

1 **Comment on ‘Carbon intensity of corn ethanol in the United States: state of the science’**

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22 **Abstract**

23 Scully *et al* [1] in their recent contribution review and revise past life cycle assessments (LCAs)
24 of corn-grain ethanol's carbon (C) intensity to suggest that a current 'central best estimate' is
25 considerably less than all prior estimates. Their conclusion emerges from selection and
26 recombination of sector-specific greenhouse gas emission predictions from disparate studies in a
27 way that disproportionately favors small values and optimistic assumptions without rigorous
28 justification nor empirical support. Their revisions most profoundly reduce predicted land use
29 change (LUC) emissions, for which they propose a central estimate that is roughly half the smallest
30 comparable value they review (Figure 1). This LUC estimate represents the midpoint of (i) values
31 retained after filtering the predictions of past studies based on a set of unfounded criteria; and (ii)
32 a new estimate they generate for domestic (i.e. U.S.) LUC emissions. The filter the authors apply
33 endorses a singular means of LUC assessment which they assert as the 'best practice' despite a
34 recent unacknowledged review [2] that shows this method almost certainly underestimates LUC.
35 Moreover, their domestic C intensity estimate surprisingly suggests that cropland expansion newly
36 sequesters soil C, counter to ecological theory and empirical evidence. These issues, among others,
37 prove to grossly underestimate the C intensity of corn-grain ethanol and mischaracterize the state
38 of our science at the risk of affecting perverse policy outcomes.

39

40 **Key Words:** Land use change, corn ethanol life cycle assessment, land intensification, co-
41 products, yield price elasticity, soil carbon, CCLUB, GREET

42

43 **Introduction**

44 The carbon intensity (CI) of corn grain ethanol has long been assessed and debated due, in part, to
45 its inherent uncertainty and its regulatory implications for policies like the U.S. Renewable Fuel
46 Standard (RFS) and the California Low-Carbon Fuel Standard [3–9]. The CI of corn ethanol
47 represents the estimated life cycle greenhouse gas (GHG) emissions associated with burning a unit
48 of ethanol as fuel. It additively accounts for emissions and offsets associated with all aspects of
49 ethanol use and production, including those associated with on-farm biofuel feedstock production
50 and any direct and indirect land use change (LUC) that results from feedstock demand. In their
51 recent review, Scully *et al* [1] select and revise past emissions estimates for each of these
52 components and combine them into an aggregated value they present as a ‘central best estimate’
53 of U.S. ethanol’s total CI. Yet, their proposed value proves to be considerably smaller than all
54 prior estimates, an outcome that primarily results from their profoundly reduced estimate of LUC
55 emissions (Figure 1).

56 Emissions from LUC have persistently been one of the most uncertain elements of
57 ethanol’s GHG profile [7,8,10]; their estimation requires that the patterns of LUC be predicted or
58 observed and compared to the predictions of a counterfactual scenario representing expected
59 outcomes absent bioenergy policy. To date, this has largely been accomplished using partial or
60 computable general equilibrium models (hereafter “P/CGEs”) which simulate part or all of the
61 global economy, respectively, to predict LUC in the presence and absence of bioenergy policy. In
62 their review of LUC estimates, Scully *et al* exclusively consider P/CGE predictions and endeavor
63 to identify those which are ‘best’. However, they dismiss that variation among past predictions
64 reflects the vetted diversity of relevant thought by asserting a single method they favor and
65 rejecting all non-compliant predictions. We contend that impartial valuation of past predictions

66 instead necessitates a rigorously objective, empirical basis. To do less is to merely add to the
67 existing diversity of opinion.

