sustainability

Article

Assessing the Multifaceted Tradeoffs of Agricultural Conservation Practices on Ecosystem Services in the Midwest U.S.

Amit P. Timilsina [1], Garrett Steinbeck [2], Ajay Shah [1] and Sami Khanal [2,*]

[1] Department of Food, Agricultural and Biological Engineering (FABE), The Ohio State University (OSU), Wooster, OH 44691, USA; timilsina.3@osu.edu (A.P.T.); shah.971@osu.edu (A.S.)
[2] Department of Food, Agricultural and Biological Engineering (FABE), The Ohio State University (OSU), Columbus, OH 43210, USA; gws.steinbeck@gmail.com
* Correspondence: khanal.3@osu.edu; Tel.: +1-614-688-2347

Abstract: A comprehensive understanding of the potential effects of conservation practices on soil health, crop productivity, and greenhouse gas (GHG) emissions remains elusive, despite extensive research. Thus, the DeNitrification–DeComposition (DNDC) model was employed to evaluate the impact of eleven commonly practiced management scenarios on ecosystem services in the Western Lake Erie Basin, USA, from 1998–2020. Out of eleven scenarios, eight were focused on corn–soybean rotations with varied nitrogen application timing (50% before planting and 50% at either fall or spring during or after planting), or nitrogen source (dairy slurry or synthetic fertilizer (SF)), or tillage practices (conventional, no-till), or cereal rye (CR) in rotation. Remaining scenarios involved rotations with silage corn (SC), winter crops (CR or winter wheat), and alfalfa. The silage corn with winter crop and four years of alfalfa rotation demonstrated enhanced ecosystem services compared to equivalent scenario with three years of alfalfa. Applying half the total nitrogen to corn through SF during or after spring-planted corn increased yield and soil organic carbon (SOC) sequestration while raising global warming potential (GWP) than fall-applied nitrogen. The no-till practice offered environmental benefits with lower GWP and higher SOC sequestration, while resulting in lower yield than conventional tillage. The incorporation of CR into corn–soybean rotations enhanced carbon sequestration, increased GHG emissions, improved corn yield, and lowered soybean yield. Substituting SF with manure for corn production improved corn yield under conventional tillage and increased SOC while increasing GWP under both tillage conditions. While the role of conservation practices varies by site, this study's findings aid in prioritizing practices by evaluating tradeoffs among a range of ecosystem services.

Keywords: greenhouse gas; DeNitrification–DeComposition; organic carbon; tillage

check for updates

Citation: Timilsina, A.P.; Steinbeck, G.; Shah, A.; Khanal, S. Assessing the Multifaceted Tradeoffs of Agricultural Conservation Practices on Ecosystem Services in the Midwest U.S. *Sustainability* **2024**, *16*, 5622. https://doi.org/10.3390/su16135622

Academic Editors: Jose Navarro Pedreño, António Dinis Ferreira, Peter Goethals, Eun-Sung Chung and Vincenzo Torretta

Received: 16 May 2024
Revised: 23 June 2024
Accepted: 25 June 2024
Published: 30 June 2024

1. Introduction

Conventional agricultural practices, including intensive tillage, overuse of fertilizers, and monoculture cropping, have been linked to significant soil degradation, poor water quality, and biodiversity loss [1]. This has spurred a growing recognition among farmers and researchers of the need for sustainable production systems with an emphasis on adoption of agricultural conservation practices [2,3]. Key conservation practices encompass strategies like crop diversification [4], such as the incorporation of cover crops (CCs) and perennial crops within corn–soybean rotations, reduction of tillage to limit soil disturbance [5], and the use of organic amendments [6]. These practices offer the potential to mitigate environmental impacts through the improvement in soil health [7–9] and the curbing of GHG emissions [10], while maintaining and/or enhancing crop productivity [11,12].

