COMET-Farm Sensitivity Analysis Report

Prepared by Darya Watnick
Mad Agriculture Fellow, Summer 2020

Master of Environmental Management Candidate '21
Yale School of the Environment

Abstract

In this sensitivity analysis, I examine the impact of parameter changes on carbon sequestration within the COMET-Farm tool. The objective of this analysis was to provide a guide for users of the COMET-Farm tool on the relative importance of different COMET-Farm parameters for the purposes of generating future carbon sequestration estimates, e.g., for enrollment into soil carbon offset marketplaces. The project showed that certain parameters have no impact on carbon sequestration, namely yield and irrigation. Other parameter changes, such as tillage method and manure/compost application, produce more significant outputs in carbon sequestration numbers.

Background

Background on COMET-Farm

COMET-Farm is a whole farm and ranch carbon and greenhouse gas accounting system developed by the US Department of Agriculture's Natural Resources Conservation Service and Colorado State University.[1] Underlying COMET-Farm is soil information from Web Soil Survey and the DayCent simulation model.[2] DayCent is a daily time step model for biogeochemical processes, simulating the major processes that affect soil organic matter (SOM), such as plant production, water flow, nutrient cycling, and decomposition. DayCent has submodels for nitrification and denitrification, CH_4 oxidation (though CH_4 emissions don't appear to currently be reported by COMET-Farm), and soil water and temperature.[3] Some current literature reports

[1] "Commonly Used NRCS Tools - COMET-Farm | NRCS."
[2] Paustian et al., "Farm-Scale Full GHG Accounting with the COMET-Farm Tool."
[3] Gryze et al., "Simulating Greenhouse Gas Budgets of Four California Cropping Systems under Conventional and Alternative Management," 1806.

that DayCent overestimates and underestimates N_2O emissions, often due to fertilizer applications.[4,5]

COMET-Farm currently has a number of different users. It is the official greenhouse gas quantification tool of the USDA.[6] Nori, a carbon removal marketplace that pays farmers to store carbon in their soil, uses COMET-Farm to model how much carbon was removed from the atmosphere and stored in soil.[7] The California Department of Food and Agriculture's Healthy Soils Program uses a specialized version of COMET-Planner, which gives outputs at the county level based on a sample-based approach and model runs in COMET-Farm.[8]

From a user standpoint, especially for users who have a specific purpose, it is useful to know how sensitive the COMET-Farm model is because of the large amount of data input required. Users who are working with the tool and developing programs at a large scale, such as carbon marketplaces, will benefit from knowing how to optimize the time spent on parameterization when developing their program.

This sensitivity analysis project is aimed at these kinds of users of the COMET-Farm tool. I examined which parameters have the biggest impact for carbon sequestration and which require the most precision in their inputs. This report will cover the process of developing and running the sensitivity analysis. Then I present the results of the sensitivity analysis of each parameter change on its own relative to the baseline and then of all of the parameter changes relative to each other. I will discuss the results and offer some thoughts about the changes. Lastly, given the constraints of this particular project, I will conclude with some ideas for future research.

Methods

To run the scenarios in COMET-Farm I used one plot, Field 151, from a farm in Eastern Nebraska. Field 151 is 149 acres. For the past 20 years, it has been under a corn-soybean rotation, with a winter wheat planting in 2013, followed by a fallow year. Recently, the farmers of Field 151 have been reducing the intensity of their tillage with practices such as strip- and no-tillage. They are now transitioning to organic certification so they are switching out synthetic fertilizers to compost and manure applications. .

The soil of Field 151 is 55% Yutan silty clay loam, 25% Filbert silt loam, 15% Fillmore silt loam and 5% Scott silt loam. The Yutan series consists of very deep, well-drained soils formed in loess. Yutan soils are fine-silty, mixed, superactive, mesic Mollic Hapludalfs. The Fillmore and Filbert soil series are both very deep, somewhat poorly drained also formed in

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4 Del Grosso, Halvorson, and Parton, "Testing DAYCENT Model Simulations of Corn Yields and Nitrous Oxide Emissions in Irrigated Tillage Systems in Colorado," 1386.
5 Necpálová et al., "Understanding the DayCent Model," 120.
6 "Commonly Used NRCS Tools - COMET-Farm | NRCS."
7 "Nori."
8 California Department of Food and Agriculture Healthy Soils Program and California Climate Investments, "Quantification Methodology."