68

69 **Unjustified selection of past land use change estimates**

70 Scully *et al* present a set of P/CGE-based LUC estimates and then assert as justification for
71 selective consideration that “*variability among the[se] LUC estimates stem primarily from*
72 *differences in the four major elements that comprise these [carbon intensity] values: the agro-*
73 *economic model, economic data year, yield price elasticity, and land intensification.*” Despite
74 offering no statistical evidence that these four criteria are the primary determinants of variability
75 (see Supplemental Discussion 1), they operationalize them as selection criteria they call “best
76 practices” and use them to reject non-compliant studies from further consideration. For each
77 practice, they state a modeling configuration that they believe to be optimal—though they offer no
78 rigorous scientific basis for these choices (see Supplemental Discussion 2)—and then they assess
79 studies’ binary compliance with each. Accordingly, they require that LUC predictions be generated
80 using (i) the GTAP-BIO computable general equilibrium model, with (ii) an economic data year
81 of 2004, (iii) a yield price elasticity between 0.175 and 0.325, and (iv) include additional treatment
82 of “land intensification”. These requirements distill to an unsubstantiated endorsement of a
83 singular treatment of cropping-intensification in ethanol life cycle assessment (LCA); one that was
84 explicitly discussed in an unacknowledged review by Malins *et al* [2] that showed it almost
85 certainly underestimates LUC by overestimating agriculture’s capacity to intensify production on
86 existing cropland (see Supplemental Discussion 2).

87 When applied to the studies Scully *et al* initially consider, these criteria systematically
88 eliminate those reporting all but the smallest LUC emissions without adequate justification (see

89 Supplementary Discussion 2). Requiring use of GTAP is a necessary precondition of the
90 subsequent criteria; requiring 2004 as the economic data year arbitrarily mandates use of outdated
91 data [11] and specifically dismisses GTAP studies reporting high LUC estimates; and requiring
92 explicit treatment of ‘land intensification’ in addition to a relatively high yield price elasticity that
93 implicitly accounts for some of the same process [12] likely double-counts intensification
94 responses to bioenergy demand and thus underestimates rates of LUC [2]. Ultimately, select
95 elements of just two of the 16 studies Scully *et al* initially reviewed comply with these criteria: (i)
96 the smallest of the four total-LUC prediction reported by Taheripour *et al* [11]; and (ii) one
97 domestic and two international LUC predictions reported in the ICF report that Scully *et al* most
98 consistently reference as Rosenfeld *et al* [13], and which are simply the LUC results from one of
99 the two corn feedstock scenarios (“Corn Ethanol 2013”) provided in the Argonne National
100 Laboratory’s (ANL) GREET LCA model. Notably, Taheripour *et al* repeatedly describe the value
101 selected from their study as a heuristic based on outdated data and do not endorsed it [11]; instead,
102 they endorse a larger value that Scully *et al* reject for its use of a more recent economic data year.
103 Likewise, Scully *et al*’s retention of just one GREET scenario also appears to be a specific and
104 unsubstantiated endorsement of that which predicts the lowest LUC emissions.

105

106 **A new, self-calculated and unrealistic estimate of domestic land use change emissions**

107 In addition to their use of these selection criteria, Scully *et al* also generate their own domestic
108 LUC emissions estimate using CCLUB—the LUC emissions accounting framework in GREET
109 [14]—which oddly predicts that gross domestic cropland expansion results in soil C sequestration.
110 This prediction is particularly curious because soil C is generally lost upon converting perennial
111 vegetation to annual cropland regardless of the land use history or subsequent tillage regime [15–

112 21] and U.S. cropland is no exception. More broadly, the authors' inclusion of a self-calculated
113 data-point is also surprising for a self-described 'review' and is accompanied by little explanation
114 nor any validation (see Supplementary Discussion 3).

115 We recreated the CCLUB configuration used by Scully *et al* and found that they only report
116 the most anomalous prediction generated for the management assumptions they adopt (Figure 2).
117 CCLUB allows users to pick from two corn-specific LUC scenarios that predict the extent of LUC
118 resulting from bioenergy demand, and three distinct sets of emissions factors (EFs)—the so called
119 “Winrock,” “Woods Hole,” and (for domestic LUC only) “CENTURY/COLE” (hereafter
120 “CENTURY-based”) EFs—that represent the expected loss or gain of ecosystem C stocks per unit
121 area following LUC. While CCLUB asks users to select a set of EFs, the results of all three are
122 reported side-by-side in the model output. Only when the CENTURY-based EFs are used with the
123 ‘Corn Ethanol 2013’ scenario—the authors’ specification—does CCLUB predict net C
124 sequestration from domestic LUC (Figure 2).

