American Farmland Trust
SAVING THE LAND THAT SUSTAINS US

Soil Health: The Resilience Reports TECHNICAL NOTE

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Introduction

This document provides more information explaining the methodology behind the use of the DNDC model (DeNitrification DeComposition) for biogeochemical modeling and use of OpTIS (Operational Tillage Information System) for practice adoption/implementation data, presented in the four AFT Resilience Reports.

The two main goals of this study were 1) to estimate how the soil health practices such as cover crops, reduced till, and no-till impact cropping system resilience to climate changes and 2) to assess the proportion of cropland acres adopting these practices on the ground. We applied these goals to the following cropping systems: corn-soybeans in Illinois, forage crops in western New York, and almonds and wine grapes in California. We used the following ecological outcomes to assess resilience: crop yield, nitrate leaching, change in soil organic carbon, and sediment loss. Fewer of these outcomes were available for the perennial systems, which we explain below.

DeNitrification DeComposition (DNDC) model

The DNDC model is a process-based biogeochemical model used for estimating ecological outcomes from agroecosystems based on their soils, climate, and management. Ecological **outcomes** include greenhouse gas emissions, water quality and quantity impacts, and annual crop yields. **Process-based models** use math to represent biological and geochemical (**biogeochemical**, mainly carbon and nitrogen) processes in ecosystems. Process-based models are better suited for estimating ecological outcomes with complex interacting factors (such as a changing climate and management practices) as opposed to empirical models, which simply predict outputs based on inputs without accounting for interacting mechanisms. Process-based models make it possible to compare ecological outcomes from different management practices in future climate conditions –**something field studies alone cannot provide**.

Scientists have been developing, testing, and improving DNDC in agroecosystems for over 30 years across a wide range of annual crop agroecosystems (Gilhespy et al 2014). DNDC has been extensively evaluated against datasets of SOC, GHG fluxes, and N leaching—including N leaching and N2O simulations compared against 56 field studies in the Corn Belt (Giltrap et al. 2010; Gilhespy et al. 2014; Yeluripati et al. 2015). We used DNDC version 11.0.0, which is sensitive to CO_2 concentration inputs, which we provided (see "Climate projections" below). We used an "out-of-the-box" approach where we did not provide additional calibration for this project. Model spin-up began in year 2012, ten years prior to results shown in the reports.

Climate projections

DNDC uses climate information in its simulations. In order to estimate future ecological outcomes, we ran the model using projected future climate data, specifically daily temperature, precipitation, and annual atmospheric CO_2 concentrations for the years 2022-2072. We used the LOCA-CMIP5 (Localized Constructed Analogs Coupled Model Intercomparison Project phase 5) Climate Projections (Brekke et al. 2013 and Bracken 2016) of the representative concentration pathway (RCP) 6.0 (van Vuuren et al 2011). Data were downloaded from https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Projections:%20Complete%20Archives. These climate projections come from global circulation models that have been statistically downscaled to 3.7 mi^2 resolution.

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (Fujino et al. 2006 and Hijioka et al. 2008) for producing and making available their model output. For CMIP, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

Soils

Each cropping system report is based on DNDC simulations from 16 representative soil samples from that region. Each soil sample set was chosen using ground truth data and satellite imagery to confirm farms at those locations grow the crop used in that report. An initial set of 50 fields was selected. Using the most common map unit in the selected fields, soil data for the upper 50 cm were retrieved from the Soil Survey Geographic Database

(SSURGO). Then, 16 of the 50 points were randomly chosen that fell within the 20-80 percentile range for soil organic carbon and clay percentage. In Illinois, 16 sample points were chosen for northern Illinois and 16 for southern Illinois for a total of 32 simulation points for that report.

Crop systems

Here we describe the way the cropping systems were set up in DNDC. Crop management methods used to set DNDC inputs below were defined using publicly available crop production guidelines with sources ranging from university extension reports, peer reviewed journal articles, and AFT program staff experience.

California almonds

Almond trees were simulated as being planted in 2014 to give them time to establish prior to the 2022 start of results shown in the reports. In year 1 leaves and stems were pruned in December. In year 2 suckers were removed in June and leaves and stems were again pruned in December. Years 3 onward nuts were harvested in October and leaves and stems were pruned in December. The trees received drip irrigation from April 1 to September 15 that is dynamically applied as needed determined by water demand of the crop and weather conditions. Urea ammonium nitrate (UAN) **fertilizer** was applied in April, May, and July at 73 lb N per acre, totaling 220 lb N per acre. The trees also received a 500 lb per acre application of potassium sulfate every November.

