



Direct green waste land application: How to reduce its impacts on greenhouse gas and volatile organic compound emissions?



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ARTICLE INFO

Article history:

Received 24 December 2015

Revised 9 March 2016

Accepted 15 March 2016

Available online 28 March 2016

Keywords:

Oxygen consumption

Nitrous oxide

Carbon dioxide

Soil

Denitrification

Ammonia oxidation

ABSTRACT

Direct land application as an alternative to green waste (GW) disposal in landfills or composting requires an understanding of its impacts on greenhouse gas (GHG) and volatile organic compound (VOC) emissions. We investigated the effects of two approaches of GW direct land application, surface application and soil incorporation, on carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄), and VOC emissions for a 12 month period. Five treatments were applied in fall 2013 on fallow land under a Mediterranean climate in California: 30 cm height GW on surface; 15 cm height GW on surface; 15 cm height GW tilled into soil; control + till; control + no till. In addition, a laboratory experiment was conducted to develop a mechanistic understanding of the influence of GW application on soil O₂ consumption and GHG emission. The annual cumulative N₂O, CO₂ and VOC emissions ranged from 1.6 to 5.5 kg N₂O-N ha⁻¹, 5.3 to 40.6 Mg CO₂-C ha⁻¹ and 0.6 to 9.9 kg VOC ha⁻¹, respectively, and were greatly reduced by GW soil incorporation compared to surface application. Application of GW quickly consumed soil O₂ within one day in the lab incubation. These results indicate that to reduce GHG and VOC emissions of GW direct land application, GW incorporation into soil is recommended.

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1. Introduction

Residential yard trimmings, termed green waste (GW), accounts for 13.5% of the estimated 254 million Mg of solid waste disposed in the United States (U.S.EPA, 2013). At least 23 states have completely or partially banned the disposal of GW in landfills (Arsova et al., 2008). Composting and direct land applications are the two primary alternatives to disposal of GW in landfills (CalRecycle, 2010). Decomposition of organic materials can produce greenhouse gases (GHGs), such as nitrous oxide (N₂O) and methane (CH₄), as well as volatile organic compounds (VOCs), a precursor to ground-level ozone formation, which is a U.S. Clean Air Act criteria pollutant (U.S.EPA, 2006). Waste processing is an important driver for the increase in atmospheric GHGs and VOCs (IPCC, 2014). Knowledge about composting (Belyaeva, 2010; Lou and Nair, 2009; Roger, 1993) and its environmental impacts has increased over the past decades (Boldrin et al., 2009; Hellebrand, 1998; Kumar et al., 2011). For example, N₂O and CH₄ emissions during GW composting ranged from 0.03 to 0.13 and 5.9 to 6.5 g kg⁻¹ of GW material (dry weight), respectively (CalRecycle,

2015; CARB, 2015). However, direct land application of GW receives little attention.

Direct land application of GW, e.g. as mulch in citrus and avocado orchards, is widely practiced in some regions of California because the raw un-composted yard trimmings are more economical than finished compost (Menge et al., 1999). The lack of composting facilities and legislative mandates to reduce GW disposal in landfills also contribute to the frequent use of fresh GW (CalRecycle, 2010). Since GW applied as mulch is typically applied at high rates, e.g. 125–250 Mg dry weight ha⁻¹ (Blake et al., 2002), the GHG and VOC emissions occurring with surface application need to be assessed and compared to the emissions which occur following incorporation of GW into soil as these emissions could have a significant impact on GHG balance and regional atmospheric pollution.

Soils are important sources and sinks of N₂O and CH₄ (IPCC, 2007; Schlesinger, 2013), which are produced and consumed through biotic and abiotic processes including ammonia oxidation, heterotrophic denitrification, chemodenitrification, soil organic matter (SOM) decomposition, methanogenesis, and CH₄ oxidation (Schlesinger, 1997; Wrage et al., 2001; Zhu-Barker et al., 2015; Zhu et al., 2013a). The activities associated with the microbial processes involving these trace gases are strongly affected by oxygen (O₂) availability (biological oxygen demand), organic carbon (C),

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pH, nitrogen (N) forms and availability, and concentrations of certain metals (Bouwman et al., 2002; Nesbit and Breitenbeck, 1992; Sullivan et al., 2013; Zhu et al., 2013a, 2013b). High C availability in GW promotes microbial activity and O₂ consumption (Zhu et al., 2014), thereby promoting N₂O production through ammonia oxidation pathways and heterotrophic denitrification (Firestone and Davidson, 1989; Zhu et al., 2013a) and CH₄ generation. Alternatively, ammonium and nitrate, the substrates for various N₂O production pathways, may be immobilized by microbes due to the high availability of labile C sources, such as dissolved organic C (Wright et al., 2008; Zhu et al., 2013c), while CH₄ is readily consumed in the presence of O₂.

Here we investigated the effects of surface land application and soil incorporation of GW on GHG and VOC emissions for a 12 month period. We hypothesized that moisture and temperature primarily regulate the magnitude of the emissions; soil incorporation of GW generates more GHGs because of the greater likelihood of anaerobic conditions in soil than in surface applied GW; more VOCs are released from surface application than incorporation of GW due to lower opportunity of VOCs to be consumed in surface applied GW.

2. Materials and methods

2.1. Field site and experimental design

The field experiment was carried out at the Campbell tract research site at the University of California, Davis, CA (38°32'6"N, 121°46'35"W). The soil is classified as Yolo silt loam, a fine-silty, mixed, non-acid, thermic Typic Xerorthent (USDA-National Cooperative Soil Survey, available at <http://casoilresource.lawr.uc-davis.edu/gmap/>). The soil characteristics are shown in Table 1. After harvesting processing tomatoes in the preceding year (2012), the field had been fallow until the start of the experiment in 2013 fall.