The practice of no-tillage (NT), for instance, enables crop residues to remain on the soil surface and minimizes soil disturbance. This approach makes a substantial contribution to soil erosion reduction [13], enhancement of soil aggregation and stability [14], preservation of soil water [15], and reduction of nitrous oxide emissions [16]. Furthermore, the combination of CCs and NT has been found to increase total carbon inputs and slow down soil carbon decomposition rates [17]. Similarly, the incorporation of manure amendments has been identified as a means to enhance the rates of soil carbon accumulation [5,7]. Additionally, the diversification of crop rotations has been observed to lead to reduced N_2O emissions [10,18].

The extent of the environmental benefits derived from conservation practices, however, can largely be influenced by factors such as weather, soil composition, topography, and the specific management practices employed [13,14,16,19]. Although a significant number of previous studies have highlighted the positive environmental outcomes of CCs [20–22], a subset of research [23–25] has also indicated instances of yield reductions and higher GHG emissions. Similarly, Huang et al. [17] conducted a study on a continuous corn cropping system in Kentucky, U.S. and concluded that the carbon gain of 0.22 Mg C ha^{-1} yr^{-1} in topsoil from NT practices alone is insufficient to maintain SOC levels, even in a crop rotation with considerable residue inputs. A global meta-analysis focused on the impact of manure amendments on soil C and N [26] reported that it can take up to 37 years, even after continuous application of manure, to recover just 0.47 kg m^{-2} C and 0.051 kg m^{-2} N in the top 24 cm of soil depth—a small fraction of soil nutrients that are lost during the conversion of native vegetation to cropping. These diverse findings underscore the need for further research under varying weather and soil conditions, which can help assess the impact of conservation practices and the tradeoffs between different ecosystem services.

Current approaches for monitoring the impact of conservation practices on ecosystem services primarily rely on field works [27], making it challenging to compare different conservation practices [5], especially over the long-term, which is both time-consuming and costly. Furthermore, field-based studies often produce findings at a very coarse spatial and temporal scale, leading to mixed findings regarding the impact of the conservation practices. Developing holistic and integrated strategies for improving ecosystem services associated with agricultural conservations practices require understanding how different practices interact under diverse production systems [5,28]. Since the benefits of conservation practices often become evident only after long-term adoption and may not be immediately profitable [29], long-term evaluations are essential for understanding temporal dynamics, potential delays in effects, and the stability of observed improvements over time. Moreover, assessing a broader spectrum of ecosystem services, rather than focusing on a few specific aspects, is important for understanding the interconnectedness, tradeoffs, and synergies associated with various management practices.

A common approach to bridge the knowledge gap on long-term impact of conservation practices on ecosystem services involves the use of biogeochemical or ecosystem models, which serve as alternatives to experimental studies when measurements are limited in availability or scope [30]. In recent times, process-based models such as APSIM, DSSAT, and Daycent [19,31,32] have gained traction for evaluating the impacts of conservation practices on environmental and agronomic outcomes [33,34]. Despite several prior studies focused on modeling of ecosystem services, there is a limited amount of research on a comprehensive, medium- to long-term assessment of various combinations of soil health-enhancing practices across a broad spectrum of ecosystem services, including SOC, GHG emissions, and crop productivity. Therefore, this study focuses on estimating and evaluating the effects of long-term tillage, CC use, and manure application on SOC, crop yield, and GHG emissions. For this, the study explores the use of the DeNitrification-DeComposition (DNDC) biogeochemical model.

2. Materials and Methods

2.1. Study Site

The study was conducted at one of the edge-of-field sites established in 2013 by the USDA Agriculture Research Service [35] located in Defiance County, northwest Ohio (Figure 1). The field is artificially drained with subsurface ("tile") drainage lines installed at a depth of 1.0 m below the soil surface. The dominant soil texture is fine clay. The study site has a temperate climate with warm summers and cold winters.