125 The Corn Ethanol 2013 feedstock scenario predicts that ‘cropland-pasture’ comprises the
126 vast majority (1.7M ha; 92%) of land converted from non-use to corn production and it is cropland-
127 pasture conversion in particular for which the CENTURY-based EFs invariably predict
128 sequestration (Figure 2). While CCLUB does not explicitly identify the lands it presumes
129 cropland-pasture to encompass, it inherits the ambiguous class from GTAP which defines it as
130 land “*in long-term crop rotation which is marginal for crop uses*” [22] following the USDA’s
131 definition for it as land that is “routinely rotated between crop and pasture use... and may remain
132 in pasture indefinitely” [23]. Cropland-pasture is therefore, by definition, land that has been
133 removed from annual cultivation for some indeterminate time and is thus akin to those enrolled in

134 the CRP—a U.S. federal program that retires land from production for the duration of at least one
135 10- or 15- year contract.

136 Yet, the treatment of cropland-pasture underlying the CENTURY-based EFs instead
137 assumes that it has been cultivated for 25 years prior to its conversion to corn production. Unlike
138 the other two sets of EFs, which are based on summaries of empirical data, the CENTURY-based
139 EFs are based on the predictions of a biophysical model—a variant of the popular CENTURY
140 model—that simulates SOC stocks and their responses to LUCs. The EF's reported in CCLUB
141 represent the average annual SOC changes (losses or gains) ensuing from these simulated
142 transitions and are reported for each U.S. county. Like most biophysical models, CENTURY
143 requires that SOC stocks be 'spun-up'—a necessary technical procedure that predicts baseline
144 SOC stocks based on a prescribed land use history. For their spin-up of cropland-pasture, the
145 CCLUB developers prescribed a proximate history of “*50 years as cropland followed by 25 years*
146 *of pasture and 25 years of cropland*” [24].

147 By simulating the most recent 25 years of cropland-pasture as cropland, this treatment,
148 effectively pre-depletes the simulated baseline SOC stocks such that when cropland-pasture is
149 subsequently converted to corn production in the model, its SOC is predicted to respond similar to
150 converting generic 'cropland' to corn production (Figure 3 & S1). Indeed, the CENTURY-based
151 EFs for cropland-pasture and cropland conversion are statistically indistinguishable when effects
152 are considered to a maximum depth of 30 cm, and only slightly distinct when considered to a
153 greater depth of 100 cm (mean < 0.04 MgC ha⁻¹ yr⁻¹; $\alpha = 0.05$; Table S1). For both cropland-pasture
154 and cropland, the CENTURY-based EFs oddly predict that their conversion sequesters SOC
155 regardless of the accompanying tillage and yield assumptions (Figure S1, Table S1). While a meta-
156 analysis of empirical studies by the CCLUB developers and others suggests that crop rotations

157 containing corn may sequester small amounts of C over time [20], it does not show this in the
158 context of LUCs like cropland-pasture conversions to corn, nor even when generic cropland on
159 which corn is rotated with other crops is converted to a continuous corn rotation [25]. Moreover,
160 while there exists tremendous variance among observed responses [20], CCLUB's county-level
161 CENTURY-based EFs for conversion of cropland and cropland-pasture to corn exhibit little
162 variance and similar rates of C sequestration in virtually all U.S. counties (Figure 3 & S1).