loess, though the Filber series is very slowly permeable. Both soils are fine, smectitic mesic Vertic Argiabolls.[9]

Nebraska has a continental climate, characterized by a large temperature variability with warm summers dominated by thunderstorms and cold winters influenced by snow and wind. The eastern half of the state, where Field 151 is located, receives moisture from the southerly winds coming across the Gulf of Mexico.[10]

Parameter Changes

These tables represent the categories of the parameters that I manipulated within COMET-Farm and the specific changes that I made for each scenario that I ran through the model.

Parameter Category	Planting Date		Harvest Date		Yield			Residue Removal	
Changes Made	Within 2 weeks	Within 1 month	Within 2 weeks	Within 1 month	90% of actual	75% of actual	50% of actual	25% removal	50% removal

Tillage Date		Tillage Method						
Within 2 weeks	Within 1 month	Less intensive	More intensive	All intensive	All reduced	All mulch	All strip	All no-till

Fertilizer Application Date		Fertilizer Application Rate			
Within 2 weeks	Within 1 month	10% more	25% more	10% less	25% less

Fertilizer Rate/Date							
One March application	One April application	One May application	One June application	One July application	One Aug application	One Sept application	One Oct application

Irrigation Dates				Irrigation Volume I			
Within 2 weeks	Within 1 month	All dates changed within 1 or 2 weeks	All dates changed within 1 month, ahead or behind	10% more	25% more	10% less	25% less

9 Soil information pulled from Web Soil Survey and the USDA's Official Soil Descriptions
10 Shulski et al., "Climate Change: What Does It Mean for Nebraska?"

Irrigation Volume II			Manure/Compost			
5 in per application	10 in per application	No irrigation	Beef Manure	Dairy Manure	Chicken Manure	Compost

I went through and changed one parameter at a time from the historical management, the years 2000 to 2019, in COMET-Farm so that I could see how the model responded and compare the changes to the original inputs. For date changes, within two weeks or one month, every year I switched between moving the dates earlier and later from the original date. So the year 2000 would be moved earlier and 2001 would be moved to later dates.

The parameter changes to 'less intensive' tillage methods moved tillage events to a less intensive method. For seasons with two tills, I only changed the most intensive one. Intensive tillage moved to reduced till, mulch till moved to strip till, strip till moved to no-till, and no-till moved to crimp till. For the parameter changes to 'more intensive' tillage methods intensive stayed the same, as it is already the most intensive. No-till moved up to strip till, mulch moved to reduced till, and strip till moved to mulch till.

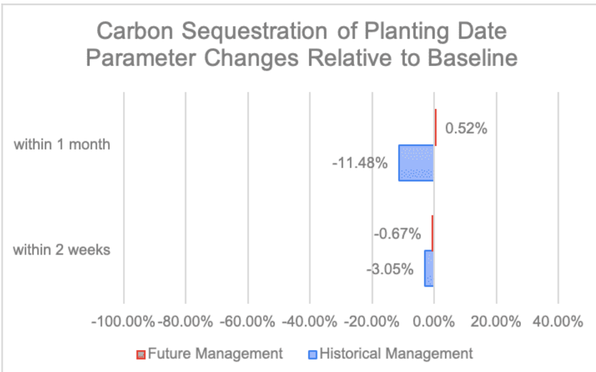
For the Fertilizer Rate and Date changes I changed the fertilizer application to one application of fertilizer (ammonium polyphosphate solution) at a rate of 150 pounds of nitrogen per acre on the 15th of each month.

