Modeling Greenhouse Gas Emissions in Response to Increased Precipitation in Southern California

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Introduction

The relationship between precipitation and soil saturation has proven to be a complicated area of study (Sehler et al., 2019). With the increased precipitation seen in Southern California in recent years, the question arises as to how this affects soil saturation for the region. Coupled with the pressing threat of climate change, this study aims to determine if this increased precipitation leads to increased greenhouse gas emissions and if so, which greenhouse gases see the greatest increases? The hypothesis is that increased precipitation will lead to increased soil saturation, resulting in less oxygen being available in the soil which leads to increased anaerobic degradation of soil organic carbon, ultimately resulting in increased greenhouse gas emissions in the region. To test this hypothesis, this project utilizes the Denitrification-Decomposition (DNDC) model which focuses on carbon and nitrogen biogeochemistry in agricultural ecosystems such as the Imperial Valley below the Salton Sea and above the United States – Mexico border, the chosen area of interest for this project.

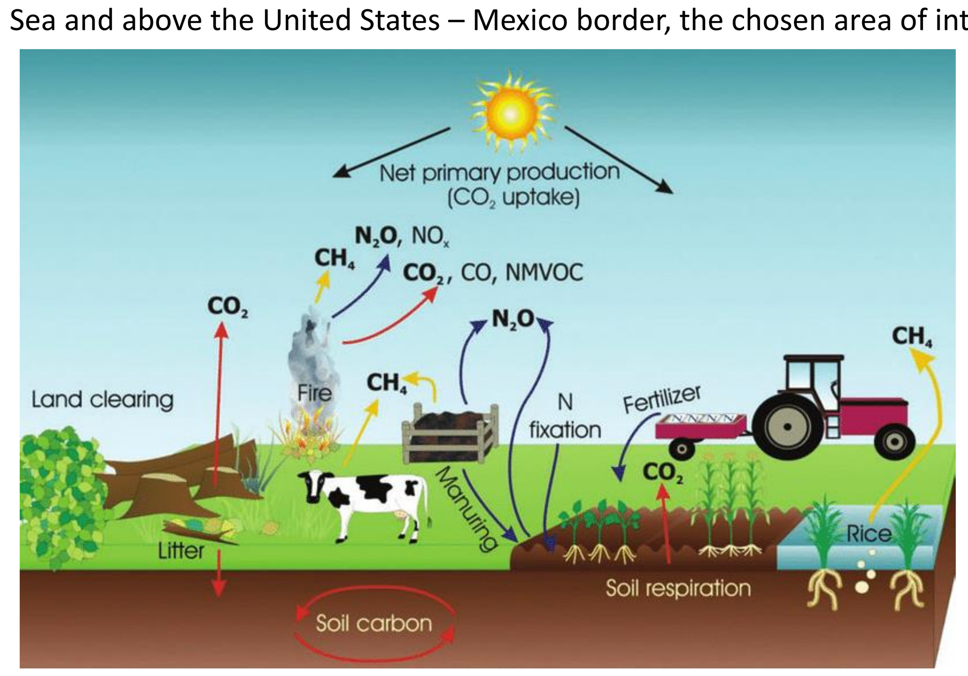

Figure 1: Overview of Greenhouse Gas Emission Sources Associated with Agricultural Activities (Follett et al., 2011)

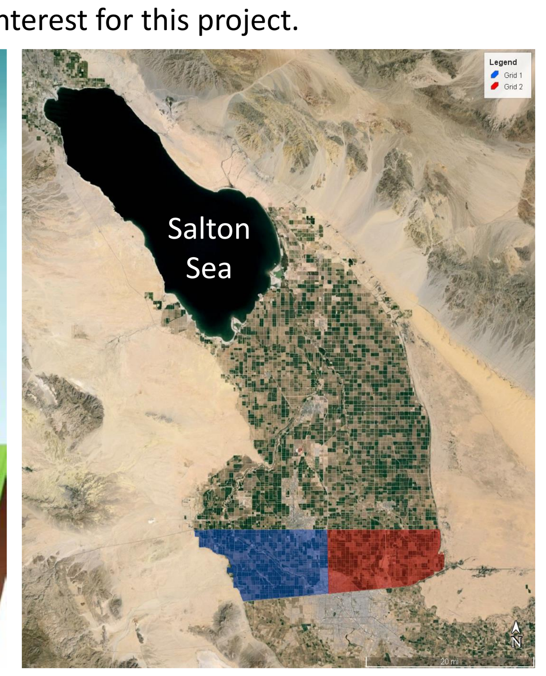

Figure 2: Site Map (Google Earth, 2024)

