TECHNICAL MEMORANDUM

FROM: USDA Office of the Chief Economist, Office of Energy and Environmental Policy

DATE: December 14, 2022

SUBJECT: Review of Recent PNAS Publication on GHG Impacts of Corn Ethanol

Executive Summary

In 2022, the *Proceedings of the National Academy of Sciences* published "Environmental Outcomes of the U.S. Renewable Fuel Standard", which we refer to hereafter as Lark et al. 2022. Lark et al. 2022 found that applying their estimate of domestic soil carbon loss associated with ethanol production to the Renewable Fuel Standard (RFS) regulatory impact analysis (EPA 2010) would significantly increase the carbon intensity of corn ethanol, raising the value from being 21.4% lower than gasoline to at least 24.3% higher than gasoline. Lark et al. estimated soil carbon losses are mostly the result of the conversion of Conservation Reserve Program (CRP) land into crop production and foregone cropland retirements. The implied annual losses per acre, however, are likely an order of magnitude larger than what we would expect, given USDA's estimated annual soil carbon gains per acre of CRP grassland.

Based on our review of Lark et al. 2022, we identified three major methodological flaws with the soil carbon calculations:

- Failure to account for cropland-to-cropland conversions that would occur from the increase in corn ethanol demand. This could include, for instance, the transition of land that is moving in-and-out of other row crops into corn production.
- The (mis)classification of CRP land as native or longer-term grasslands in the soil carbon calculations.
- The carbon response functions used by Lark et al. (2022), from Poeplau et al. 2011, are misapplied and overestimate emissions from grassland-to-cropland conversions.

Lark et al. 2022 Findings

Lark et al. (2022) found that the Renewable Fuel Standard (RFS) created demand for 1.3 billion bushels of corn, increased corn prices by 31%, and increased corn acreage by 9% throughout the 2008-2016 time period. This corn area increased most markedly in North and South Dakota, western Minnesota, and the Mississippi Alluvial Plain.

Furthermore, this demand increase led to a 2% increase in crop acreage of 5.2 million acres between 2008 and 2016. Of this, 4.4 million acres occurred from the conversion of pasture or land in the Conservation Reserve Program (CRP) to cropland (a 26% increase beyond business-as-usual). Land abandonment (i.e., cropland area that would have otherwise been converted to pasture or retired in CRP) decreased by one million acres.[1] This is 6% less abandonment than what would have occurred under business-as-usual.

Lark et al. estimated that this expansion in corn production led to a 397.7 million metric ton of carbon dioxide equivalent (MMT CO_2e) increase in greenhouse gas (GHG) emissions from

[1] Lark et al. 2022 reported their findings in hectares, which we convert to acres. The acreage we report doesn't add up exactly (i.e., 4.4 + 1 does not equal 5.2) presumably due to internal rounding issues.

ecosystem carbon releases during the 2008-2016 time period. Of this, they attributed 320.4 MMT CO_2e to the expansion of 4.4 million acres of cropland, while 77.3 MMT CO_2e occurred via foregone sequestration on cropland that otherwise would have gone into CRP or grazed pasture. Lark et al. 2022 also estimated a 32.8 MMT CO_2e increase in nitrous oxide (N_2O) emissions from greater nitrogen fertilizer application.

Discrepancy Between Lark et al. 2022 Findings and USDA CRP Estimates

Lark et al. 2022 focused on two types of transitions: a) between CRP and cropland and b) between pasture and cropland. Lark et al. 2022 is not explicit about the percentage of emissions that occur between these two types of land transitions.

However, the known conversion of pasture to cropland during the 2007-2017 period cannot explain the 4.4 million acre increase in cropland expansion that Lark et al. reports. From Table 1, there were 14.5 million acres that moved between pasture and cropland from 2007 to 2012, and 10.1 million acres from 2012 to 2017 nationally. However, in net, there were 1.2 million fewer acres in cropland from this transition between 2007 and 2012, and there was only a 1.3 million acre increase in cropland between 2012 and 2017. Further, Lark et al. 2022 experienced challenges with modeling these types of land transitions, as their estimated parameter values in the pasture-cropland land use transition were statistically insignificant.

Instead, Lark et al. concludes that the land conversion is predominately occurring from the conversion of CRP land to cropland. In Table 1, there was a net increase in cropland from CRP land of 4.7 million acres between 2007 and 2012, and an additional 4.5 million acres between 2012 and 2017. Lark et al. appears to be attributing a considerable portion of this land transition to corn ethanol demand. We note here that CRP enrollment is set administratively and is independent of the RFS.