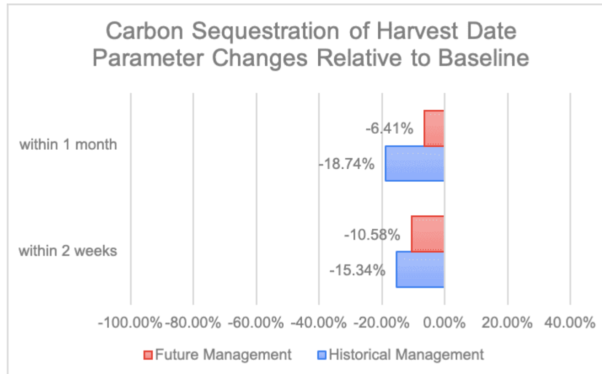
For the manure and compost parameter changes I removed the original fertilizer applications and replaced them with a manure or compost application after a soybean rotation, before a corn rotation, on October 31st of each year. All of the applications were solid and 99% ammonium nitrogen. Beef manure, dairy manure, and chicken manure were 0% moisture and compost was 50% moisture. I calculated the tons per acre of each kind of manure or compost necessary to apply about 120 pounds of nitrogen of acre, given the default percent nitrogen in COMET-Farm.

Results

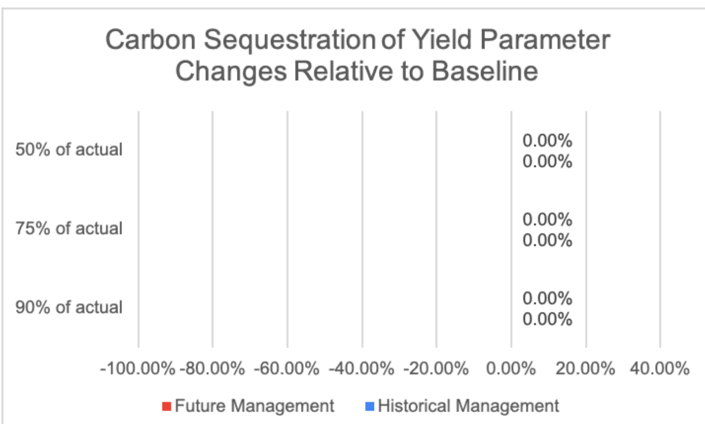
The breakout summary charts represent the percent change of carbon sequestration compared to the baseline numbers, the original outputs from Field 151 before I made any changes to the parameters. The positive numbers show more sequestration (as a percent change) and the negative numbers show less sequestration (as a percent change) compared to the baseline for historical management—which was 111.5 tonnes of CO_2 equivalent per year. The baseline for future management was 134.2 tonnes of CO_2 equivalent per year, or 0.9 t CO_2eq ac^{-1} yr^{-1}.

The future management scenario for Field 151, from 2020 to 2029, adds new practices including switching from synthetic fertilizers to beef manure, adding a cover crop rotation of annual rye-legume-radish, switching to no-till practices, and reducing the number of irrigation dates in a season, as well as the amount of each irrigation event. Because of these changes in future management of Field 151 we are going to see more additional carbon sequestered as compared to the baseline management of the field.

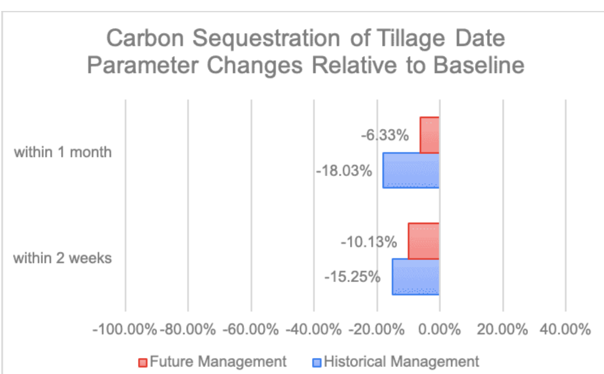


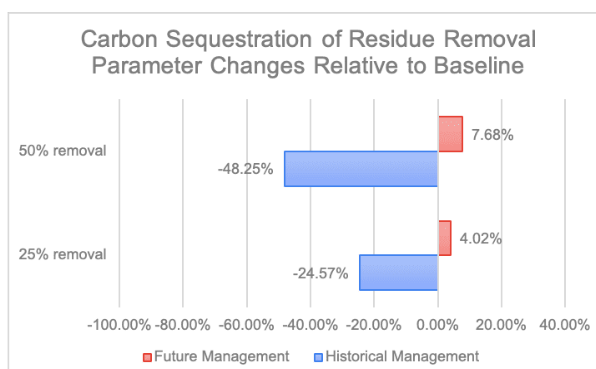


For the charts on Planting Date, Harvest Date, and Tillage Date I changed the dates of planting or harvesting by two weeks or one month, each year switching off between moving the date ahead or behind the original date.