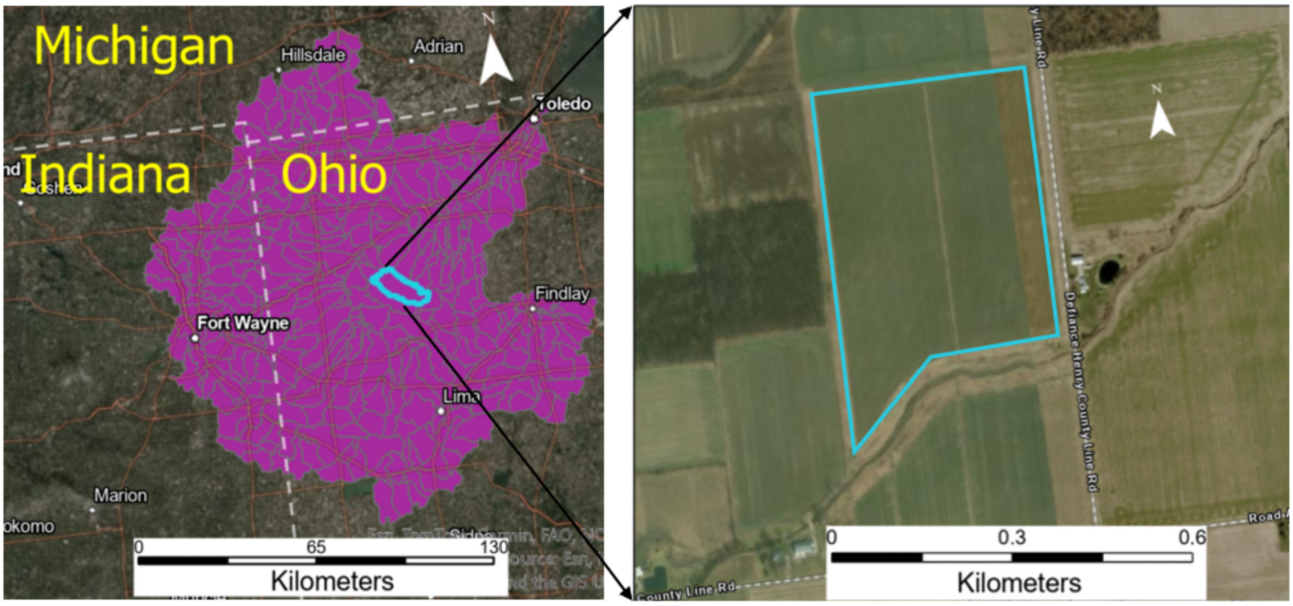

Figure 1. Location of the study area within the sub-basin of Maumee River Watershed.

2.2. Biogeochemical Model and Input Data

In this study, we used the Canadian version of DNDC (DNDC 9.5 v. CAN), a process-based model designed primarily for simulating biogeochemical processes in cool regions [36]. This model integrates six sub-modules—mineralization, nitrification, denitrification, fermentation, plant growth, and soil climate—that interact to simulate ecosystem services under various agricultural management practices and production environments [36,37]. It has the capacity to forecast crop performance [38–40], greenhouse gas fluxes (e.g., CO_2, N_2O, CH_4, NO_x), soil water, and temperature profiles, along with substrate concentrations [41,42] under various soil, weather, and management practices. The input data needed to run the DNDC model for this study were collected from various sources (Figure 2). Weather data consisted of historical daily maximum and minimum temperatures, precipitation, wind speed, solar radiation, and humidity collected for the period 1987 to 2020. Inorganic N deposition via rainfall was obtained from the National Atmospheric Deposition Program [43]. Soil inputs, such as textures, organic carbon, bulk density, slope, and water-related soil physical properties, were obtained from the Gridded Soil Survey Geographic Database (gSSURGO) [44]. The model was calibrated and validated for this study site as part of our previous work on the development of a DNDC model calibration approach to improve the simulation of water and nutrient dynamics [42].

