The Nature Conservancy

OpTIS and DNDC Methodology

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OpTIS

Methodology

The Operational Tillage Information System (OpTIS) is a remote sensing algorithm that uses earth-observing satellite data to document the adoption of soil health practices.

Remote sensing imagery is sourced from MODIS sensors on Terra and Aqua, Landsat 5, Landsat 7, Landsat 8, Landsat 9, Sentinel 2A, and Sentinel 2B. Imagery is cloud masked and reprojected onto a 30-m grid in Albers Equal Area projection.

Precipitation from PRISM (PRISM Climate Group) and ERA 5 in Canada are used in the OpTIS algorithm to account for soil and crop residue moisture effects.

Yearly median plant and harvest dates are estimated at the geohash 3 level using a time series of Landsat and Sentinel NDVI observations, and these dates are used to parameterize the cover crop and residue cover mapping.

The fundamental unit of analysis by OpTIS is a field segment. The CONUS field segment layer was created with CLU boundaries as the input dataset and was gap-filled with Regrow's Parcel ID boundaries. It was further segmented so that each polygon is a contiguous group of 30-meter pixels with the same crop history based on CDL classification for the multi-year range study.

Commodity row crop acres are defined by the extent of the field segment layer with the following restrictions applied. Field segments with <10 acres are discarded from the analysis. The portion of fields that border roads are often 'eroded' (or masked out) as a result of the effects of half-pixel shifts common to image registration from year-to-year. Permanent grasslands and pasture are removed from the analysis. Alfalfa or hay growing for fewer than six years of the study period are included. Areas identified as being converted to or from row crop agriculture during the extent of the time period were excluded from the analysis.

Practice KPIs

Crop Type

A crop type is defined as the crop that is cultivated during the summer growing season. A crop year is defined as approximately 1 November of the previous year through 31 October of the crop year. For example, the 2020 crop year extends from 1 November 2019 through 31 October 2020 where a cover crop planted in Fall of 2019 and terminated in Spring 2020 would be part of the 2020 Regrow data. Each season is defined as the following: fall (November 1 to December 30), winter (January 1 to February 28) and spring (March 1 to April 30).

For CONUS, these crop types are assigned primarily using the USDA's Cropland Data Layer. For this dataset, 5 explicit row crop types are defined by name (corn, soybeans, spring wheat, rice, and cotton). Alfalfa, non-alfalfa hay, and grassland/pasture are included in the 'Perennial' acres. We have excluded all non-ag areas. All other row crop acres are grouped into the 'Other' crop_type category. The "other" category also includes row crop acres that are tagged by the CDL as being double-cropped, as we do not currently support double-cropping.

Winter Cover

Background

Cover crops are mapped by observing a field over the fall, winter, and spring following a given growing season. Within each season, Regrow observes the vegetation dynamics of each field, taking into account both field management activities (summer crop harvest, planting in the spring, etc) and regional variations in weed and snow cover. At each step, the persistence of vegetation on the field (a collection of pixels) and likelihood it is a cover crop is assessed. Winter commodities are not considered green cover.

Fall

In the fall, vegetation cover on any field with an annual commodity crop planted during the summer (as observed in the CDL) is monitored. The following are several indicators of cover cropping:

- Harvest event: determined by observing a sharp drop in NDVI on the field
- Presence of green pixels following harvest
- Persistence of green pixels through the fall

In the absence of a harvest event, green pixels persisting over time may still indicate a cover crop, but there is more uncertainty with the assessment.

Winter

During the winter season, green pixels are continually monitored - but there are generally fewer opportunities to observe the field due to cloud cover. Regionally, Regrow also interprets the presence / absence of green cover differently due to variations in snow fall and freezing temperatures.

- In northern states, snow and winter temperatures will kill off cover crops as the season progresses.
- In southern and more mild states, both cover crops and weeds are able to continue growing throughout the season.

To take these regional variations into account, Regrow requires fields in more mild areas to have green cover for longer (number of observations over time) before classifying a field as having cover crops. These thresholds are set at the local level (i.e. state) to take both weather and grower practices into account.