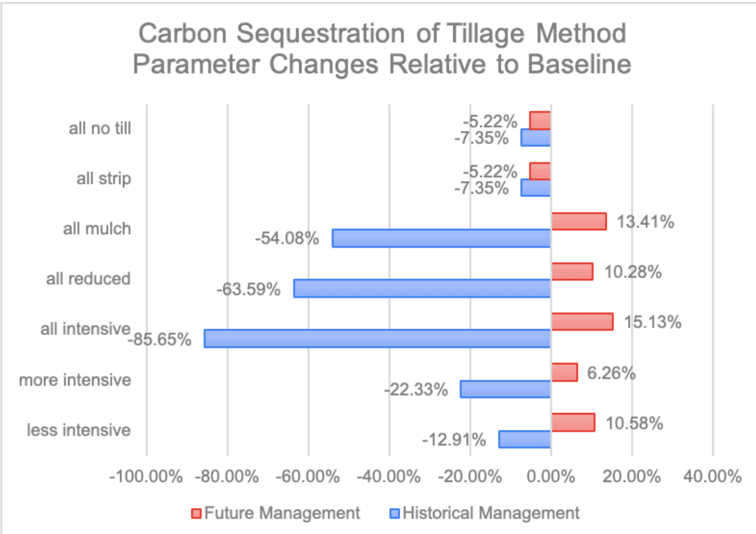


Yield parameter changes additionally revealed no changes to the carbon sequestration in either the future management or the historical management.

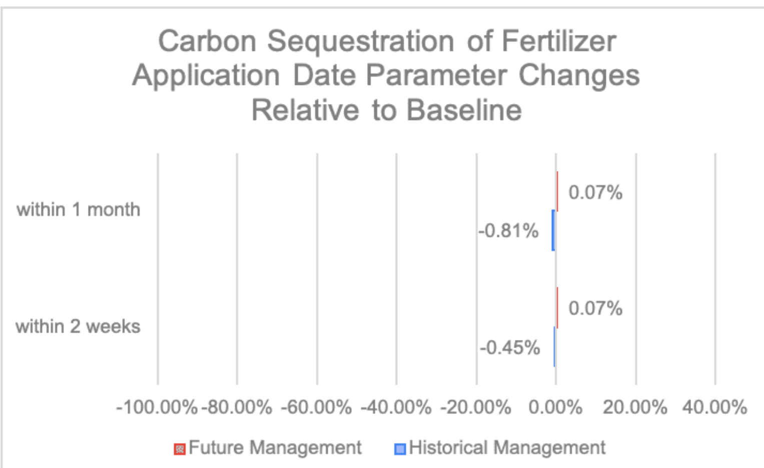




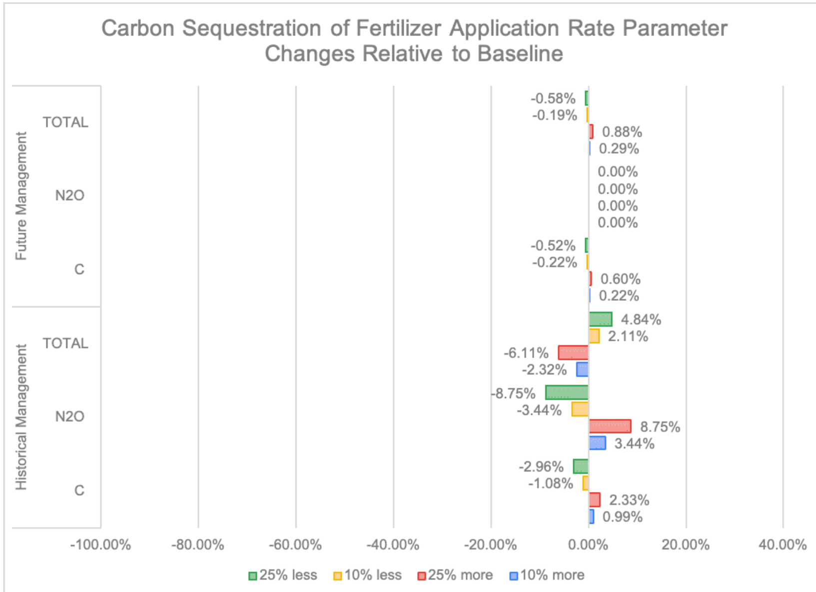
The original baseline amount of residue removal for Field 151 was 0. For these parameters I increased the amount of removal to 25% and 50% to see how the model would respond to more residue removal in the carbon sequestration output.



