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EARTH AND ENVIRONMENTAL SCIENCE
SUPPLEMENTARY-RESULT

Greenhouse Gas Emissions from Subtropical Agriculture Fields Decrease Over Time

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Abstract

Expansion of cultivated lands and field management impacts greenhouse gas (GHG) emissions from agriculture soils. Soils naturally cycle GHGs and can be sources or sinks depending on physical and chemical properties affected by cultivation and management status. We looked at how cultivation history influences GHG emissions from subtropical soils. We measured CO_2, N_2O, and CH_4 fluxes, and soil properties from newly converted and continuously cultivated lands during the summer rainy season in calcareous soils from south Florida. Newly converted soils had more soil organic matter (OM), more moisture, higher porosity, and lower bulk density, leading to more GHG emissions compared to historically cultivated soils. Although more nutrients make newly converted lands more desirable for cultivation, conversion of new areas for agriculture was shown to release more GHGs than cultivated lands. Our data suggest that GHG emissions from agricultural soils may decrease over time with continued cultivation.

Keywords: Carbon dioxide; agroecology; soils; cultivation

1. Introduction

Greenhouse gas emissions from agriculture are an important environmental impact to consider. Plant and livestock production currently account for 13% of global greenhouse gas (GHG) emissions (EPA, 2020). Fertilizer use, tillage, and irrigation contribute to carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions (Tilman et al., 2001), yet are necessary to support continued cultivation of soils. Humans convert new land for agriculture because of issues with soil fertility and climate change (Galford et al., 2010). Such changes in land cover and land-use can make up 24 to 49% of the GHG budget associated with agricultural land management (Galford et al., 2010). While extensification, the cultivation of new land, is one way to maintain or increase production, intensification, or increasing inputs per area, can support continued cultivation of land (Pellegrini & Fernandez, Pellegrini & Fernández, 2018). Farm management practices, such as the use of cover crops and conservation tillage can improve soil fertility allowing for continued cultivation and possibly reduce GHG emissions (Kallenbach et al., 2010; Snyder et al., 2009; Tully & Ryals, 2017). Considering agriculture is a significant contributor to GHGs, there is a need to understand how land cultivation and farm management practices impact GHG emissions from agricultural soils.

2. Objective

The objective of this study was to compare soil characteristics and GHG emissions between newly converted and historically cultivated subtropical agricultural soils. GHG measurements from soils located at the University of Florida Institute of Food and Agricultural Sciences Tropical Research and Education Center in Homestead, Florida, USA are relevant for future large-scale research in agroecosystem management in south Florida and other regions with similar calcareous soil type and agricultural management. More broadly, information on GHG emissions associated with cultivation status and history of agricultural soils can help quantify future GHG emissions associated farm management.

3. Methods

Krome gravelly loam soils (Nobel et al., 1996), were sampled once in May, July and August 2018 for GHG emissions and soil moisture in four 20m x 20m plots. Two plots were historically cultivated for vegetable production (> 20 years). The other two plots were covered in turf and scattered trees until the top 0.30m of oolithic limestone rock was crushed and plowed in March 2018. Plots used in this study were neither fertilized nor irrigated but divided into 36 sub-plots and planted with multiple cover crops. Vented static flux chambers (Holland et al., 1999) were randomly installed at 4 sub-plots in each of the 4 larger plots at a depth of 2-3 cm. Headspace samples (20 mL) were taken 0, 15, 30, and 45 minutes after chambers were capped and analyzed for CO_2, N_2O, and CH_4, using a gas chromatograph with ECD and FID detectors. Fluxes were determined from the four time points using linear regressions fitted to the changes in concentration over time when the regression line had an $R^2 > 0.65$. Our minimal detectable flux for CO_2, CH_4, and N_2O was 1.98, 1.70, and 2.04 g ha^{-1} day^{-1}, respectively. N_2O and CH_4 were converted to carbon dioxide equivalents (CO_2 eq.) using conversion factors 298 and 25, respectively. Soil samples (n=36) were collected from each sub-plot of the four plots at 10 cm depth and analyzed for organic matter (OM), extractable ammonium (NH_4^+) and nitrate (NO_3^-) in March 2018. Soil porosity and bulk density were collected from all sub-plots in one cultivated and one converted plot. Mixed effects models were used to compare GHG fluxes and soil properties between cultivation history.

4. Results

A majority of the CH_4 (37/48) and N_2O (40/48) fluxes were below the detection limit; detectable fluxes (CH_4 (10/11) and N_2O (8/8)) were from newly converted soils. The average flux for CH_4 and N_2O was 0.0013 and 0.0036 kg ha^{-1} day^{-1}, respectively, while the average CO_2 flux was 12.66 kg ha^{-1} day^{-1}. In CO_2 eq, CH_4 and N_2O accounted for 1.5% of the overall CO_2 emission. CO_2 eq were 73% higher in newly converted soils compared to cultivated soils (Figure 1). Soil OM and soil porosity were significantly higher in newly converted soils compared to cultivated lands (Table 1). Cultivation decreased soil moisture compared to converted soils (Table 1). Bulk density was lower in newly converted soils than cultivated soils. Soil NH_4^+ and NO_3^- content were approximately 2.5 times and 8 times higher in the converted soils, respectively.

