summer drought and warming had no significant effect on mean N_2O fluxes recorded at any time," nor did "elevated CO_2 in combination with warming and drought." Thus, it would appear that if climate change proceeded as predicted for this particular part of the world, it would likely not be magnified to any significant degree by climate-change-induced increases in ecosystem N_2O emissions.

Introducing their study of the subject, Carter *et al.* (2011)[9] write that "in temperate regions, climate change is predicted to increase annual mean temperature and intensify the duration and frequency of summer droughts, which together with elevated atmospheric carbon dioxide concentrations, may affect the exchange of nitrous oxide (N_2O) and methane (CH_4) between terrestrial ecosystems and the atmosphere." Working in a dry temperate heathland with a nutrient-poor sandy soil located about 50 km northwest of Copenhagen, Denmark -- the vegetation of which was dominated by Scotch Heather (*Calluna vulgaris*), Wavy Hairgrass (*Deschampsia flexuosa*) and various mosses -- Carter *et al*. set out to investigate "the effects of future climatic and atmospheric conditions on the biosphere-atmosphere exchange of N_2O and CH_4."

With respect to N_2O emissions, the researchers found that "as single experimental factors, elevated CO_2, temperature and summer drought had no major effect on the N_2O fluxes, but the combination of CO_2 and warming stimulated N_2O emission, whereas the N_2O emission ceased when CO_2 was combined with drought." Given such observations, Carter *et al*. say that their study "highlights the importance of evaluating climate change parameters in multifactor treatments as the response of CH_4 and N_2O flux rates to different two- and three-factor combinations may not be predicted from the responses to the individual treatments." And in summing up their work they add that "overall, our study suggests that in the future, CH_4 uptake may increase slightly, while N_2O emission will remain unchanged in temperate ecosystems on well-aerated soils."

In summation, it would appear that concerns about additional global warming arising from enhanced N_2O emissions from agricultural soils in a CO_2-enriched atmosphere of the future are not well founded.

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[8] http://www.co2science.org/articles/V14/N16/B3.php.

[9] http://www.co2science.org/articles/V14/N33/B3.php.

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Cover photo of clover in field provided by Christina Pinckard.

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