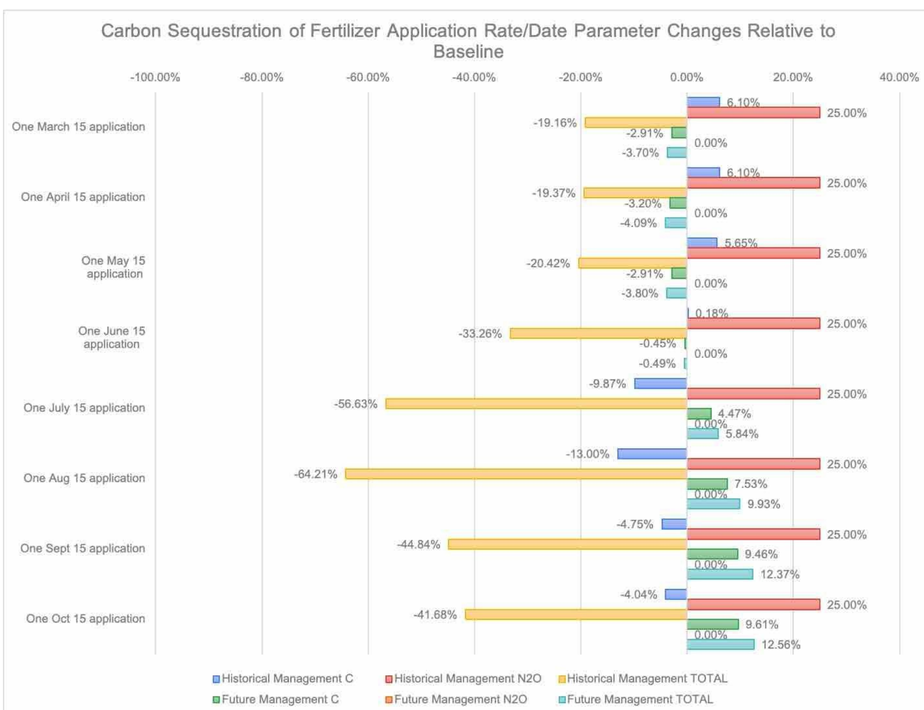
Changes to the tillage method had some of the greatest impacts on carbon sequestration relative to the baseline out of all of the parameter changes in this sensitivity analysis. Changing to all intensive tillage decreased the amount of carbon sequestration from the baseline by more than 85%.



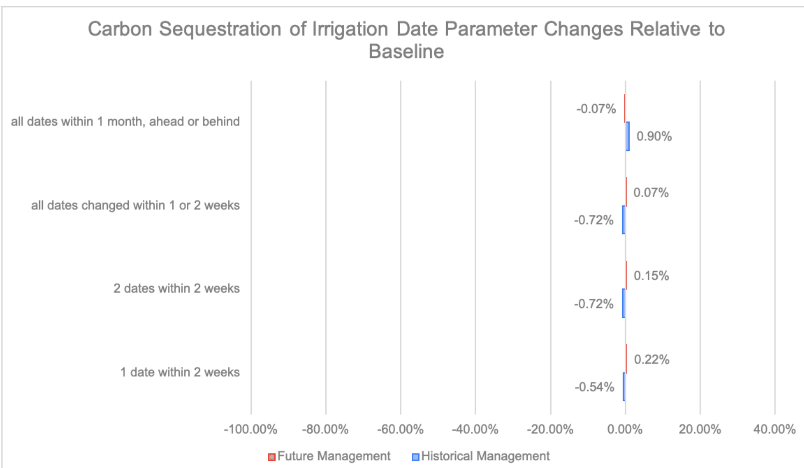
For the fertilizer application date parameter change I changed the date of the fertilizer application or the largest fertilizer application if there was more than one in a season. This parameter change had very little impact on the carbon sequestration numbers.