Spring

During the spring season, a field is again monitored for green cover in addition to field events similarly to the fall season. Examples include:

- Increase in greenness over the spring
- Planting event: detected by observing a decrease in greenness on the field near planting time, followed by the emergence of a summer crop

As with harvest, a field can have a cover crop detected without observing a planting event, but observing the planting event increases confidence of the presence of a cover crop rather than a winter commodity crop.

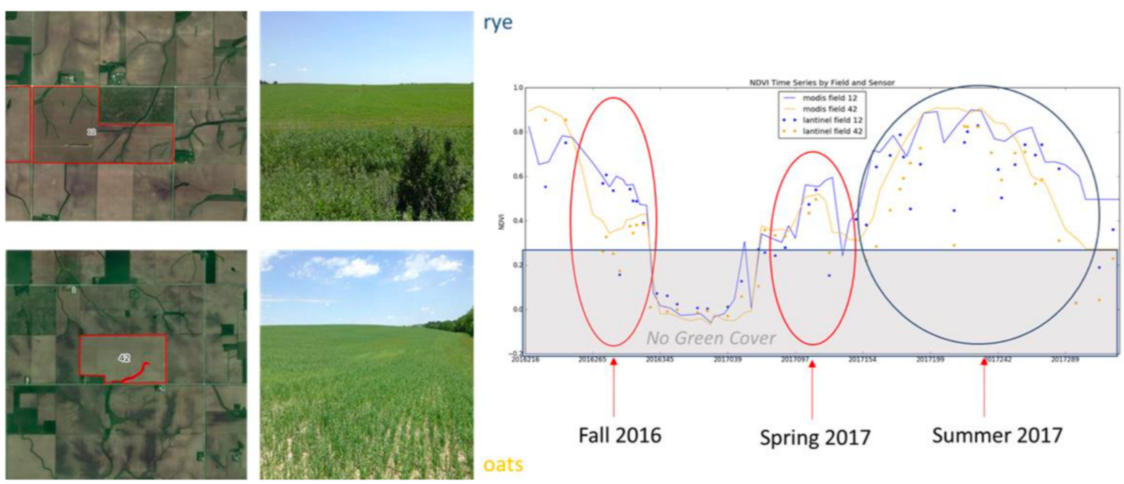

Figure 1. Time series plot of assessment of winter green cover for cover crop year 2017 (fall 2016, spring 2017, and summer 2017) on two fields with evidence of cover crop planting from roadside surveys.

Green Pixel Presence and Persistence

At a pixel level, winter cover is estimated with multiple NDVI time series of median, max, and min composites over the fall, winter and spring using multiple sensors to create a cover/no cover likelihood map. The sum of these 0/1 maps is the cover crop count, which measures how many times a pixel was likely to be classified as cover cropped. A higher count indicates more confidence that a pixel represents a cover crop. Baseline NDVI thresholds are taken from grass areas dynamically by each remote sensing sensor within a region (the minimum NDVI threshold being 0.25), and are used to distinguish a pixel as cover cropped. Pixels identified as winter commodity crops based on CDL are not classified as cover crops.

One factor in classifying a pixel as cover cropped or not is evidence of a plant or harvest event. A pixel is classified as not cover cropped if no planting or harvesting event was detected over the whole year, regardless of other factors. Observing both events has a larger weight on the final classification as cover cropped than observing only one of the events. This check eliminates the inclusion of volunteer green cover as being classified as cover crop. For example, in the Delta region, the cover crop count map threshold is higher in order to classify a pixel as cover cropped than an area without as much persistently green vegetation on fields.

Each pixel is then classified into one of three classes:

0. **No cover**
1. **Cover crop**

255. **No data** - not enough data to estimate

When determining cover crop for a field (a collection of pixels), the timing and intensity of greenness is compared to thresholds derived from seasonal imagery to determine cover status. A field segment is determined to be cover cropped if it passes a regionally calibrated percentage of the pixels within the field segment that is classified as cover cropped. The percentage is also calibrated considering the summer crop and healthy vegetation persistence. The type of cover is determined from the most common cover class.