If we take this conclusion at face value and calculate the carbon emissions associated with shifting CRP land to cropland, the domestic land-use change (LUC) emissions reported by Lark et al. from this transition are still an order of magnitude greater than what we would expect. The sequence of land use transitions that is implied by Lark et al.'s expansion of cropland from CRP is: cropland → CRP land → cropland. We can conclude that the maximum amount of soil organic carbon (SOC) that could be emitted during the transition from CRP back to cropland cannot exceed the amount of carbon accumulated during the time the land was enrolled in CRP.

If a 320 MMT CO_2e loss in soil organic carbon were to occur on 4.4 million acres, which is what Lark et al. 2022 reports, then this corresponds to 72.7 MT CO_2e/acre soil carbon loss on average. CRP contracts have a length of 10 to 15 years. So, if this land was in CRP for 15 years prior to shifting back to cropland, which is at the upper end of a typical CRP contract, this would imply that this land sequestered 4.85 MT CO2e/acre/year during that time period.

USDA has extensively studied the issue of soil carbon sequestration on CRP land. For comparison, the approach USDA uses to assess CRP, the DAYCENT Model, uses a rate of about 0.4 MT CO_2e/acre/year to score CRP grassland projects. Eighty-three percent of CRP acres were in grassland in 2021. Other relevant analyses show lower organic carbon uptake rates on CRP land (Tyner et al. 2010; Plevin et al. 2014; Scully et al. 2021; Fargione et al. 2008). Therefore, soil carbon losses reported in Lark et al. 2022 from the conversion of land in the CRP into cropland are an order of magnitude larger than the soil carbon parameters that USDA uses to estimate the soil carbon sequestration of CRP land.

The size of this discrepancy with the Lark et al. 2022 findings with other evidence is also apparent in USDA GHG Inventory data. Throughout the 2000-2015 time period, USDA reported annual soil carbon sequestration gain of 4 to 8 MMT CO_2e/year for all U.S. lands enrolled in CRP (Figure 1). If we assume CRP mitigates 8 MMT CO_2e/year (the upper bound of this range) for 15 years, the total amount of carbon accumulated on all CRP lands would be 120 MMT CO2e. By comparison, Lark et al. 2022 reports a SOC emissions loss estimate of 320.4 MMT CO2e, which is 167% greater than the upper bound SOC accumulation on all CRP grasslands using USDA's current methods.

There are two caveats with our calculations. First, some CRP land has been out of crop production for longer than 15 years. For reference, during the 2013-16 time period, 36% of CRP landowners re-enrolled (Bigelow et al. 2020). Second, Spawn-Lee et al. (2021) argue that CENTURY's emission factors, which is the pre-cursor model to DAYCENT, underestimate the GHG benefits of CRP. Nonetheless, even if we assume that 100% of CRP land was out of crop production for 30 years instead of 15 years, Lark et al.'s estimates are too high. (30 years for 100% of landowners is an unrealistic assumption since it would imply that all landowners would have had two or three successive CRP contracts.) Under a 30-year time horizon, Lark et al. would conclude a carbon sequestration rate of 2.42 MT CO_2e/acre/year for grasslands projects, which is still well above other estimates.

Why Does Lark et al. 2022 Report Such High Soil Carbon Losses?

Because of the considerable discrepancy between Lark et al. 2022's findings with USDA data, USDA undertook a review of the Lark et al. 2022 data, assumptions, and modeling framework. Our conclusion of the review is that there are three central reasons why Lark et al. 2022 overestimates the ecosystem carbon emissions from the conversion of land in CRP to cropland.

Two of the reasons pertain to how land is classified, and the third reason is regarding the soil carbon loss function. We note that Taheripour et al. 2022a & 2022b arrived at similar conclusions.

Issues 1 and 2 – Land Classifications

Lark et al. 2022 developed "transition probabilities," the probability of land transitions between cropland, pastureland, and CRP land, using the USDA Natural Resources Conservation Service's National Resources Inventory (NRI) and other data sources. The NRI collects annual land-use data at an array of fixed sample points across the U.S. Since the point-level data from the NRI only indicate the county in which the point is located but not the GIS location, Lark et al. merged other county-level data (such as expected cropland returns, CRP enrollment details, and weather data) to develop the land transition probabilities.