163 To our knowledge, there exists no empirical evidence supporting the proposition that
164 cropland-pasture conversion to corn production generally enhances SOC stocks. While the breadth
165 and ambiguity of cropland-pasture's definition admittedly confounds direct comparison with
166 empirical studies, land leaving the CRP, for one, falls within the purview of cropland-pasture and
167 has been estimated to account for ~30% of RFS caused domestic LUC [26]. Field studies assessing
168 SOC changes after recultivation of CRP lands consistently report either net emissions or
169 indeterminate change [19,27–31], with estimated SOC losses as high as 154 MgCO_{2e} ha⁻¹ when
170 CRP land is converted to a corn-soy rotation managed with conventional tillage [29]. Conversion
171 to no-till management results in lower but still substantial GHG costs [19]. We know of no studies
172 reporting net gains. These emissions reflect the tendency of abandoned croplands to recover SOC
173 to varying degrees during their retirement that can later be lost if re-cultivated [16,32–40].

174 Had Scully *et al* instead or further considered CCLUB's Winrock-based estimate, they
175 would have reported a less optimistic CI estimate for domestic LUC of +8.7 gCO_{2e} MJ⁻¹ (Figure
176 2)—a value more in line with many of the estimates they dismissed, and a contemporaneous study
177 in *Environmental Research Letters* [41]. The Winrock EFs calculate cropland-pasture emissions
178 as simply one-half the estimate generated using the corresponding pasture/grassland EFs. Despite
179 its simplicity, this approach may more accurately represent the C dynamics of cropland-pasture

180 conversion by implicitly assuming higher levels of vulnerable SOC upon initiation of corn cropping.
181 Adding this Winrock-based estimate, for the sake of example, to Scully *et al* 's international LUC
182 estimate (6.0 gCO_{2e} MJ⁻¹)—which, itself, is likely an underestimate given the selection criteria by
183 which it was obtained—yields an estimated total-LUC C intensity of 14.7 gCO_{2e} MJ⁻¹; a value
184 nearly four-times larger than the total-LUC value proposed by Scully *et al* as a 'central best
185 estimate' and comparable to the raw median of estimates they initially reviewed (Figure 1). Scully
186 *et al* recommend that, "*future studies conduct a thorough review of the various emissions factors*
187 *to assess the validity of their assumptions and functions*". We reaffirm this recommendation but
188 add that, in the absence of such an assessment, reporting the range of possible outcomes ought to
189 be considered the minimum reporting standard.

190

191 **Misconstruing the state of the science**

192 Scully *et al*'s 'central best estimate' of total-LUC emissions is less than even the smallest
193 such estimate they initially reviewed (Figure 1). This statistical feat is only possible because they
194 first, when able, parse the domestic and international estimates of studies and then treat them as
195 being entirely independent when subjecting them to the aforementioned selection routine that
196 rejects nearly all but the smallest estimates of each. They then calculate a 'credible range' of total-
197 LUC estimates by combining the smallest disparate domestic and international estimates to define
198 the lower bound of their range (-1 gCO_{2e} MJ⁻¹), and by defining its upper bound as the retained
199 estimate of Taheripour *et al* [11] (8.7 gCO_{2e} MJ⁻¹), which is the largest possible value compliant
200 with their selection criteria. The value they present as a 'central best estimate' is the midpoint of
201 this range (3.85 gCO_{2e} MJ⁻¹) and is less than half the estimate of Taheripour *et al*—the smallest

202 peer-reviewed total-LUC estimate the authors initially reviewed—though, again, Taheripour *et al*
203 expressly renounced this estimate as outdated and instead favor a larger value [11].