Tillage

Background

Residue cover fraction is estimated in every available image for each location using the Normalized Difference Tillage Index (NDTI) and the Crop Residue Cover Index (CRC), parameterized at the geohash level 3 scale. The time series of residue cover fraction at the pixel level is then analyzed for patterns and consistency, returning a residue cover fraction value together with a certainty level at the time of planting at the 30-m pixel scale. For residue cover, the mean of all 30-meter pixels with a valid estimate within the field segment is calculated and reported. The residue cover percentage at the field scale is categorized into one of four levels of residue cover:

1. 0 to 15% - **Very low**
2. 16 to 30% - **Low**
3. 31 to 50% - **Moderate**
4. 51 to 100% - **High**

Residue is evaluated both in the spring and fall, with the annual tillage intensity calculated from the average residue cover observed across the two seasons. As different crops generate differing amounts of crop residue (ie corn is a high residue crop, soybeans are a low residue crop), the tillage classification also considers the prior crop on the field. We report on assumed tillage practices linked with these residue levels, derived from the residue cover levels and previous year's crop (i.e. residue type):

1. **Conventional tillage**— same as very low residue cover level (0-15%) for all previous year crop types;

2. **Reduced tillage, low residue**— same as low residue cover (16-30%) for all previous year crop types;
3. **Reduced tillage, high residue**— moderate residue cover (31-50%) where corn was the previous year's crop;
4. **No-till**— moderate residue cover (31-50%) where any crop except corn was the previous year's crop and high residue cover (51-100%) for all previous year crop types

In 2022 a change was made to the OpTIS tillage classification code that incorporated confidence into our classification workstream. Therefore, we are excluding pixels that surpass our no_data_fraction threshold of 70% due to the presence of clouds, which impact our ability to see and report on what's happening on ground. As such, the no_data acres have increased for tillage over previous data deliveries, but we are more confident in the tillage classifications under this new regime.

Remote Sensing Validation

Disclaimer: This analysis is focused on PPPx2 regions but was performed for all of CONUS.

Cropland acres

A total of 8,049,260 acres of commodity row crops were monitored with OpTIS for the years 2015 to 2021 across 17 states. Total state acres mapped by Regrow indicate a systematically low bias when comparing to the USDA harvested acres. The log difference chart of crop acres mapped vs. reported highlights that most states are within the target ± 20% accuracy level of Regrow. The Corn Belt, Plains and Delta regions have the strongest alignment with USDA acreage while Appalachia, specifically Tennessee and Kentucky, falls outside this threshold and requires further investigation that is ongoing.