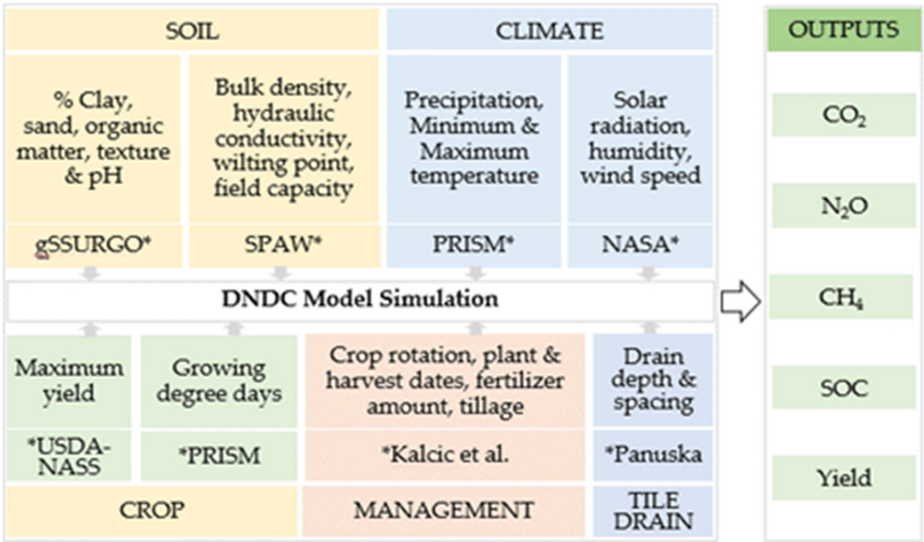

Figure 2. Data and their potential sources for setting up the DNDC model for the MRW. Note: * sign denotes data source; gSSURGO [44], SPAW [45], PRISM [46], NASA [47], USDA NASS [48], Kalcic et al. [49], Panuska [50].

2.3. Management Scenarios

The DNDC model was used to simulate the impacts of a stack of alternative management practices on a series of ecosystem services, including GHG emissions (N_2O, CO_2, and CH_4), global warming potential (GWP), and changes in annual SOC and corn and soybean yields. Based on the inputs from farmers and the extension educators in the Western Lake Erie Basin on their preferred and commonly used management practices, eleven alternative management scenarios were developed. These scenarios involve varying combinations of crop diversity (including crop types and years in crop rotations), fertilizer types (such as manure and synthetic fertilizer), timing of synthetic fertilizer application for corn (with options including 50% prior to planting and the remaining half either in the fall, or during spring planting, or after planting), and tillage (both NT and conventional tillage (CT)) practices (Table 1). The site considered for this study is managed by a farmer and is also being used for the edge-of-field monitoring research by the USDA Agriculture Research Service [35] since 2013. Out of eleven scenarios, three management scenarios had silage corn (SC) following winter wheat (WW) or cereal rye (CR) and three to four years of alfalfa (AL), hereafter referred to as SC-AL scenarios (SN1–SN3). The SC-AL scenario, which includes SC and WW followed by three years of AL in a rotation (SN1), represents the current management practice in the study site. This practice is unique and uncommon compared to the traditional corn and soybean rotations dominant in the Midwest U.S. Therefore, we considered two baseline scenarios for comparing various management practices in our study, with the SC-AL scenario being one of them.

The remaining eight scenarios are based on corn (C) and soybean (S) rotation practices; collectively referred to as CS scenarios (SN4–SN11). Among these, the second baseline scenario (SN4) represents the corn–soybean rotation typical of the Midwest U.S. agricultural region, where 50% of the total N fertilizer is applied in the fall and remaining 50% at corn planting in the spring (Table 1). Other CS scenarios (SN5–SN11) varied from the baseline scenario in terms of CC, tillage, fertilizer source, or timing of synthetic fertilizer application to corn at the rate of 220 kg ha^{-1} (Table 1). SN5 and SN6 were similar to the baseline CS scenario except for the timing of synthetic fertilizer application. In SN 5, 50% SF was applied before planting and the remaining 50% at planting, whereas in SN6, 50% of total N fertilizer was applied before planting and 50% as a side dressing 28 days after planting. SN7 is similar to SN5 but with NT.

