Supplementary Material

**­Implementing the Soil Enrichment Protocol at Scale: Opportunities for an Agricultural Carbon Market**

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# Permanence of agricultural carbon credits in the SEP is managed using aggregated project accounting and programmatic mechanisms.

CAR requires that projects storing carbon in biological systems maintain the carbon pool for a period of 100 years following the year of the quantified project activity (CAR 2021). Release of stored carbon for which the project has already been credited is considered a “reversal.” For a forest project, permanence is considered for the entire forest rather than for individual trees. Similarly, an aggregated cropland project under the SEP employs GHG accounting at the project level. This means that interannual fluctuations at the field level will “net out” at the project level. However, field-level accounting does come into play in the event of significant natural events (i.e., “unavoidable reversal events”) or fields that are removed from the project (i.e., “avoidable reversals”). In the case of reversals, there are programmatic mechanisms to “make the system whole” in ways that protect the integrity of any credits already sold and/or retired (i.e., used) for credit buyers. Thus, buyers never have to worry about a reversal of their own offsets.

The SEP employs a standardized assessment of the risk of unavoidable reversals, such as a flood which removes significant topsoil from the project area. This assessment is described in detail in Section 5.3.1 of the SEP (CAR 2020). The 100-Year permeance period is among the highest standards for carbon removals and is used by the Climate Action Reserve, California Air Resources Board (CARB), and Verra, among others. The assessment in the SEP considers natural reversal risk, geographic spread of the project activity, whether or not the project developer is a private or public entity, and if the project employs a financial mechanism to ensure against reversals (e.g., insurance). The final risk calculation, between 5% - 16.9%, represents the fraction of soil carbon-related credits which are deposited into the registry’s shared risk buffer pool account. If an unavoidable reversal occurs, the project developer is required to present the registry with an accounting of the affected acres and the soil carbon credits which have been issued to those acres. The registry will then retire a commensurate number of credits from the buffer pool.

Since SEP projects can use aggregated project accounting to handle interannual variability due to weather and management decisions, the main source of avoidable reversals will be the removal of fields from the project. If a field exits the program, the project developer can continue remote monitoring and annual reporting on the permanence of the soil carbon on that field. Indigo may use publicly available satellite data to detect significant management, such as crop type, planting, harvesting, tillage, and land conversion (Sulla-Menashe et al. 2019; Indigo Ag 2020). If management changes are detected that would result in a release of soil carbon, the quantification and reporting responsibilities are the same as with unavoidable reversals, above. However, the compensation for the reversal comes from the project developer, rather than the buffer pool. This remote monitoring may be used on all fields following the end of the crediting period. The SEP offers the possibility of the project developer seeking approval for an alternative compensation mechanism, such as an insurance product, which would compensate for reversals for the remainder of the 100-year permanence period.

One last consideration for permanence of stored carbon is the effect of tonne-year accounting (TYA). TYA works on the premise that the atmospheric benefit (the avoided radiative forcing had the carbon been released to the atmosphere as carbon dioxide) of the stored carbon is not a step-wise function (i.e., 0% benefit for 100 years and then 100% benefit thereafter) (Fearnside 2002). Rather, it is a continuous function, conceptually modeled after the decay curve of CO2 molecules in the atmosphere. For simplicity, the Reserve uses a linear function, recognizing 1% of the atmospheric benefit of the carbon storage every year out to year 100 (CAR 2020). This means that a reversal at year 50 will have roughly half the penalty of a reversal in year 2. Conversely, project developers may elect to apply the TYA approach to the actual credit issuance. In the most extreme example, a project developer could make no up-front commitment to permanence, but in return only receive 1% of their credits for each year that they maintain permanence. This approach to accounting is generally not financially attractive, but it does open the opportunity for different types of entities with different appetites for risk and reward to design a SEP project that fits their own business profile while protecting the atmospheric integrity of the resulting credits.

# The SEP enables improved baselining by using an ensemble of model runs.

# A key advance of the SEP is allowing the use of an ensemble of model runs to create a “blended baseline" as described in Section 3.4.1.4 (CAR 2020). For a given field, there is a thread for every possible rotation of crops in the baseline at each stage (i.e. Baseline 1: Corn → Soy → Wheat, Baseline 2: Soy → Wheat → Corn, Baseline 3: Wheat → Corn → Soy). If external market forces or weather drive a grower to change the cash crop planted in any particular year (e.g., choose to follow corn with corn instead of soy), the project scenario would be compared to a blend of all possible rotations to try to account for this variation. The alternative would be to ignore that these changes happen and compare a baseline Soy year to a project Corn year. In this case there may have been carbon gains that were due to the crop (which was planted to meet market demand) and may not be a result of management, potentially leading to over crediting. The blended baseline mitigates this risk.

# Continued research enables further improvement to the quantification of credits by reducing uncertainty, improving validation data for models, and the full accounting of GHG emissions and carbon sequestration from agriculture.

To better understand the implications of more sampling (in space, in time, and in depth) on our approach to quantification, as well as to better elucidate the effects of the simultaneous use of multiple regenerative practices on soil health, field productivity, and grower profitability, Indigo launched a long-term research effort – the Soil Carbon Experiment. In the Soil Carbon Experiment, fields are sampled more intensively than in the larger SEP project. For example, SOC samples are collected a higher spatial density (1 per 5 acres for soil organic carbon [SOC]), a more frequent interval (annually), with greater segmentation (0-15 cm and 15-30 cm), at greater depth (a subsample of points are taken down to 1 m), and tested on a greater diversity of metrics (soil nutrients, soil respiration, and wet aggregate stability are measured at points in addition to SOC and bulk density [BD]). This density of sampling generates rich datasets to understand chemical, physical, and biochemical properties of soil. Additionally, we collect detailed management history, economic information, and qualitative information about grower’s experiences with and attitudes towards specific practices. Indigo intends to share the results of this study publicly through peer-reviewed publications and to make the data available to researchers with adequate safeguards to protect the privacy of growers involved in the study. These data, in combination with data from the SEP project fields, and the ever-expanding literature, enable us to constantly improve our quantification approach.

**Improvements in lab-based soil analysis methods hold near-term promise to improve estimations of carbon stocks.**

Two analytical methods show significant promise to enable estimation of multiple parameters with a single technique: mid-infrared diffuse reflectance (MIR) spectroscopy and laser-induced breakdown spectroscopy (LiBS). MIR spectroscopy enables rapid and low-cost quantitative analysis of soil carbon (total, organic, and inorganic) and other important soil properties including soil texture, pH, nitrogen, and micronutrients (Baldock et al. 2014; Wijewardane et al. 2018; Dangal et al. 2019). One limitation to scaling MIR use for soil testing is that its accuracy is significantly improved by soil processing steps which are more intensive, and time-consuming than sample preparation methods that commercial labs are accustomed to handling (Wijewardane et al. 2020). LiBS also shows promise as a method to estimate chemical and physical soil properties such as soil organic matter, nutrient availability, and other properties like pH and texture without the use of expensive reagents (Villas-Boas et al. 2019a and 2019b, Yu et al. 2020). Encouragingly, the sample preparation for LiBS generally aligns with commercial soil lab practices, with soil pelleting being the only additional sample preparation step. The primary limitation of LiBS is its need for calibration on a larger variety of soils; this challenge can be overcome with time and resources. If scalable and cost-effective sample processing methods are developed for MIR, or greater calibration data further improve LiBS performance, each method has the potential to increase throughput, decrease costs, and improve quantification efforts. Collaborative research between soil scientists, engineers, and commercial soil labs is essential to realize this goal.

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