Green waste, i.e. residential yard waste collected two weeks before the experiment and passed through a 13 cm screen at a local composting facility (Northern Recycling, Zamora, CA), was applied at the University of California Davis, CA, research site Campbell tract on October 14, 2013. At this time of the year, the sources of the applied GW were mainly leaves, grass clippings, and tree branch trimmings. The moisture content of the applied GW was 52% of dry mass, and other GW properties are reported in Table 1. The C to N ratio of the GW material used in this study was 36 and similar to the average of 40 found among 6 GWs from other collection facilities in California (Table S1, see Supporting Information). The following treatments were established in 3 m × 3 m plots in a randomized complete block design with three replications per treatment: (1) 30 cm GW (applied on the soil surface to an initial height of 30 cm, equivalent to 1000 Mg dry weight GW ha⁻¹); (2) 15 cm GW (applied on the soil surface to an initial height of 15 cm, equivalent to 500 Mg dry weight GW ha⁻¹); (3) 15 cm + till (applied 15 cm high, followed by incorporation with 3 passes of a

disk to a depth of 15–20 cm); (4) control + till (tilled control); (5) control (untilled control). Irrigation events were scheduled during extended periods of dry weather in January, June, and September.

2.2. Gas flux measurements

The N₂O, CH₄, CO₂, and VOC fluxes were measured immediately before and daily or every other day following each rainfall or irrigation event, in order to capture the peak of the emissions and subsequent decline back to ambient levels. During the time in between these events, when soils were relatively dry and the fluxes subsided to background levels, the gas fluxes were measured weekly. During the year, measurements were taken on 87 sampling dates. Gas fluxes were measured using a static chamber technique (Hutchinson and Livingston, 1993). In the center of each replicate plot, 25.4 cm diameter round PVC chamber bases were inserted 8 cm deep into the soil, i.e. the bases extended through the GW of the surface applications. The bases were left in place for the entire duration of the field experiment.

During gas sampling, insulated vented PVC chambers were fit onto the bases and sealed with a rubber gasket overlapping base and chamber. 20-mL gas samples were removed from the chamber headspace by inserting a polypropylene syringe into the chamber through a septum at 0, 20, 40 and 60 min after deploying the chambers. The gas was immediately transferred into evacuated 12-mL glass vials with grey butyl rubber septa (Exetainer, Labco Ltd., Buckinghamshire, UK). The gas samples were analyzed within two weeks on a Shimadzu gas chromatograph (GC) (Model 2014) linked to a Shimadzu auto sampler (Model AOC-5000). The GC was equipped with a ⁶³Ni electron capture detector for N₂O, a flame ionization detector for CH₄, and a thermal conductivity detector for CO₂. The GC was calibrated daily using analytical grade standards (Airgas Inc., Sacramento CA) prepared at the same time as the samples were collected. The minimum detectable change in static chamber concentration on this GC system is 0.02 μL N₂O L⁻¹ (equal to 25 mg N₂O-N ha⁻¹ h⁻¹ field flux) and 0.1 μL CH₄ L⁻¹ (equal to 110 mg CH₄-C ha⁻¹ h⁻¹ field flux).

For VOCs, gas samples were collected at time 0 and 60 min. before and after deploying the chambers, respectively. Charcoal tubes containing 400 mg and 200 mg of activated carbon in two successive sections were used for sample collection and breakthrough determination, respectively (Orbo 32, Sigma-Aldrich, St. Louis, MO). 1 L of headspace gas was removed from the chambers with gas-tight Hamilton syringe, followed immediately by immobilization onto the charcoal sorbent tubes. Tubes were capped immediately after sampling and transferred to the laboratory in <1 h. Samples were refrigerated at 4 °C until they were processed. The tubes were eluted at the flow rate of 0.5 L per min for 1 min followed by analysis by GC-MS, according to NIOSH methods 1500, 1501, and 1552 (Kumar et al., 2011; NIOSH, 2003). The details for sample processing and analysis in laboratory were described by Kumar et al. (2011). A calibration standard solution was prepared by mixing a known volume of chromatographic-grade methanol, *n*-hexane, isooctane, 1-hexene, toluene, *m*-xylene, 1, 3, 5-trimethyl benzene (mesitylene), 1, 4-diethylbenzene, limonene, 2-pentanone, hexanal, and 1-hexanol in a vial and diluting with CS₂. The instrument was calibrated to ensure the linearity of the system. If the response factor to the calibration standard varied by >10–15% the GC was recalibrated. Carbon disulfide was also analyzed to ensure that the system was contamination free.

2.3. GHG flux and VOC calculation

Greenhouse gas and VOC fluxes were calculated from the rate of change in chamber concentration, chamber volume, and soil

Table 1
Characteristics of the soils and green waste (GW).

	Silt loam	Clay	Loamy sand	GW
Sand (%)	29	30	74	
Silt (%)	42	35	16	
Clay (%)	28	35	10	
pH (KCl 1:1)	6.1	5.6	5.8	6.9
(H ₂ O 1:1)	7.4	7.0	6.4	7.3
NH ₄ ⁺ -N (mg kg ⁻¹)	3.0	3.6	2.9	39
NO ₃ ⁻ -N (mg kg ⁻¹)	21	0.5	21	2.6
Total C (g kg ⁻¹)	14.1	11.2	11.0	341
Total N (g kg ⁻¹)	1.12	1.10	1.23	9.5

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