Tillage occurred in the alleys. Conventional tillage consisted of a disc pass every April 1, 6 inches deep, no inversion. No-till consisted of no tillage passes at all.

Cover crops were seeded in the alleys. The model is not capable of simulating cover crop mixes, which are typical in traditional almond systems. So, instead, we simulated two cover crop types that are usually found in traditional mixes. The triticale and fava bean cover crops were managed the same: they were planted 2 weeks after almond harvest and terminated (mowed) 2 weeks prior to almond bud break. All biomass was left on the field. Cover crops did not receive any irrigation, fertilizer, or tillage.

California wine grapes

Vineyards were simulated as being planted in 2013 so that they were established prior to the 2022 start of results shown in the reports. In years 1 – 4 a portion of stems and leaves were removed in order to simulate pruning of weaker stems. In years 5 onward the vines had stems and leaves pruned once in May and once in June followed by fruit harvest in September. The vines received drip irrigation from April 1 – October 1 that is dynamically applied as needed determined by water demand of the crop and weather conditions.

Prior to planting, a granular fertilizer was applied at 58 lb N per ac. From years 2 onward, the vines received UAN twice per year: 22.3 lb N per acre at bud break in March and 22.3 lb N per acre as UAN at fruit set in May.

Tillage occurred in the alley. **Conventional till** in vineyards was discing, 4 inches deep to incorporate pruning residue in July. **No-till** consisted of no tillage passes at all.

Cover crops were planted in the alley. We were unable to simulate a mixed cover crop, so instead we simulated two cover crops separately. The barley and fava bean cover crops were both planted two weeks after grape harvest and terminated (mowed) two weeks prior to grape bud break. All biomass was left in the alley. Cover crops did not receive any irrigation, fertilizer, or tillage.

Illinois corn-soybean systems

Two alternating versions of this system were simulated such that corn and soy were simulated every growing season. Corn was planted on May 13 and harvested on October 15 of every year. Soybeans were planted on May 27 and harvested on October 21 of every year. Both corn and soybean were grown without irrigation.

Conventional tillage consisted of 1 pass 5 days prior to planting, 4 inches deep, without inversion and 1 pass 5 days after harvest, 8 inches deep, without inversion. **No-till** consisted of no tillage passes at all.

We compared three nitrogen programs for corn and set up soybeans the same in each corn-soybean rotation (Table 1).

Table 1. Nitrogen application rates in lb N per acre. Spring N applications were urea, fall N application was anhydrous ammonia. Rate information comes from USDA surveys and University of Illinois extension.

Crop	Annual total	Planting (May)	Late June	Fall (Oct.)	Rate source
Corn	170	34	136	0	https://quickstats.nass.usda.gov/results/050CC39E-F86B-33C7-A934-AFE5E621D13F
Corn	220	44	176	0	https://farmdocdaily.illinois.edu/2022/10/fall-anhydrous-ammonia-application-practices-and-profitability-on-fields-enrolled-in-precision-conservation-management.html
Corn	170	0	43	142	https://quickstats.nass.usda.gov/results/050CC39E-F86B-33C7-A934-AFE5E621D13F
Soybean	23	23	0	0	https://quickstats.nass.usda.gov/results/69CF4B75-9BD3-3FF8-B8FF-B23F8A05F174

We used cereal rye as a **cover crop**, which was planted two weeks after cash crop harvest and terminated (mowed) two weeks prior to cash crop planting. All biomass was left on the field. Cover crops did not receive any additional fertilizer, irrigation, or tillage.

New York forage crops

We explored three western New York forage cropping systems/rotations: corn grain monoculture, corn silage monoculture, and corn grain – soybean rotation. Note: we also simulated a 4 year alfalfa – 1 year corn grain – 1 year triticale rotation but did not present results from this rotation after concluding that more model development needs to occur to simulate the perennial alfalfa appropriately. All New York systems were rainfed; no irrigation was applied.