Methods and Materials

The DNDC model offers two modes: site and regional. The regional mode will be utilized for this study which requires dividing the chosen area of interest into grid cells for which various input parameters are compiled in a database prior to running the model. The input parameters that data was obtained for in this model are soil type, crop cover type, and climate. The remaining input parameters were copied over from the DNDC "Shangrila" database and as discussed in the next steps section, can be revised to better align with the conditions of the Imperial Valley area of interest in future runs of the model.

Soil Type

Data for this input parameter was obtained from the United States Department of Agriculture (USDA) Web Soil Survey. Precise soil data for the two grid cells were compiled and then compared to the DNDC soil parameters library which includes 14 different soil types. Since the DNDC model requires grid cells with uniform soil conditions, the most prevalent soil type for both grid cells was determined to be silt clay loam.

Table 1: Grid 1 Soil Type Data

DNDC Soil Code	DNDC Soil Name	Acres in Grid 1	Percent of Grid 1
0	None	456.3	0.7%
1	Sand	1,564.4	2.4%
2	Loamy Sand	3,332.6	5.2%
3	Sandy Loam	6,095.8	9.5%
4	Silt Loam	0.0	0.0%
5	Loam	3,973.9	6.2%
6	Sand Clay Loam	0.0	0.0%
7	Silt Clay Loam	24,872.0	38.7%
8	Clay Loam	294.8	0.5%
9	Sandy Clay	0.0	0.0%
10	Silty Clay	22,964.4	35.7%
11	Clay	717.9	1.1%
12	Organic	0.0	0.0%
13	Pristine Peat	0.0	0.0%
14	Cultivated Peat	0.0	0.0%
Total		**64,272.1**	**100.0%**

Table 2: Grid 2 Soil Type Data

DNDC Soil Code	DNDC Soil Name	Acres in Grid 2	Percent of Grid 2
0	None	146.0	0.3%
1	Sand	1,915.4	3.3%
2	Loamy Sand	6,288.2	10.9%
3	Sandy Loam	10,477.7	18.2%
4	Silt Loam	0.0	0.0%
5	Loam	3,756.6	6.5%
6	Sand Clay Loam	0.0	0.0%
7	Silt Clay Loam	21,043.9	36.6%
8	Clay Loam	167.2	0.3%
9	Sandy Clay	0.0	0.0%
10	Silty Clay	13,362.0	23.2%
11	Clay	345.4	0.6%
12	Organic	0.0	0.0%
13	Pristine Peat	0.0	0.0%
14	Cultivated Peat	0.0	0.0%
Total		**57,502.4**	**100.0%**

Crop Cover Type

Data for this input parameter was obtained from Stanford University's California Crops base map. Crop cover data was compiled for the two grid cells and then compared to the DNDC crop parameters library which includes over 80 crop cover types. With this, the areas in hectares for six crop cover types that comprise the two grid cells was determined.

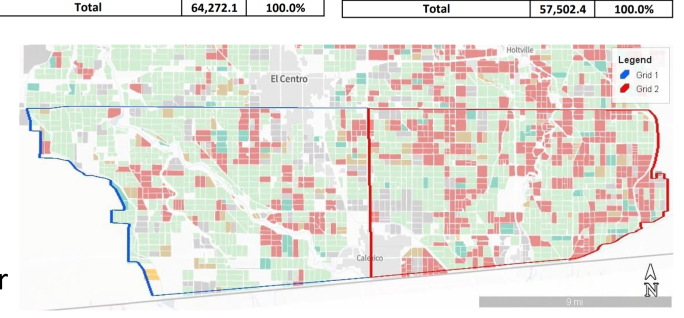

Figure 3: Crop Cover Type Map (Stanford University, 2018)