204 The more general approach used by Scully *et al* and some of the non-peer-reviewed
205 analyses they consider [13,42] of deconstructing and recombining elements of disparate LCAs
206 belies the scientific intent of LCA and may ultimately miscount emissions. LCA is, by its nature,
207 an integrated science in which the assumptions underlying system elements and boundaries are to
208 be treated consistently throughout. When LCAs are instead deconstructed and recombined,
209 assumptions can get lost or conflict among recombinant elements. Scully *et al*, for example,
210 assume a large degree of cropping intensification in their treatment of LUC, which presumably
211 requires additional fertilizer and amendments that would increase emissions from the ‘farming’
212 sector. Yet, because they determine farming emissions separately as the mean of a GREET-based
213 estimate and their own revisions toecoinvent, their estimate does not appear to account for these
214 additional intensification emissions. In fact, Scully *et al* laud GREET’s recently *reduced* estimates
215 of fertilizer usage, and they, themselves, revise downward ecoinvent’s relatively high emissions
216 estimate for irrigation based on their own unrepresented analysis of USDA-reported water use
217 trends. These revisions appear to diminish the chance that their farming estimate even
218 coincidentally captures some of the emissions from the intensification they implicitly assume.
219 Moreover, since their LUC prediction is itself the mean of four disparate predictions from two
220 studies and their own self-calculated value—each with distinct assumptions—it is not clear how
221 one would even determine the precise acreage or type of intensification assumed. To avoid these
222 ambiguities and maintain coherence, earnest LCA as a discipline has increasingly embraced
223 sensitivity and uncertainty analyses, rather than piecemeal selection, as a means of better
224 understanding—rather than erasing—variance [7,43,44].

225 Scully *et al* provide neither a comprehensive nor an impartial review. As we have shown,
226 well-established concerns are not acknowledged nor discussed. Instead, assertions are made either
227 without support or are ostensibly supported by unvetted analyses. When discussing LUC in the
228 U.S., for example, they cite a single, second-hand account of a non-peer-reviewed conference
229 presentation to claim that “*agricultural land area declined by 38 million acres [between 2002-*
230 *2017]*” [45]. Yet, using those same USDA data, Lark *et al* [46] showed instead that cropland
231 underwent a net expansion after implementation of the RFS by as much as 13.9M acres (between
232 2007 - 2017; see Supplemental Note 2 and Table S7 in [46]). Moreover, Lark *et al* [46] further
233 corroborated their findings with three independent data sources and ultimately favored a smaller
234 net estimate of 6.5M acres between 2009-2016. Separate peer-reviewed studies have estimated
235 similar recent rates of net expansion using a range of data sources [26,47–50] as has a
236 comprehensive review of biofuel-relevant LUC by the US Environmental Protection Agency [51],
237 yet none of these antithetical studies are acknowledged by Scully *et al*.

238 In all, the C intensity estimate of Scully *et al* for corn-grain ethanol is hardly credible. It is
239 based on a flawed assessment that systematically disqualifies high estimates without cause, a new
240 self-calculated estimate that contradicts empirical observation and can be explained by a semantic
241 contradiction, and an inconsistent general methodology that belies the science it seeks to emulate.
242 While we do not claim to know the true C intensity of corn ethanol, we strongly assert that the
243 estimate of Scully *et al* should not be interpreted as such. It grossly mischaracterizes the land
244 system, our means of understanding it, and, ultimately, the state of our science. In so doing, it has
245 the potential to spawn perverse policy outcomes by attributing far greater climate benefits to the
246 production and use of corn grain ethanol than can be supported by current evidence.