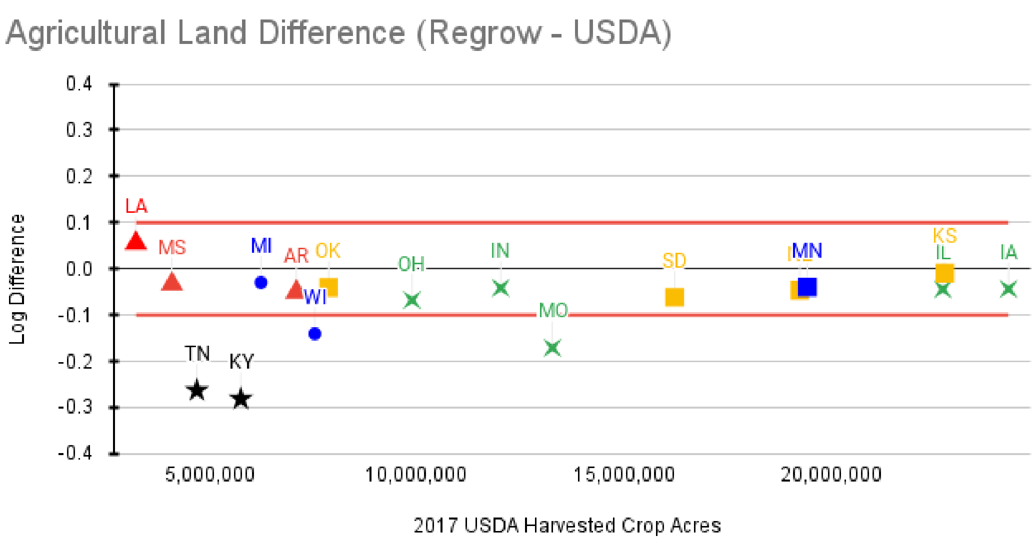

Figure 2. Plot of the log difference in acres of field segments mapped by Regrow and USDA 2017 harvested acres by region: Delta (red triangle ▲), Great Plains (yellow square ■), Cornbelt (green x), Lake (blue circle ●), and Appalachia (black star ★). Red lines are the target accuracy level for Regrow set at 0.1 and -0.1 log difference.

Cover Crop Acres

There are several components that contribute to the total cover crop estimates as mentioned in the methodology section above. Below are plots that showcase the threshold and availability influences for each region and the associated certainty impact they have on cover crop estimates.

Regional thresholds

As mentioned above in the methodology section, Regrow requires fields in more mild areas to have green cover for longer (number of observations over time) before classifying a field as having cover crops. These thresholds are set at the local level (i.e. state) to take both weather and grower practices into account. Below is a map of regional thresholds where the Southern states have a higher threshold vs Northern Plains states.

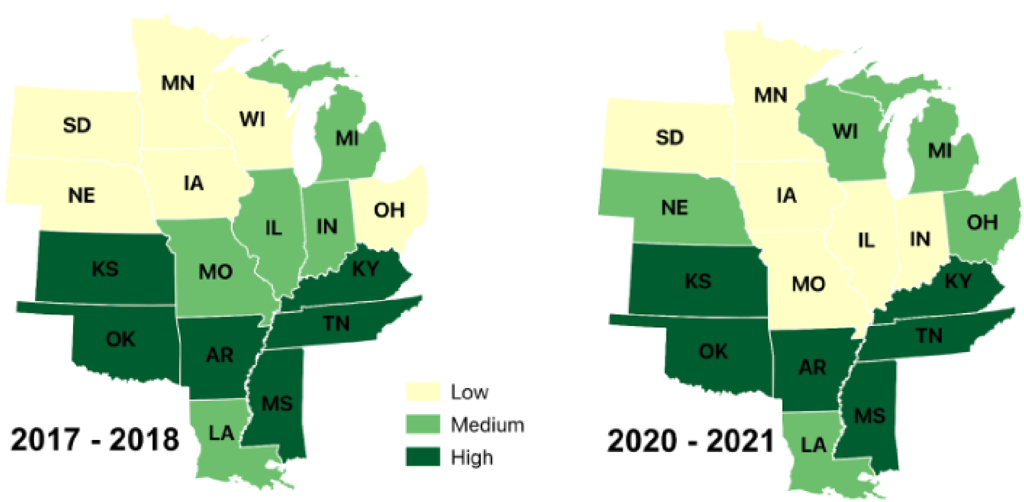

Figure 3. State maps of cover crop thresholds by state for 2017-2018 and 2020-2021.