Table 3: Crop Cover Type Data

Grid	Pasture		Truck Nursery and Berry Crops		Field Crops		Grain and Hay Crops		Idle / Urban		Citrus and Olives	
Grid 1	Percentage	56.8%	Percentage	20.8%	Percentage	3.9%	Percentage	4.9%	Percentage	13.2%	Percentage	0.4%
Grid 2	Percentage	12.2%	Percentage	53.7%	Percentage	5.5%	Percentage	6.4%	Percentage	22.2%	Percentage	0.0%
Grid	**Alfalfa**		**Truck Crops**		**Corn**		**Winter Wheat**		**Fallow**		**Citrus**	
Grid 1	Hectares	14,785	Hectares	5,418	Hectares	1,013	Hectares	1,266	Hectares	3,443	Hectares	101
Grid 2	Hectares	2,838	Hectares	12,514	Hectares	1,290	Hectares	1,484	Hectares	5,160	Hectares	0

Climate

Data for this input parameter was obtained from the National Centers for Environmental Information (NCEI) / National Oceanic and Atmospheric Administration (NOAA) in addition to the State of California. DNDC requires maximum and minimum air temperatures in degrees Celsius along with the precipitation in centimeters for each day in which the model will be run.

Station_42713

Day	Maximum Air Temperature (°C)	Minimum Air Temperature (°C)	Precipitation (cm)
1	20.44	5.89	0.025
2	20.50	5.94	0.025
3	20.56	5.94	0.000
4	20.61	6.00	0.025
5	20.72	6.06	0.025
...	...	...	...
365	20.33	5.83	0.051

Figure 4: Climate Data

Results

Statewide precipitation data between 2001 and 2023 was obtained in the form of annual accumulated precipitation in inches. A histogram of the data resembles a Poisson distribution. With this, it was decided that 75% and 95% probability data sets would be utilized for the model to aid in the comparison of greenhouse gas emission rates in relation to increased precipitation:

- 95% of the data exceeds 14 inches of annual accumulated precipitation
- 75% of the data exceeds 18 inches of annual accumulated precipitation

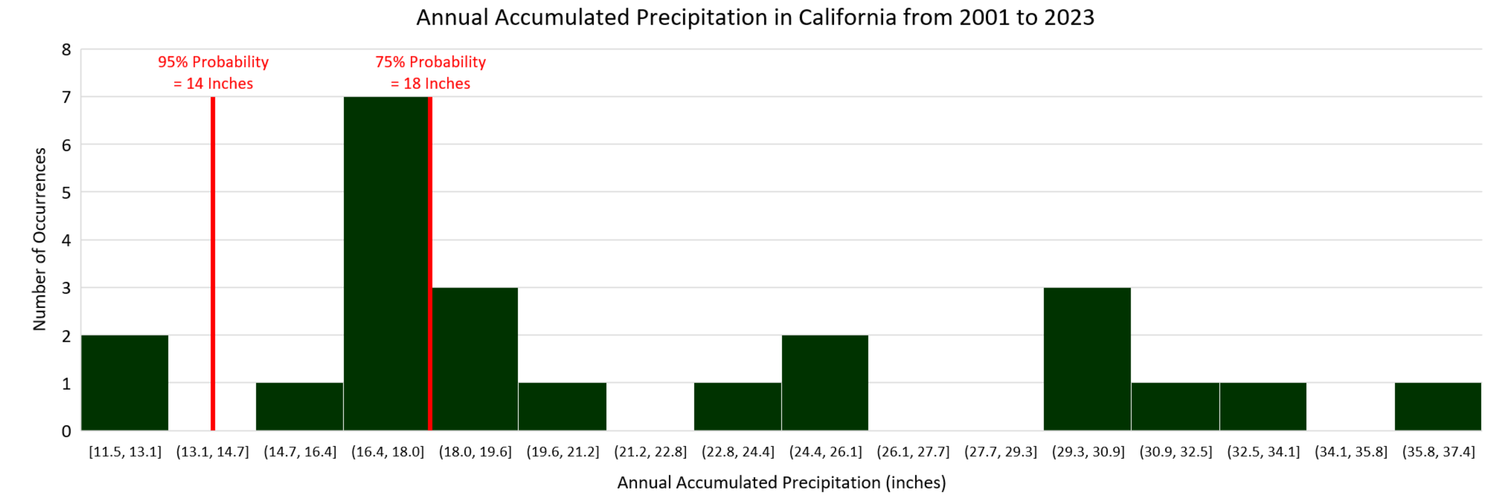

Figure 5: Annual Accumulated Precipitation in California from 2001 to 2023

With the two sets of precipitation data obtained, two runs of the DNDC model were conducted. All other parameters such as soil type and crop cover type remained constant and only the climate data, specifically the precipitation data, was changed between the two runs. DNDC runs four different scenarios: maximum and minimum values for full irrigation and maximum and minimum values for zero irrigation. Averages of the maximum and minimum values were calculated and then compared against each other for the two runs, the greater value for which is highlighted in Table 4 below.