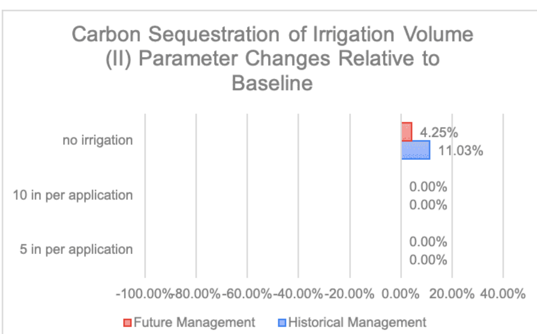
The changes to the fertilizer application rate took the original fertilizer application amount, in total pounds of nitrogen per acre and increased that amount by 10 or 25% or decreased the amount by 10 or 25%. Fertilizer was applied at the time of planting corn, which was roughly every other year. This chart includes N_2O emissions, so it also shows the overall carbon sequestration and the difference between the carbon sequestration and the N_2O emissions, represented as total sequestration.

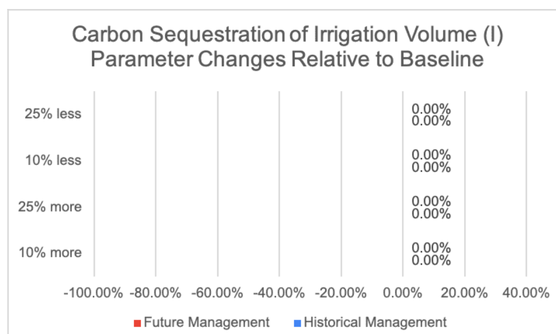


In the Fertilizer Application Rate/Date scenario I changed the fertilizer to one large application of ammonium polyphosphate solution, equivalent to 150 pounds of nitrogen per acre, on the 15th of each month for the years of historical management. In each subsequent scenario I changed the month of the application to see how the month impacted the carbon sequestration outcome from the model. This graph also includes N_2O emissions because the amount of fertilizer was 25% more than the baseline scenario. In addition, I included the total carbon sequestration, which is the amount of carbon sequestered minus the N_2O emissions from that scenario.