5. Discussion

Land conversion to agriculture in subtropical calcareous soils had higher GHG emission shortly after conversion than soils historically used for subtropical agriculture. Given the soil type and surface bedrock, we were unable to have an undisturbed control plot. Higher nitrogen content and soil moisture, as found in the newly converted soils, are both driving factors for GHG production in soils (Snyder et al., 2009). Lower porosity and higher bulk density in the cultivated soils might reflect the frequent tillage, compaction, and loss of organic matter, compared to the newly converted soils, which were only tilled once prior to the experiment. The recently converted soils had higher OM, NO_3^-, and NH_4^+ content, which is more desirable for agriculture in the short term.

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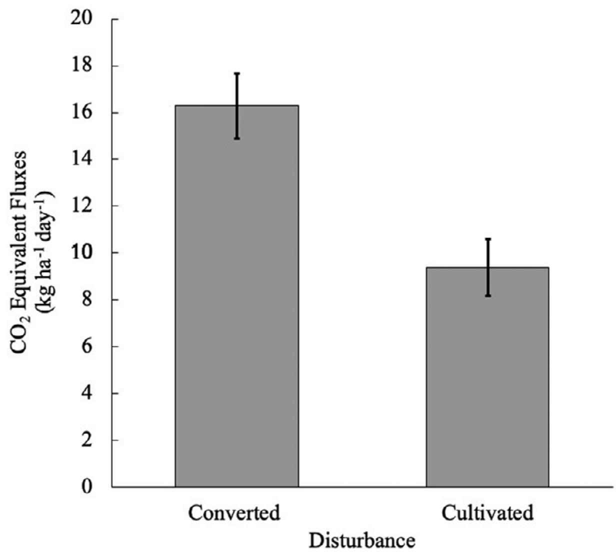

Figure 1. Mean (±SE) CO_2 Equivalent fluxes (sum of CO_2 and non-CO_2 fluxes) from converted and cultivated soils ($F_{1,2} = 13.82$ $p = 0.065$). Fluxes were measured three times over 4 months during the summer rainy season.

Table 1. Summary table of results for soil physical and chemical properties (± SE). Different letters indicate mean values are significantly different ($p < 0.05$).

	Disturbance				
	Converted	Cultivated	*DF*	*F-value*	*p-value*
Soil Organic Matter (%)	16.33 ± 0.57[a]	6.90 ± 0.13[b]	2	60.18	0.016
Soil Porosity (%)	65.27 ± 1.14[a]	56.46 ± 1.10[b]	1	30.65	<0.001
Soil Moisture (%)	16.20 ± 1.68[a]	7.83 ± 0.78[a]	2	7.72	0.109
Soil Bulk Density (g/cm^{-3})	0.92 ± 0.03[a]	1.15 ± 0.03[b]	1	30.5	<0.001
Extractable NH_4^+ ($mg\ kg^{-1}$)	16.93 ± 1.28[a]	5.38 ± 0.74[b]	2	47.73	0.02
Extractable NO_3^- ($mg\ kg^{-1}$)	56.21 ± 1.85[a]	7.08 ± 0.26[b]	2	692.14	0.0014

6. Conclusions

Conversion of land for cultivation breaks up the structure of undisturbed soils and disrupts natural biogeochemical cycles. Soil structure and nutrient availability in converted lands may be desirable, at least in the short term despite the increase in GHG emissions. Farm management practices that facilitate nutrient storage (i.e., cover crops, conservation tillage) could allow for continued cultivation of lands and help reduce GHG emissions from agricultural soils (Galford et al., 2010; Tully & Ryals, 2017). Our results suggest that GHG emissions may decrease overtime as subtropical land is continuously cultivated and soil OM and porosity decrease. Additional studies that assess the indirect as well as direct sources of GHG emissions from subtropical agriculture are needed to accurately identify farm management practices that can decrease the GHG costs of agriculture (Gelfand & Robertson, 2015).

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Author Contributions. TF, ZB and ARS conceived and designed the study. TF conducted data collection. TF and KH performed the statistical analysis. All authors contributed to writing the article.

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Conflict of Interest. The authors have no conflicts to declare.

Data Availability Statement. The data that support these findings are openly available upon request to the corresponding author.

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Peer Reviews

Reviewing editor: Dr. Bartosz Adamczyk
Natural Resources Institute Finland, Viikki, Helsinki, Finland, 00790

This article has been accepted because it is deemed to be scientifically sound, has the correct controls, has appropriate methodology and is statistically valid, and met required revisions.