With this approach, one methodological reason Lark et al. overestimated soil carbon losses is that they do not capture land transitions within various types of cropland. Some of these cropland-to-cropland transitions are shown to increase soil carbon levels. For instance, soil carbon levels would increase from the conversion of carbon-depleted land that transitions in-and-out of row crops to no-till or reduced-till corn.

A second reason that Lark et al. 2022 overestimates soil carbon losses is the application of the carbon response functions in Poeplau et al. 2011. Poeplau et al. 2011 is a meta-analysis of empirical measurements of soil organic carbon (SOC) emissions associated with different land use transitions. Poeplau et al. 2011 developed a general "grasslands to cropland" carbon response function, using data from a mixture of grassland, pastureland, and fallow/idle land to cropland transitions. The emission factor developed, however, largely represents a soil organic carbon level for longer-term grassland, which is evident in the high emission estimates in Lark et al. 2022. By applying soil carbon parameters associated with a "grassland-to-cropland" transition to a CRP-to-cropland transition, Lark et al. effectively treats CRP land as long-term or natural grassland. They do this even though most CRP contracts last between 10 and 15 years, which is insufficient time for soil carbon to recover to pre-conversion levels of natural grasslands.

<u>Issue 3 – Carbon Response Functions</u>

A main motivation for Lark et al. 2022 to use spatially explicit soil carbon response functions (developed by Poeplau et al. 2011) to estimate land-use change is that published domestic emission factors for each land cover type only represent national averages. However, the Lark et al. (2022) carbon response functions are also not adequately calibrated to the study region.

Poeplau et al. 2011 compiled 176 observations related to grassland to cropland conversions. However, 27% of these observations are from two Canadian studies that were published in 1945 and 1982. Thus, there are several reasons why the application of the Poeplau et al. 2011 carbon response functions might misrepresent SOC estimates:

- Mean annual temperatures in the two Canadian studies are considerably colder than in the U.S. Midwest states of Iowa, Illinois, and Nebraska. Thus, the "external validity" (i.e., can the study findings be accurately extrapolated elsewhere) of Poeplau et al. 2011 is questionable since mean annual temperature is a critical input into the carbon loss functions.
- Lark et al. 2022 applied the grassland carbon loss functions to depths of 100 centimeters, whereas the 90% confidence interval of soil depths in Poeplau et al. 2011 is 15 to 38 centimeters.

- Thirty percent of the observations in Poeplau et al. 2011 were obtained from studies that predated 1980, and 63% of the grassland to cropland study sites in the US are from 1945 and 1957, when soil sampling and measurement methods were likely less accurate than newer technologies. The tools and methods used to obtain SOC data are integral to developing accurate emissions estimates, and there are likely to be greater uncertainties when using studies that are over 65 years old (Gross et al. 2018; American Society of Agronomy 2018).
- Taheripour et al. 2022a & 2022b found that the carbon response functions used by Lark et al. 2022 overestimate measured soil carbon emissions as compared to independent field measurements. Specifically, Taheripour et al. (2022 a or b) compared the predicted soil carbon losses in Lark et al. 2022 with observed soil carbon losses in Sanderman et al. 2017, which we reproduce in Figure 2. The left panel (A) is the figure produced by Lark et al. 2022, which compares predicted GHG emissions (from Lark et al.) to observed GHG emissions (from Sanderman et al. 2017) from all LUC transitions. If predicted and observed GHG emissions are equivalent, the data points would follow a 45-degree angle (i.e., the slope of the line would equal one) starting from the graph's origin. We see that there is a trend along this 45-degree path, and that the Poeplau et al. 2011 carbon response functions reasonably predict soil carbon emissions relative to observed soil carbon emissions for all land transitions. The right panel (B), however, represents the fit among the subset of grassland-to-cropland transitions. The estimated regression line does not adequately follow the 45-degree path and indicates that the Lark et al. 2022 carbon response functions are systematically overestimating soil carbon losses specifically for the grassland-to-cropland land use change category.

Other Concerns with Approach of Lark et al.