Table 4: DNDC Model Results

			Soil Organic Carbon, SOC (kgC/ha)	Carbon Dioxide, CO_2 (kgC/ha)	Methane, CH_4 (kgC/ha)	Nitrous Oxide, N_2O (kgN/ha)	Nitric Oxide, NO (kgN/ha)	Dinitrogen, N_2 (kgN/ha)	Ammonia, NH_3 (kgN/ha)
Full Irrigation	**Maximum**	**75% Probability = 18 Inches**	620625	8659	242.56	5.678	2.626	9.114	791.067
		95% Probability = 14 Inches	620661	8621	242.57	5.635	2.617	9.178	791.699
	Minimum	**75% Probability = 18 Inches**	317795	6577	202.81	4.843	2.585	9.464	751.939
		95% Probability = 14 Inches	317820	6548	202.80	4.838	2.588	9.572	752.855
	Average	**75% Probability = 18 Inches**	469210	7618	222.69	5.261	2.606	9.289	771.503
		95% Probability = 14 Inches	469241	7585	222.69	5.237	2.603	9.375	772.277
Zero Irrigation	**Maximum**	**75% Probability = 18 Inches**	620611	8673	242.52	5.318	2.416	9.148	792.443
		95% Probability = 14 Inches	620647	8635	242.53	5.237	2.383	9.210	794.231
	Minimum	**75% Probability = 18 Inches**	317793	6579	202.81	4.519	2.371	9.468	753.825
		95% Probability = 14 Inches	317820	6550	202.80	4.504	2.368	9.572	755.050
	Average	**75% Probability = 18 Inches**	469202	7626	222.67	4.919	2.394	9.308	773.134
		95% Probability = 14 Inches	469234	7593	222.67	4.871	2.376	9.391	774.641

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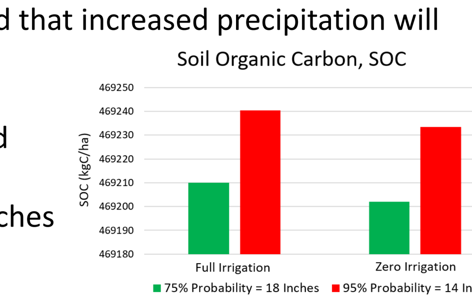
Discussion

Soil Organic Carbon and Precipitation Relationship

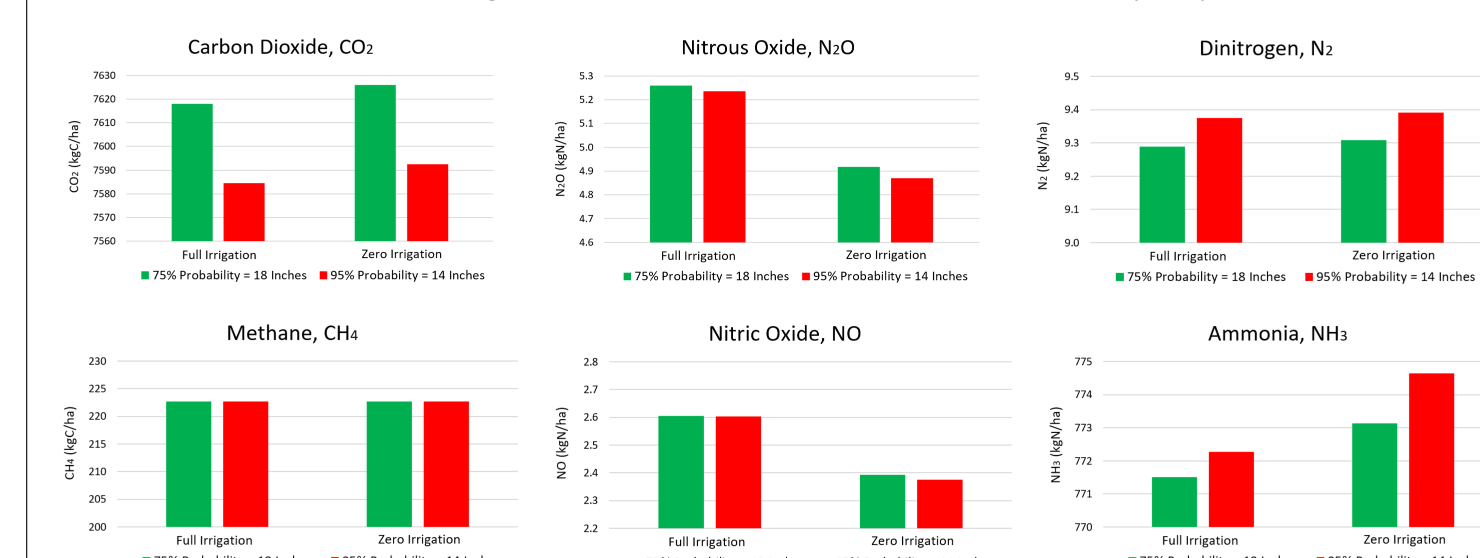
Analyzing the results of the runs of the DNDC model, it is found that the 14 inches of annual accumulated precipitation yields a greater soil organic carbon (SOC) value for both the full irrigation and zero irrigation scenarios. Referring back to the introduction section, it was hypothesized that increased precipitation will ultimately lead to increased anaerobic degradation of SOC. Since the 14 inches value is the lower of the two precipitation data sets, the results support the hypothesis since less anaerobic degradation of SOC occurred due to the soil being less saturated. This produces the higher SOC value as reported by the DNDC model in comparison to the value for the 18 inches of annual accumulated precipitation.