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Review 1: Greenhouse Gas Emissions from Newly Cultivated Lands for Subtropical Agriculture

Reviewer: Dr. Bonnie McGill

Carnegie Museum of Natural History, Pittsburgh, United States, 15213-3131

Date of review: 13 July 2020

Conflict of interest statement. Reviewer declares none

Comments to the Author: Interesting paper that found greater soil GHG emissions on newly vs. historically cultivated land in FL. This is important work due to threats to loss of habitat and biodiversity due to land conversion, and the need for accurate accounting of human GHG emissions. My comments below are in allyship of this work!

I recommend mentioning the context of ag intensification v. extensification (e.g. https://www.pnas.org/content/115/10/2335).

The statistics could be considered pseudoreplication (see https://doi.org/10.2307/1942661). I suggest including additional testing of the data to demonstrate statistical independence and show the correct calculation of the F-ratio.

Soil structure is surprising, I would expect the cultivated plots to have higher bulk density and lower porosity because of the erosion of soil aggregates, meaning soil particles fill pore spaces, and compaction. The newly converted soils having more soil moisture is expected with 2x the SOM. In line 89 moisture didn't really double, it's that the cultivated lands were halved by human impacts. In line 53 I suggest making humans the ones doing the conversion of land, rather than the passive voice insinuation of humans.

Line 48: demand for food is driven by increasing levels of consumption as well as population; also hunger is not just a product of not enough food, but the systems by which people access food. (FYI, in general, tying environmental damage to human population growth, insinuates mainly in nations with majority people of color, is problematic.)

Does "scarification" mean plowed? How deep? Were the new fields planted into anything, was N fertilizer used?

The paper does not include any caveats. Before we can conclude that new cultivation has less GHG emissions than historically cultivated land, we need the net GHG impact (e.g., see https://lter.kbs.msu.edu/citations/3465/download/Gelfand-2015-Ecology-Agric-Landscapes.pdf), I recommend adding a statement about this as a next step.

Thank you for the opportunity to review your work.

Score Card

Presentation

4.7 /5

Is the article written in clear and proper English? (30%)	5/5
Is the data presented in the most useful manner? (40%)	5/5
Does the paper cite relevant and related articles appropriately? (30%)	4/5

Context

4.0 /5

Does the title suitably represent the article? (25%)	4/5
Does the abstract correctly embody the content of the article? (25%)	4/5
Does the introduction give appropriate context? (25%)	3/5
Is the objective of the experiment clearly defined? (25%)	5/5

Analysis

4.2 /5

Does the discussion adequately interpret the results presented? (40%)	4/5
Is the conclusion consistent with the results and discussion? (40%)	5/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	3/5

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doi:10.1017/exp.2020.48.pr2

Review 2: Greenhouse Gas Emissions from Newly Cultivated Lands for Subtropical Agriculture

Reviewer: Dr. Lukas Kohl

University of Helsinki, Agricultural Science, Finland

Date of review: 04 August 2020

Conflict of interest statement. reviewer declares none

Comments to the Author: Fall and co-authors compared soil properties and greenhouse gas (GHG) emission between soils recently converted to agricultural use and soils under continuous agricultural use for >20 years. This study addresses a topic questions of global importance to the soil and agricultural scientist, was conducted according to the state of the art, and is well presented.

Limitations: The authors did not include control plots of unconverted land. Yet, the conclusions imply that that land conversion increases GHG emissions. This cannot be inferred given that we don't know how much GHG would be emitted had the land not been converted. This is issue can be addressed by carefully rewording the conclusion section – the authors could e.g. conclude that GHG emissions from agriculturally used fields decrease over time.

I also think that the methods need to be stated more clearly:

-The authors should state how they judged goodness-of-fit for the linear regression used to calculate GHG fluxes from each chamber closure

-Most measured CH4 and N2O fluxes were below the limit of detection (LOD), but the manuscript does not state what the LOD of their method is. This should be added.

-A clarification on the number of replicates per plot & sampling time (plus pooling of subsamples if applicable) is needed. Also, the number of measurement time points for GHG fluxes should be stated (how many times per year, covering which seasons?).

-How were GHG concentrations measured (gas chromatography? Which detectors?)

Score Card

Presentation

5.0 /5

Is the article written in clear and proper English? (30%)	5/5
Is the data presented in the most useful manner? (40%)	5/5
Does the paper cite relevant and related articles appropriately? (30%)	5/5

Context

5.0 /5

Does the title suitably represent the article? (25%)	5/5
Does the abstract correctly embody the content of the article? (25%)	5/5
Does the introduction give appropriate context? (25%)	5/5
Is the objective of the experiment clearly defined? (25%)	5/5

Analysis

3.0 /5

Does the discussion adequately interpret the results presented? (40%)	3/5
Is the conclusion consistent with the results and discussion? (40%)	3/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	3/5

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