There are some other major concerns with the Lark et al. 2022 study that were highlighted in past critiques of the study. These include:

a) Taheripour et al. 2022a found that Lark et al. 2022 double-counted N_2O emissions from fertilizer usage when appending their LUC emissions to the EPA regulatory impact analysis findings. This is salient as N_2O emissions comprised 8% of Lark et al. 2022's overall increase.

b) The title of the paper implies that Lark et al. 2022 estimates the causal impact of RFS on corn, soybean, and wheat prices. However, Lark models the impact of general corn ethanol demand on prices instead, which was not exclusively influenced by the RFS. There are reasons why corn ethanol demand has increased outside of the RFS, which include other policy supports (i.e., corn ethanol providing an oxygenate after the MTBE ban) and increases in oil/gasoline prices.

c) Lark et al. 2022 does not consider ethanol plant proximity when allocating their derived percent change in land use that is attributable to the RFS as in other studies. Ethanol plant proximity was found to impact the spatial distribution of corn acreage and/or CRP re-enrollment in Brown et al. 2014 and Wright et al. 2017. Lark et al. 2022 allocates the resulting LUC equally within their spatial boundaries, such that each field-level parcel of cropland expansion is assigned a proportion of change that was due specifically to the RFS.

d) Cho and McCarl 2017 showed climate change is pushing corn acres northward into regions like North Dakota, South Dakota, and Minnesota irrespective of biofuels, and this effect was not factored into the Lark et al. 2022 framework.

Conclusion

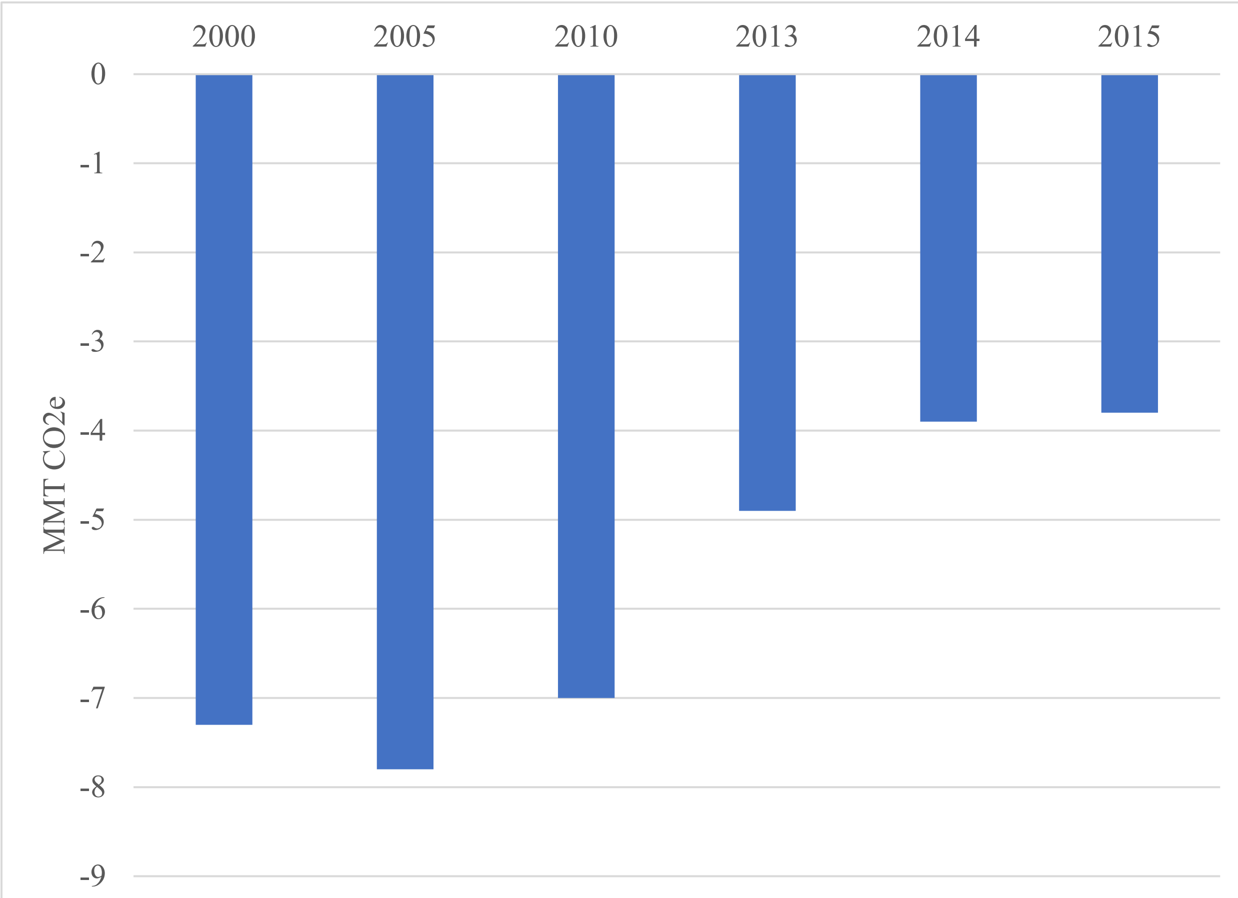
The findings of Lark cannot be corroborated with USDA site level, modeled, or national datasets. On the contrary, our review concludes that the Lark et al. 2022 significantly overestimated soil carbon losses associated with biofuel production and did not clearly demonstrate a link to the RFS.