Imagery availability

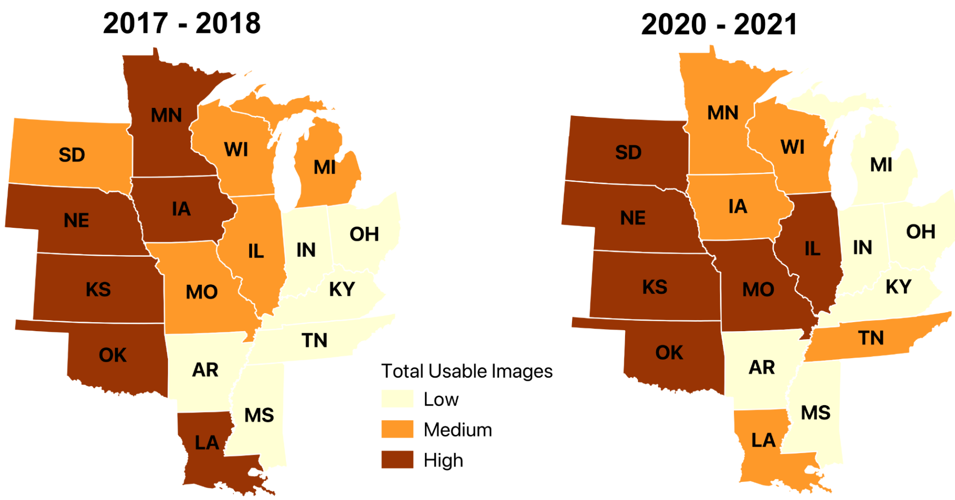

Figure 4. State maps of images used for the period in 2017-2018 on the left and 2020-2021 on the right.

Regrow vs. USDA metrics

Below is a scatter plot of log difference in 2017 cover crop acres mapped by Regrow and USDA 2017 AgCensus cover crop acres. Data points are marked by region: Delta (red triangle ▲), Great Plains (yellow square ■), Cornbelt (green x), Lake (blue circle ●), and Appalachia (black star ★). Red lines are the target accuracy level for Regrow set at 0.1 and -0.1 log difference.

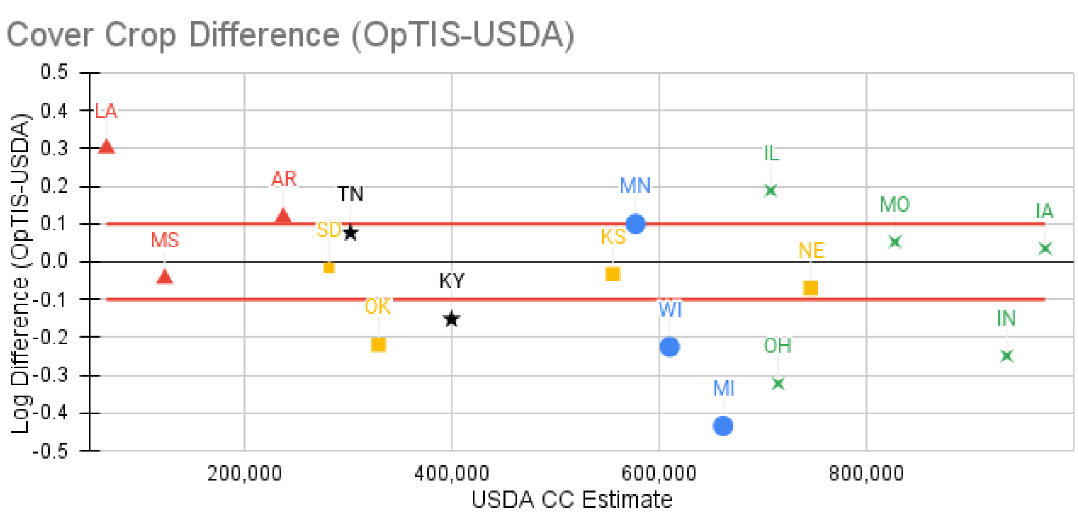

Figure 5. Cover Crop Difference, Regrow vs. USDA (2017-2018)

Ground truth validation

Using **roadside surveys** of management practices (n=607) in the Corn Belt in 2018 collected via OpTIS mobile app, mapping by OpTIS determined 38 fields (6%) as cover cropped and 444 (73%) as not cover cropped. The resulting accuracy is 79.4% and kappa coefficient is 0.28.

OpTIS 2 Cover Crop Confusion Matrix Using OpTIS roadside surveys		Field Observations		
		Yes Cover Crop	No Cover Crop	Sum
Remote Sensing	Yes Cover Crop	38	15	53
	No Cover Crop	110	444	554
	Sum	148	459	607

Using **centroids of fields in Maryland** (n=11,766) with and without cover crops planted for the years 2018, 2019, and 2020, mapping by OpTIS determined 1,992 fields (16.93%) were cover cropped and 5,105 (43.38%) as not cover cropped. The resulting accuracy is 60%, and kappa coefficient is 0.20.