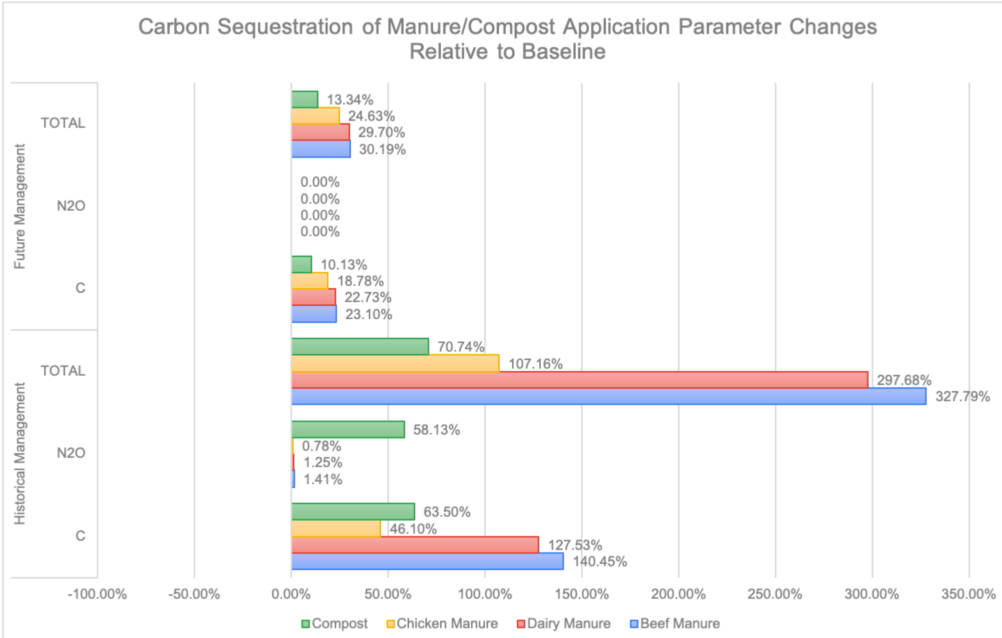


Changes to the irrigation parameters, both date and volume, had very little impact on the carbon sequestration outputs. I conducted three different simulations around irrigation. Changing the dates of irrigation had a very negligible impact - even when the dates were changed by an entire month from the original dates of the irrigation events.



