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Can conservation tillage reduce N_2O emissions on cropland transitioning to organic vegetable production?

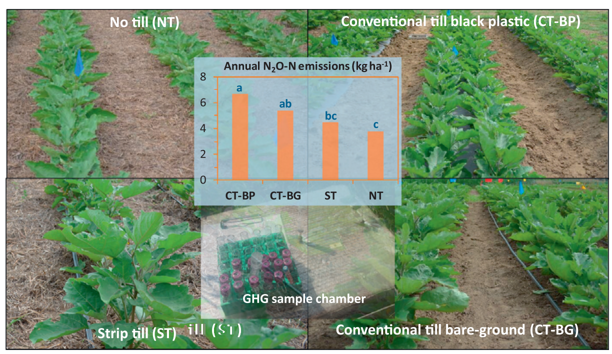
Guihua Chen [a,*], Lauren Kolb [b], Michel A. Cavigelli [c], Ray R. Weil [d], Cerruti R.R. Hooks [a]

[a] University of Maryland, Department of Entomology, College Park, MD, USA
[b] The City of Boulder's Open Space and Mountain Parks, Boulder, CO, USA
[c] United States Department of Agriculture, Agricultural Research Service, Beltsville Agriculture Research Center, Beltsville, MD, USA
[d] University of Maryland, Department of Environmental Science and Technology, College Park, MD, USA

HIGHLIGHTS

- Tillage effects on N_2O emissions were evaluated jointly with winter cover crops in organic vegetable production system.
- Conventional tillage [with black plastic mulch (CT-BP) or bare-ground (CT-BG)] increased soil temperature and mineral N.
- Annual N_2O emissions were lower in strip till (ST) and no till (NT) than in CT-BP and lower in NT than in CT-BG.
- Vegetable yield was lowest in NT in year 1 and in CT-BP in year 3.
- Yield-scaled N_2O-N emissions were lower in NT and ST than in CT-BP.

GRAPHICAL ABSTRACT



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ABSTRACT

Nitrous oxide (N_2O) is an important greenhouse gas and a catalyst of stratospheric ozone decay. Agricultural soils are the source of 75% of anthropogenic N_2O emissions globally. Recently, significant attention has been directed at examining effects of conservation tillage on carbon sequestration in agricultural systems. However, limited knowledge is available regarding how these practices impact N_2O emissions, especially for organic vegetable production systems. In this context, a three-year study was conducted in a well-drained sandy loam field transitioning to organic vegetable production in the Mid-Atlantic coastal plain of USA to investigate impacts of conservation tillage [strip till (ST) and no-till (NT)] and conventional tillage (CT) [with black plastic mulch (CT-BP) and bare-ground (CT-BG)] on N_2O emissions. Each year, a winter cover crop mixture (forage radish: *Raphanus sativus* var. longipinnatus, crimson clover: *Trifolium incarnatum* L., and rye: *Secale cereale* L.) was grown and flail-mowed in the spring. Nearly 80% of annual N_2O-nitrogen (N) emissions occurred during the vegetable growing season for all treatments. Annual N_2O-N emissions were greater in CT-BP than in ST and NT, and greater in CT-BG than in NT, but not different between CT-BG and CT-BP, ST and NT, or CT-BG and ST. Conventional tillage promoted N mineralization and plastic mulch increased soil temperature, which contributed to greater N_2O-N fluxes. Though water filled porosity in NT was higher and correlated well with N_2O-N fluxes, annual N_2O-N emissions were lowest in NT suggesting a lack of substrates for nitrification and denitrification processes. Crop yield was lowest in NT in Year 1 and CT-BP in Year 3 but yield-scaled N_2O-N emissions were consistently greatest in CT-BP and lowest in NT each year. Our results suggest that for coarse-textured soils in the coastal plain with

* Corresponding author.
E-mail address: gchen2@umd.edu (G. Chen).

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winter cover crops, conservation tillage practices may reduce N_2O emissions in organic vegetable production systems.

1. Introduction

Anthropogenic greenhouse gases (GHGs) emitted into the atmosphere are likely the dominant cause of observed global warming since the middle 20th century (IPCC, 2014). While most emissions of these GHGs are from combustion of fossil fuels and industrial processes, GHGs emitted from agricultural lands are responsible for roughly 10–12% of human induced emissions globally (Smith et al., 2007). Nitrous oxide (N_2O) is an important GHG because it has the greatest radiative force on a per mass basis with a global warming potential that is roughly 265-fold greater per unit mass than that of carbon dioxide (CO_2) in a 100-year life time (IPCC, 2014). Additionally, N_2O has become the most important substance contributing to ozone layer depletion after chlorofluorocarbons were phased out (Ravishankara et al., 2009). During the last three decades, the atmospheric N_2O concentration increased at a rate of 0.73 ppbv yr^{-1} (parts per billion by volume per year) or 0.2–0.3% yr^{-1}, primarily due to accelerated emissions from agricultural soils (IPCC, 2013). Agricultural soils are responsible for 75% of N_2O emissions globally (Scheehle and Kruger, 2006) and for about 79% of total N_2O emissions in the United States in 2014 (US EPA, 2016). Therefore, changes in agricultural management practices are needed to mitigate N_2O emissions while maintaining productivity and sustainability of agricultural soils.