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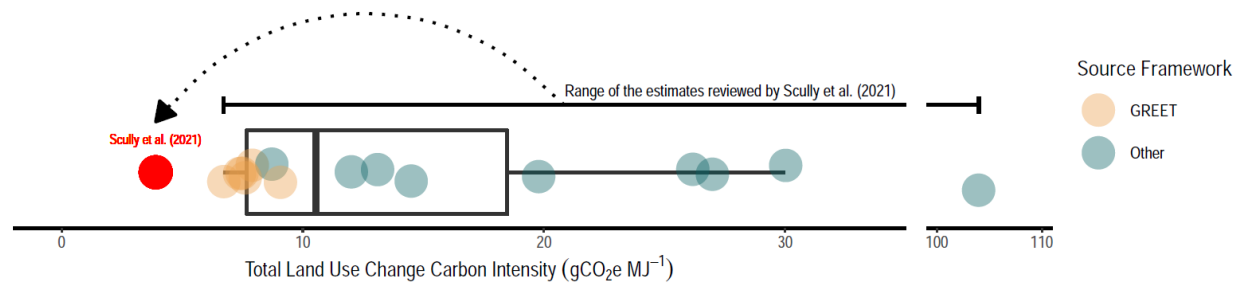
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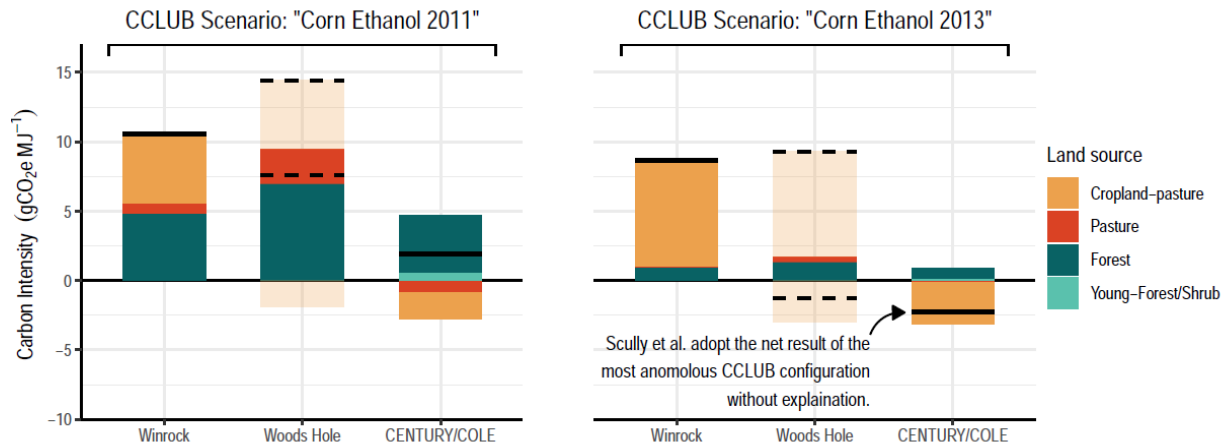
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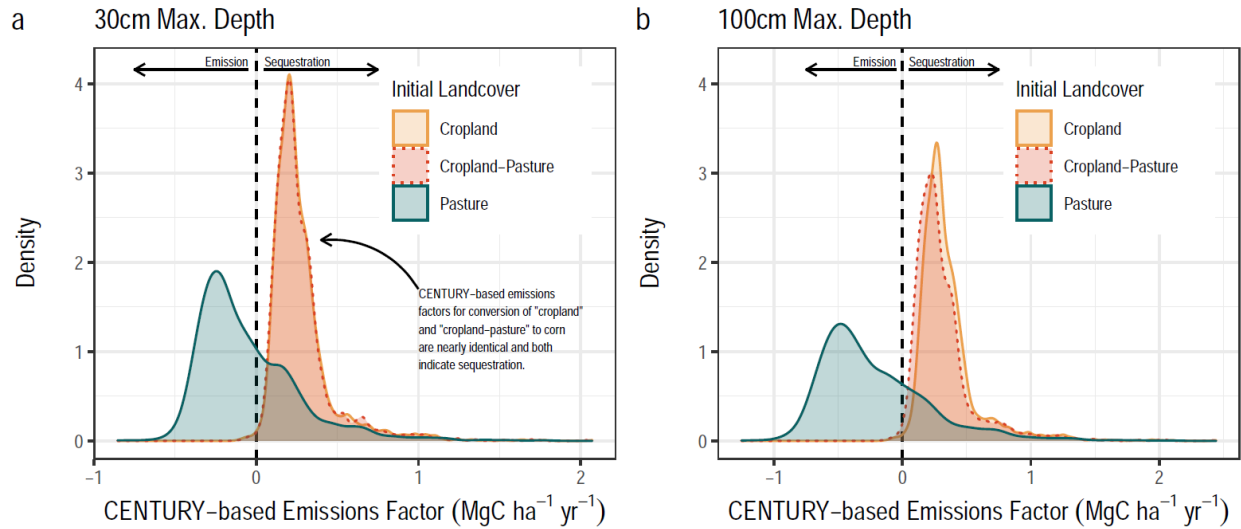
376 **Figure 1.** Boxplot showing the total (i.e. international + domestic) land use change carbon intensity
 377 estimates of all the studies initially considered by Scully *et al.*, as well as the much lower estimate
 378 they advance after reviewing these studies. These values were taken from figure 2 of Scully *et al.*
 379 When a study reported parsed international and domestic estimates, we combined them into a
 380 single ‘total’ estimate when possible and excluded estimates (n = 11 of 26) from which a total
 381 estimate could not be obtained. Predictions are colored to illustrate the disproportionate
 382 representation of GREET-based estimates (this includes studies authored by primary GREET
 383 developers and the so-called “USDA 2018” study which also uses GREET). The width of the box
 384 represents the interquartile range of the 15 estimates, their median is denoted by the vertical middle
 385 line, and their 95th percentile range is shown as the affixed whiskers. The full range of the
 386 estimates reviewed is indicated by the bracket above the boxplot. Points have been randomly
 387 jittered vertically to enable visualization of overlapping data points.