Greenhouse Gas Emissions and Precipitation Relationship

It was also hypothesized that increased precipitation would lead to increased greenhouse gas emissions. Comparing the results of the two runs of the model, the following conclusions are made for both the full irrigation and zero irrigation scenarios:

- Carbon dioxide (CO_2) emissions are greater for the 18 inches of annual accumulated precipitation.
- Methane (CH_4) emissions are equal for the 18 inches and 14 inches of annual accumulated precipitation.
- Nitrous oxide (N_2O) emissions are greater for the 18 inches of annual accumulated precipitation.
- Nitric oxide (NO) emissions are greater for the 18 inches of annual accumulated precipitation.
- Dinitrogen (N_2) emissions are greater for the 14 inches of annual accumulated precipitation.
- Ammonia (NH_3) emissions are greater for the 14 inches of annual accumulated precipitation.



These conclusions do not produce a clear agreement nor disagreement with the hypothesis. The results are practically split in half with three greenhouse gases having greater emissions for the 18 inches of annual accumulated precipitation and two greenhouse gases having greater emissions for the 14 inches of annual accumulated precipitation. While the higher precipitation value of 18 inches sees one more greater greenhouse gas emission value in comparison to the 14 inches data set, this is not enough to reasonably conclude that the results support the hypothesis of increased precipitation resulting in increased greenhouse gas emissions. As discussed in the next steps section below, there are ways to improve the DNDC model before additional runs are conducted to potentially produce results that better support the hypothesis as it relates to the relationship between greenhouse gas emissions and precipitation.

Next Steps

DNDC Model Improvements

In a regional mode run of the DNDC model, ten Geographic Information System (GIS) files in addition to a climate library are required for the model to run. The ten GIS files are as follows: Climate Soil, Crop Area, Crop Parameters, Fertilization, Flooding, Irrigation, Manure Amendment, Planting Harvest Dates, Residue Management, and Tillage. The two GIS files highlighted plus the climate library were the only input parameters revised for the Imperial Valley area of interest for this project. As mentioned in the methods and materials section, the remaining input parameters were copied over from the DNDC "Shangrila" database. Therefore, there is room for improvement in the model by researching and revising the input parameters associated with the remaining GIS files.

Comparison to Greenhouse Gas Emissions Data

The California Air Resources Board is responsible for updating the California Greenhouse Gas Emission Inventory Program. An appropriate next step would be to obtain greenhouse gas emissions data from this agency. It is important to note that the data obtained shall correspond to greenhouse gas emissions from natural sources rather than anthropogenic sources to align with the results produced by the DNDC model. Comparing raw data to the model data will allow for a determination of the aptness of the model. This, along with revising the remaining GIS files as discussed above, will aid in the creation of a reliable model that can eventually be expanded to cover a larger area of interest in the Imperial Valley in further research of the relationship between increased precipitation and greenhouse gas emissions.