Efforts to reduce the impact of agriculture on GHG emissions have largely been focused on sequestering carbon in soils to offset CO_2 emissions from fossil fuels, partially because of its relatively low cost (Antle et al., 2002). Soil carbon sequestration also provides agronomic and environmental benefits such as improved soil quality and function, and reduced erosion potential (Dabney et al., 2001; Mallory and Porter, 2007; Carr et al., 2013; Abdalla et al., 2014). It has been widely reported that instituting conservation tillage and cover cropping increase soil carbon storage, water holding capacity, and aggregate stability (Mendes et al., 1999; Kabir and Koide, 2000; Tonitto et al., 2006; de Carvalho et al., 2014). Soil carbon storage, soil health and other ecosystem services provided by cover crops may be enhanced if used in conjunction with conservation tillage practices (Liu et al., 2010; Altieri et al., 2011; Bernstein et al., 2011; Ryan et al., 2011; Carr et al., 2013).

However, limited knowledge is available regarding how conservation management practices would impact N_2O emissions (Franzluebbers, 2005). Different management practices can interact, resulting in synergies, where one practice enhances the mitigation potential of another; or tradeoffs, where one practice reduces or eliminates benefits of the other (Franzluebbers and Follett, 2005; Boeckx et al., 2011; Abdalla et al., 2014). For example, Petersen et al. (2011) and Mitchell et al. (2013) reported that cover crops stimulated N_2O emissions in some soils, especially when used in conjunction with conventional tillage practices, possibly due to release of labile carbon and nitrogen from cover crop residues. Rochette (2008) concluded from a literature review that practicing no-till will not likely increase N_2O emissions from medium to well aerated soils. However, Mutegi et al. (2010) found that N_2O emissions were similar among conventional, reduced, and no-till practices in a well-drained sandy soil when crop residues were removed, but greater from conventional tillage when residues remained. van Kessel et al. (2013) reported that conservation tillage reduced N_2O emissions significantly in long-term experiments (>10 yrs) in humid and dry climates.

Nitrification and denitrification are the main mechanisms producing N_2O in soils (Davidson et al., 2000; Baggs and Philippot, 2010). Therefore, the magnitude of N_2O fluxes depends on variables that inhibit or enhance these processes, including individual enzymatic steps in each process (Robertson and Groffman, 2007; Butterbach-Bahl et al., 2013). Such variables include soil temperature and pH (Weier and Gilliam, 1986; Skiba and Smith, 2000; Heinen, 2006), soil aeration status (for which water-filled pores space (WFPS) can often serve as a proxy) (Bateman and Baggs, 2005), and nitrogen (N) (substrate) availability (Kuestermann et al., 2013; Liu et al., 2014). Effects of tillage on N_2O emissions result from changes in soil structure, aeration, moisture, temperature, microbial activity, rate of residue decomposition, and rate of N mineralization (Signor and Cerri, 2013). Some of these changes caused by tillage increase while others decrease the potential for N_2O emissions. The same is true for cover cropping (Cavigelli and Parkin, 2012). Vegetable production systems generally use larger amounts of N inputs than most agronomic cropping systems, and vegetable crops generally take up only 20–50% of the N applied (Di and Cameron, 2002). Nitrogen not taken up by crops is susceptible to loss from fields via N_2O and N_2 emissions, nitrate leaching, and N in runoff and erosion (Kraft and Stites, 2003). Total GHG emissions from vegetable production systems are found to be greater than from other cropping systems due to a combination of shorter growing seasons, prevalence of bare soil, and slower crop N-uptake (Bos et al., 2014). Further, many organic vegetable producers in the US are land-limited and rely heavily on intensive agricultural practices, and conventional tillage remains a widespread practice among organic producers (USDA-NASS, 2009). Because current models underestimate emissions from vegetable fields (Conen et al., 2000), the difference in emissions between vegetable and other cropping systems could be greater than reported. Field measurements of N_2O emissions from vegetable fields are needed to fill gaps and improve model estimations.

The use of polyethylene as a plastic mulch for vegetable production was introduced in the early 1950s and has since gained popularity throughout the United States and worldwide (Lament, 1993). Several advantages of using black plastic mulches, including weed suppression and enhanced early crop development due to warmer soil temperatures (Marr, 1993), makes its use popular among organic vegetable producers. However, warmer soil temperatures under plastic mulch can accelerate microbial activities and may elevate N_2O emissions (Kwabiah, 2004; Cuello et al., 2015). Additionally, there are challenges associated with using fertigation (the application of fertilizer via irrigation water) in organic systems because organic fertilizer materials clog drip irrigation nozzles (Hartz et al., 2010). Therefore, rather than using split fertilizer applications via irrigation water, organic vegetable producers typically apply all fertilizers needed for the season before laying the plastic mulch. This fertilizer management practice may result in greater N_2O emissions (Deng et al., 2015).

A three-year study was conducted in a field transitioning to organic production. The main objective of the study was to investigate impacts of two conservation tillage [strip till (ST) and no-till (NT)] and two conventional tillage (CT) practices [with black plastic mulch (CT-BP) and bare-ground (CT-BG)] on soil N_2O emissions. Hypotheses were (1) conventional tillage, through residue and fertilizer incorporation and increased soil temperature, favors N_2O production compared to conservation tillage practices, and (2) black plastic mulch further elevates soil temperature and precludes split N application, thus leading to even greater N_2O emissions.

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