Nitrogen rates listed below for these New York systems were based on a county average yield calculated from the crop acres and bushels harvested reported in the [2017 US Census of Agriculture] for the following counties: Allegany, Cattaraugus, Cayuga, Chautauqua, Cortlan, Erie, Genessee, Livingston, Onondaga, Ontario, Steuben, Tompkins, Wayne, Wyoming, Yates. We then back-calculated nitrogen rates from these yields using Ketterings and Workman (2022) and checked these with an agronomist and crop advisor in western New York.

The **corn grain** monoculture was planted every June 7 and grain was harvested every October 19. UAN was applied on June 7 at 37 lb N per acre and on July 22 at 150 lb N per acre.

The **corn silage** monoculture was planted on June 7 and all aboveground biomass was harvested on September 18. Dairy manure was injected 4 inches deep on June 7 at 140.5 lb N per acre. Then on July 22 UAN was applied at 47 lb N per acre.

In the **corn-soybean rotation**, in a corn year, corn for grain was planted every June 7 and grain was harvested every October 19 (same as the corn grain monoculture above). In alternate years, soybeans were planted on June 16 and harvested on October 27. We modeled two versions of this system that alternated years so that corn and soybean were grown in every calendar year.

Tillage types are the same among the three systems. Conventional till was 1 pass 5 days prior to plant, 4 inches deep, no inversion and 1 pass 5 days after harvest at 8 inches deep with inversion. No-till was no tillage passes at all.

The rye cover crop was managed the same among the three systems: planted 2 weeks after cash crop harvest and terminated (mowed) 2 weeks prior to planting cash crop. It did not receive any additional fertilizer, irrigation, or tillage. All biomass was left on the field after termination.

Operational Tillage Information System (OpTIS)

A more complete explanation of OpTIS methodology is provided in Hagen et al. (2020). To summarize, OpTIS used data from Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on Terra and Aqua and several Landsat and Sentinel satellites; all data were resampled to a 30m resolution. Clouds were masked out. Precipitation data were used to account for how moisture affects the darkness of soil and crop residue in imagery. MODIS Normalized Difference Vegetation Index (NDVI), a measure of field greenness, was used to estimate cash crop planting and harvest dates to determine periods appropriate to map tillage and cover crops. Residue cover fraction was determined using the Normalized Difference Tillage Index (NDTI) and the Crop Residue Cover Index (CRC) from every available image. Per field, the residue cover percentage is the average of all pixels with valid images and is used to categorize the field acres by tillage type:

- Fields with 0-15% residue cover were classified as conventional tillage.
- Fields with 16-30% residue cover (or 16-50% residue cover if corn was the previous crop) were classified as reduced tillage.

- Fields with 31-100% cover (or 51-100% cover if corn was the previous crop) were classified as no-till.

NDVI from November through July was used to estimate winter cover crop presence (at least 30% of the field area has green cover in winter) or absence (less than 30% of the field areas has green cover in winter). Indicators of cover cropping include detection of a harvest event in the fall, presence of green pixels after a harvest, persistence of green pixels through the fall, winter greenness (dependent on climate), increase in greenness in the spring, a decrease in greenness corresponding to a planting event. Thresholds for persistence of green pixels to count as a cover crop are set at the local level (county or state) to account for local variations in weather and grower practices. These data were then compared to the USDA Cropland Data Layer to differentiate winter cover from winter commodities like winter wheat and perennials like alfalfa. The OpTIS data used here are for corn and soybean acres only, not all cropland acres.

Roadside surveys were used to ground truth OpTIS cover crop estimates on 607 fields in the Corn Belt in 2018 resulting in 79.4% accuracy and a 0.28 kappa coefficient (a statistic that represents the amount of disagreement between sources, higher being more disagreement). Cover crop cost-share enrollment data in Maryland were used to validate OpTIS cover crop estimates for 2018, 2019, and 2020 resulting in a 60% accuracy and 0.20 kappa coefficient. Compared to roadside surveys in the spring of 2017 and 2018 in the Corn Belt OpTIS residue cover classification accuracy was 39% and the kappa coefficient was 0.59—this kappa coefficient is weighted by type of misclassification. The inherent difference in ability to estimate residue remaining on a large field from the roadside view compared to the view from satellite imagery likely contributes to the lower degree of agreement in residue cover classification.

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