Table 1. Land Transition Between Cropland, Pasture, and CRP in 5-Year Increments (Million Acres)

	Pasture to Cropland (5 Yrs)	Cropland to Pasture (5 Yrs)	Total Land Moving Between Cropland and Pasture	Net Increase in Cropland
2002	10.1	13.2	23.4	-3.1
2007	6.3	10.8	17.1	-4.4
2012	6.7	7.8	14.5	-1.2
2017	5.7	4.4	10.1	1.3
	CRP to Cropland (5 Yrs)	Cropland to CRP (5 Yrs)	Total Land Moving Between Cropland and CRP	Net Increase in Cropland
2002	6.8	9.1	15.9	-2.3
2007	1.0	3.0	4.0	-2.0
2012	5.8	1.1	6.9	4.7
2017	4.9	0.4	5.4	4.5

Source: USDA 2020.

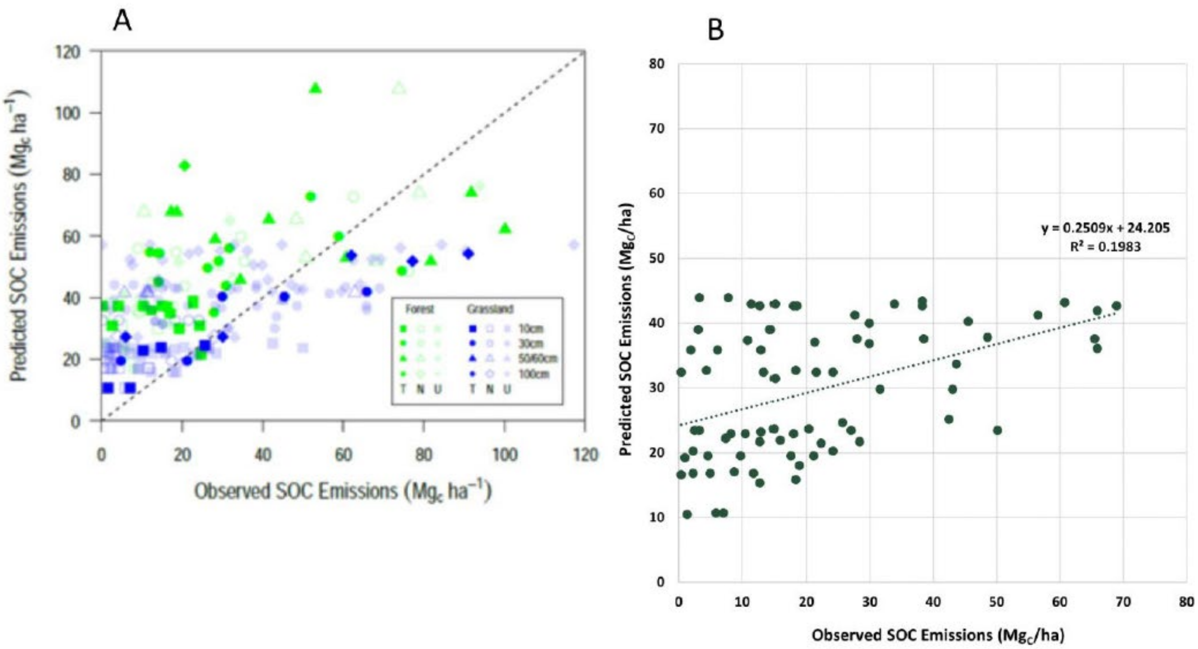
Figure 1. USDA Estimates of Soil Carbon Sequestration from CRP: Values are negative since CRP land is a carbon sink.



Source: USDA 2022.

Figure 2. Comparison of observed and predicted soil carbon changes from Lark et al. 2022

A) All land transitions, B) Subset of grassland → cropland transitions



Source: Figure reproduced from Taheripour et al. 2022a.

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