OpTIS 2 Cover Crop Confusion Matrix Using Maryland field centroids		Field Observations		
		Yes Cover Crop	No Cover Crop	Sum
Remote Sensing	Yes Cover Crop	1,992	3,829	5,821
	No Cover Crop	840	5,105	5,945
	Sum	2,832	8,934	11,766

Using **Iowa sections** (n=7,843) with cover crops for years 2018, 2019, and 2020, from which a total of 7,814 intersected with Regrow field boundaries, mapping by OpTIS detected cover crop fields for 4,463 sections, resulting in a 57% recall rate.

Year	2018	2019	2020	Overall
Sections matched to OpTIS predicted cover crop	1,538	1,517	1,408	4,463
Sections Intersecting Any Regrow Field Segment*	2,547	2,660	2,607	7,814
Recall	60%	57%	54%	57%
All Sections	2,558	2,671	2,614	7,843

Residue cover classification accuracy is 39%, while the weighted kappa coefficient is 0.59. As misclassification can range from relatively small differences (i.e. OpTIS reports 14% residue while field observer reports 20%) to large (i.e. OpTIS reports 10% residue, field observer reports 90%), we use a weighted kappa statistic to account for differences in types of misclassification. Instances where very low is misclassified as high have a weight of 16 times the cost of misclassifying very low as low.

OpTIS 2 Residue Cover Confusion Matrix		Field Observations				
		0-15%	15-30%	30-50%	50-100%	Sum
Remote Sensing	0-15%	68	83	38	8	197
	15-30%	50	80	45	16	191
	30-50%	25	75	60	38	198
	50-100%	5	60	105	144	314
	Sum	148	298	248	206	900

It is worthwhile to mention that estimating the percent residue remaining on a large multi-acre field by just standing from the roadside, without taking measurements as normally would be done, poses inherent errors and bias. Therefore the field data, in particular the roadside residue estimates, should be taken with precaution and given careful review.

DNDC

Regrow's Denitrification-Decomposition (DNDC) model is a biogeochemical model that is based on first principles of soil biogeochemistry and estimates nutrient cycling in the soil, including how soil dynamics change with the adoption of new farming practices. The model predicts greenhouse gas emissions and other environmental effects of crop production, such as crop growth and yield, based on a series of environmental drivers (crop management, weather, and soil data, cultivar etc.).

DNDC Model Version

The current version of DNDC is v11.0.0. The model updates include updated soil carbon fractions, updated soil carbon fractions and standard bug fixes, including several to the nitrogen management routines. The current version of DNDC was calibrated against crop yield data in CONUS to update crop parameters that were previously identified as being the most sensitive. The calibration and validation was performed first at the field scale using a combined dataset of field sites found in peer-reviewed literature studies for CONUS and later tested against county level yield information from NASS to ensure that the calibration was appropriate at aggregate scales and to minimize model error.

Further improvements to the model for the aggregate level include using irrigation data from MiRAD and in the model parameters. Additional methods testing was performed for running the model at the aggregate level. These include testing a range of spin-up periods (0, 3, 5, 10, 25, 50, 100 years) to identify the spin-up period that minimized model error and bias with respect to NASS county yields. The optimal practical spin-up period was identified as 25 years.

DNDC v11.0.0 comparison with previous model

The crop list for the current version of DNDC has expanded beyond the previous version, supporting additional crop types from the Cropland Data Layer (CDL). While many of the main commodity crops have been calibrated in this version, others present in the CDL at lower frequencies have not yet been calibrated. Using all the crops results in some changes to the model outputs and emission factors.

Methods of calculating irrigation in farm fields, soil characteristics and fertilizer applications were updated in this version to include remote sensing data for irrigation, algorithms with greater accuracy for soil identification and using fertilizer data directly from NASS as opposed to gap filling and rate adjustments against fertilizer applications in the prior version.

The differences in results from the DNDC model outputs between the versions are relatively low as highlighted.