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389

390 **Figure 2.** Varied carbon intensity of land use change estimates resulting from CCLUB’s two corn
 391 ethanol feedstock scenarios (“2011” and “2013”) and its three emission factor (EF) options
 392 (“Winrock”, “Woods Hole”, and “CENTURY/COLE”), all else being equal to the specifications
 393 used by Scully *et al.* Positive and negative values indicate emissions and sequestration,
 394 respectively. The emission/sequestration contribution of each land source is parsed by color and
 395 the net effect is noted as a horizontal black line. The Woods Hole EFs do not include an estimate
 396 for cropland-pasture conversion (it simply omits these emissions) so we show the net effect of
 397 adding either the corresponding Winrock or CENTURY/COLE-based cropland-pasture estimate
 398 as dashed horizontal lines. Of the six comparable estimates, Scully *et al* choose the only one that
 399 suggests sequestration, without acknowledging the others nor the relative dissimilarity of their
 400 choice.



401

402 **Figure 3.** Density distributions of CCLUB's CENTURY-based county-level soil C emissions

403 factors (EFs) for conversion of cropland, cropland-pasture, and pasture to corn production under

404 one of CCLUB's tillage/yield scenarios (plots for all 16 tillage/yield scenarios are included as

405 Figure S1 and all show the same general pattern). CCLUB provides two estimates for each

406 tillage/yield scenario: one considering effects to a maximum soil depth of 30cm (left) and the other

407 to 100cm (right). Due to the similar way in which their initial SOC stocks are spun-up, EFs for

408 cropland-pasture and cropland conversions are remarkably similar to each other yet distinct in both

409 sign and magnitude from those of pasture (i.e. grasslands). When considered to a depth of 30cm,

410 cropland and cropland-pasture EFs are statistically the same (Table S1) and, visually, their

411 distributions directly overlap; when considered to a depth of 100cm, they are statistically-distinct,

412 but both still report that significant rates of C sequestration ensue from LUC.

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426 **Conflicts of Interest**

427 The authors declare no conflicts of interest.

428 **Data and Code Availability**

429 Code and data associated with all figures and analyses presented are freely accessible through
430 GitHub (https://github.com/sethspawn/erl_response_2021.git). Data presented in our Figure 1 and
431 S2 were taken directly from Figure 2 and Table S1 in Scully *et al* (2021) and can be viewed in the
432 file “data_from_scully_fig2.csv” in our GitHub repository. Data presented in our Figures 2, 3, S1
433 and S3 and Table S1 were generated using the “CCLUB_2020_for_GREET1_2020.xlsm” file
434 included with the 2020 version of the GREET Excel Fuel-Cycle model [52] as described in the
435 text. Data used in our analysis of CCLUB’s CENTURY-based emission factors were taken directly
436 from the “C-Database” sheet of the “CCLUB_2020_for_GREET1_2020.xlsm” file.