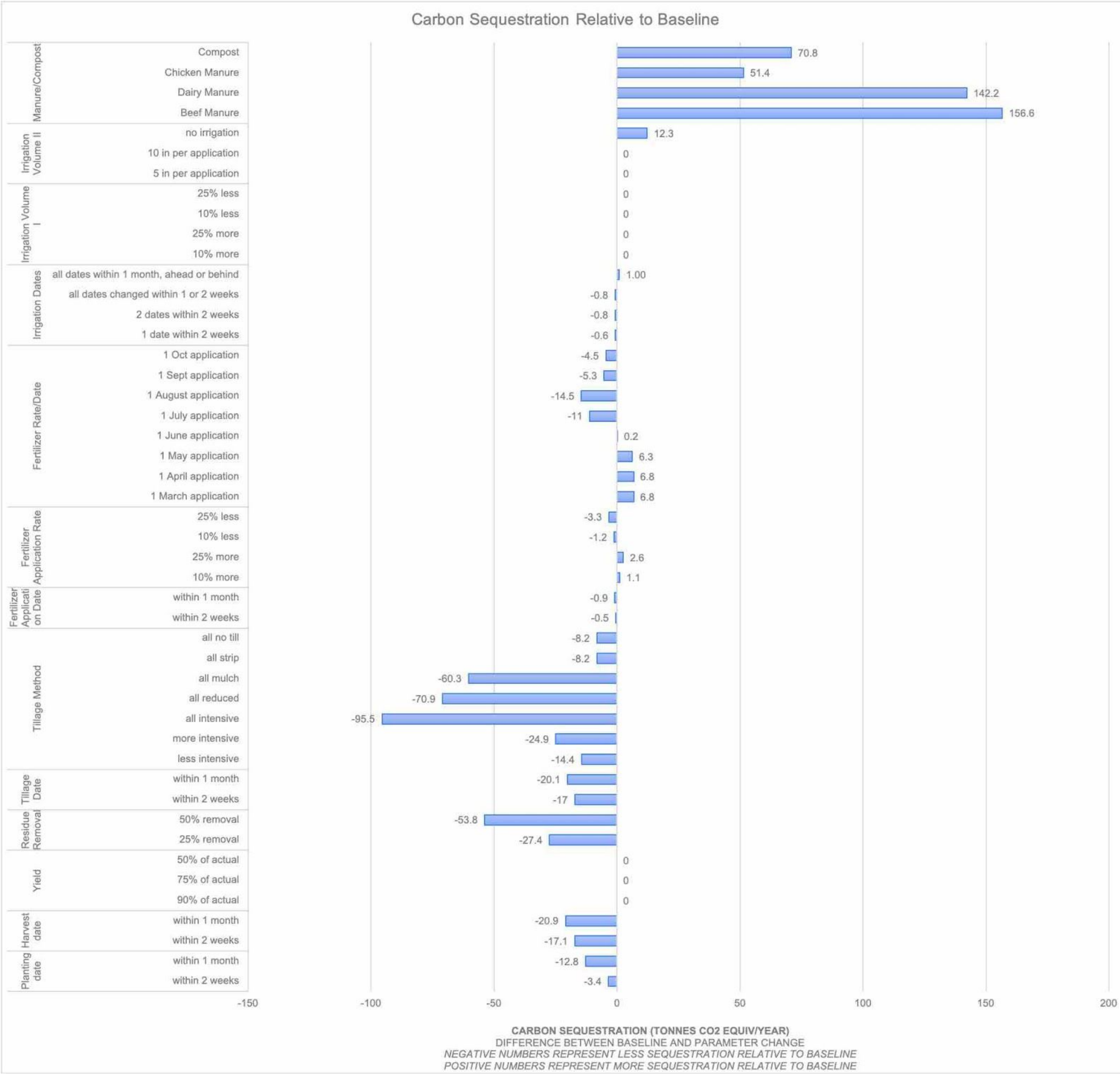


Changes to irrigation volume had no discernible impact on carbon sequestration. Only changing to no irrigation at all increased carbon sequestration by 4.25% in future management and 11.03% in historical management. Even applying unrealistically extreme volumes of 5 or 10 inches did not change the carbon sequestration numbers.



NOTE: The x-axis on this graph goes from -100% to 350% because of the large difference in overall carbon sequestration with the switch to manure and compost.

Switching from synthetic fertilizer application to manure or compost applications had a significant impact on carbon sequestration in this sensitivity analysis. This graph also includes N_2O in order to show the changes in nitrogen for the different kinds of manure and compost, in addition to the total carbon sequestration, which is the difference between the overall carbon sequestration and the N_2O emissions. In this scenario I applied the manure or compost on October 31st of each month, which is the timing for manure application in the future management of Field 151. I put about the same amount of nitrogen with each scenario (roughly 120 pounds of nitrogen per acre) but each kind has a different carbon to nitrogen ratio, which is why the carbon sequestration amounts vary. As shown in the historical management total results, beef and dairy manure have a much higher carbon sequestration rate compared to the baseline, which was only synthetic nitrogen fertilizer inputs.



This chart shows the difference between the carbon sequestration results from the baseline in the historical management of Field 151 and the carbon sequestration from each parameter change from my sensitivity analysis scenarios, rather than percent change, as in the breakout summary charts. The positive numbers represent more carbon sequestration relative to the baseline and the negative numbers show less carbon sequestration relative to the baseline amount.

Discussion

The parameter changes that had the biggest impact on carbon sequestration in historical management of Field 151 were manure and compost application, and tillage method. Replacing synthetic fertilizer applications with manure and compost significantly increased carbon sequestration from the baseline. Switching tillage methods to all intensive tillage significantly decreased carbon sequestration from the baseline.

The parameter changes that had the greatest impact on carbon sequestration in terms of precision are harvest date and tillage date. Changing the dates of these events by two weeks or a month had meaningful impacts on carbon sequestration compared to the baseline. This outcome is useful for users of COMET-Farm to know that precision is necessary for these particular parameters.

It is also worth noting that the parameter changes to fertilizer application date and irrigation date had changes to carbon sequestration that were less than 1% from the baseline numbers. This is a useful outcome for users of COMET-Farm because it shows that in these particular instances, date has a very minimal outcome on the carbon sequestration outputs. If a user doesn't know exact dates for irrigation or fertilizer application, their overall results will not be significantly impacted.

For users of COMET-Farm, especially those working in carbon marketplaces and carbon accounting, they will want to be able to quickly input data with relative accuracy as these fields expand. Currently, inputting data in COMET-Farm is a big lift on the frontend, so this sensitivity analysis is the first step in assessing the precision necessary for these kinds of large amounts of data.

Conclusion

Through this sensitivity analysis project I examined which parameter changes produce the largest results in carbon sequestration, both positively and negatively, and which require the most precision in their inputs. I changed each parameter of the historical management separately to see how the model responded and compare the outputs to the original carbon sequestration and greenhouse gas emissions outcomes. I found that manure and compost application, as a replacement for synthetic fertilizer, produces significant amounts of carbon sequestration. Replacing lower impact tillage with all intensive tillage produces significantly less carbon sequestration.

I ran my sensitivity analysis scenarios on one 149 acre field in Eastern Nebraska that was operating under a corn-soybean rotation. Further study of different management practices, both historical and future, and under a variety of ecosystems and climates, could be useful to see how the model responds to these changes and compare the results to what I found on Field 151. Considering the impact of more regenerative practices over a period of historical management, practices such as cover crops, to see how it affects future management would be interesting for further study.

Resources

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