On a CONUS level average the previous model simulates SOC of -417 kg co2-eq/ha-year and N2O of 810 kg co2-eq/ha-year, whereas DNDC v11.0.0 simulates SOC of -670 kg co2-eq/ha-year and N2O of 510 kg co2-eq/ha-year. So by comparison, SOC sequestration is about 250 kg co2-eq/ha-year higher with the new version, and N2O is about 300 kg co2-eq/ha-year lower - which is a net GHG change that's around 550 kg co2-eq/ha-year lower in comparison (NET, or SOC+GHG, difference of 393 to -160 kg co2-eq/ha-year).

At the state-level there is a fairly tight correlation between N2O fluxes in the old version and the new version, though DNDC v11.0.0 is of consistently lower magnitude. The relationship for dSOC is less tight, but DNDC v11.0.0 is consistently more negative (ie., higher sequestration) than the older version.

At the crop level, there is a general pattern of much more SOC sequestration under cover crops than with the old version. In terms of the most widely grown crops, corn and spring wheat are similar in terms of SOC, with spring wheat actually sequestering less than the previous version. Cotton and soybean had the most dramatic SOC sequestration increases (around 500), and winter wheat also increased sequestration (about 330). These changes are partly explained by the crop parameter changes, as corn was unchanged, cotton had the most dramatic parameter changes, and spring wheat had maximum biomass reduced rather than increased. However, note winter wheat parameters were unchanged, underlining crop parameters as a partial explanation.

The most dramatic reductions in n2o emissions in DNDC v11.0.0 compared to the old version were for corn (-325), spring wheat (-295) and cotton (-260). Differences in corn may in part be explained by the nutrient management updates, as those changes most dramatically impacted corn. Spring wheat and cotton are less well understood though and may be the result of model parameter changes causing interactive and spatially explicit differences resulting from productivity/residue contributions.

The Field Emission Factors were also changed slightly as a result, with GHG values on average changing from 0.081 to 0.051 kgCO2 eq/kg yield with DNDC v11.0.0; SOC changing from -0.042 to -0.067 kgCO2 eq/kg yield and Net EF changing from 0.0393 to -0.016 kgCO2 eq/kg yield.

Outcome KPIs

GHG emissions

- *Definition:* greenhouse gas emissions from crop production; regenerative agriculture practices have the ability to reduce greenhouse gas emissions from crop production and this is generally referred to as "reductions"
- *KPI value(s):* The total GHG emissions in kg calculated per field level and aggregated at each geospatial aggregation unit
- *Metric calculation details*: Regrow utilizes the DNDC scientific model to model GHG emissions consisting of the following components: CO_2, CH_4, and N_2O (indirect/direct).

SOC

- *Definition:* the ability of soil to store carbon; regenerative agriculture practices have the ability to help accelerate the soil's ability to remove greenhouse gas from the atmosphere and this is generally referred to as "removals"
- *KPI value(s):* The total soil carbon sequestration in kg are calculated per field level and aggregated at each geospatial aggregation unit
- *Metric calculation details:* Soil sequestration is calculated by taking the difference of soil organic carbon stock values between 2 points in time (i.e. annual difference). The soil organic carbon stock values encompass the total soil carbon in the soil pools down to a specified depth, but does not include any residue (litter) pools.

Additional Details

- There may be some differences in the number of fields used to calculate practice KPIs and outcome KPIs, as there is a minimum data requirement needed to initialize and run DNDC. Fields without sufficient soils, weather, or cropping data to initialize DNDC are excluded from the DNDC outcome KPI estimates.
- DNDC data for Florida is not included in this release due to issues with data availability, model limitations with certain soils common in the area (histosols), and model support for several cropping systems (eg multiple vegetable crops in a single calendar year, sugarcane, orchards, etc)
- Regrow currently supports the following crops for DNDC at the landscape scale: alfalfa, barley, canola, corn, cotton, dry_bean, flax, oat, hay, pea, peanut, popcorn, potato, pumpkin, rapeseeds, rice, rye, sorghum, soybean, sugar_beet, sunflower, sweet_corn, wheat_durum,

wheat_spring, wheat_winter.