Table 1. Cropping system and management details considered in the study.

SN	Cropping System (Scenario)	Tillage	Cover Crops	Fertilizer	Details
Silage corn and alfalfa-based scenarios (SC-AL scenarios)					
1	SC-WW-AL×3 (SN1)	Yes	No	M + SF	Current practice in the field under study
2	SC-WW-AL×4 (SN2)	Yes	No	M + SF	Same as SN1 but with four years of alfalfa
3	SC-CR-AL×4 (SN3)	Yes	Yes	M + SF	Same as SN2 but with cereal rye as a cover crop during winter
Grain corn and soybean-based scenarios (CS scenarios)					
4	C-S[F + P] (SN4)	Yes	No	SF	A common cropping system in the Corn Belt Region with corn fertilized with SF (50% in fall and 50% at planting in spring)
5	C-S[PP + P] (SN5)	Yes	No	SF	Same as SN4 but with a spring application of SF before and at planting (50% PP and 50% P)
6	C-S[PP + SD]) (SN6)	Yes	No	SF	Same as SN5 but with 50% of total SF before planting and the remaining 50% as a side dressing at 28 days after planting
7	C-S[NT&PP + P] (SN7)	No	No	SF	Same as SN5 but with no-tillage
8	C-CR-S[PP + P] (SN8)	Yes	Yes	SF	Same as SN5 but with cover crop and tillage
9	C-CR-S[NT&PP + P] (SN9)	No	Yes	SF	Same as SN8 but with no-tillage
10	C-S[M + SF]) (SN10)	Yes	No	M + SF	Same as SN5 but with the use of manure as a substitute for fall SF and spring SF at planting
11	C-S[NT&M + SF]) (SN11)	No	No	M + SF	Same as SN10 but with no-tillage

SN—scenario, SC—silage corn, WW—winter wheat, AL×3—alfalfa for three years, AL×4—alfalfa for four years, CR—cereal rye, C—grain corn, S—soybean, P—planting, PP—prior to planting, SD—side dressing, NT—no-tillage, M—manure; dairy slurry was applied based on plant-available nitrogen to supply 160 kg N at fall (15th October after soybean harvest) in CS scenarios. The slurry was incorporated 5 cm below the soil surface. The remaining 60 kg N was applied at the time of planting through the synthetic nitrogen fertilizer. SF—synthetic fertilizer; anhydrous ammonia and urea were used as of synthetic fertilizer sources.

The CR after corn harvest was included in SN8 and SN9 with CT and NT, respectively. SN10 and SN11 were CS scenarios similar to SN5 but 160 kg of N was supplied with dairy slurry under CT and NT conditions, respectively. A total of about 2026 kg of C (equivalent to 30,600 gallons with 5% solids) was applied through a dairy slurry in the fall to supply 160 kg of plant-available nitrogen for corn. Manure with 10.43 kg of N per 1000 gallons of slurry was injected 5 cm below the soil surface in the fall after the soybean harvest. The factor was used to calculate the plant-available nitrogen (PAN) from fall-applied manure [51]. In the first year of application, only 33% of the organic N was considered to contribute to PAN [52]. Details on timing and management practices are provided in the supporting document (Supplementary Tables S1 and S2).

2.4. Model Simulation and Statistical Analysis

Eleven scenarios were simulated for a total of 34 years with the historical weather data starting in 1987. The first 11 years were used as a spin-up period to allow the modeled SOC levels to reach a baseline steady state as major oscillations occur in the first few years of the model runs [53–55]. The subsequent 23 years (1998–2020) were used for the analyses. Model outputs were averaged seasonally and annually for GHGs and GWP, and interannual variability was calculated to examine changes over time under various alternative scenarios. There were five complete sequences for SN1 (2001 to 2020), four for SN2 and SN3 (1998 to 2017), and eleven for CS scenarios (1999 to 2020) within the 23-year simulation period (1998–2020). For instance, in the SN1 scenario, different crops were planted in a specific sequence over four years. Thus, out of the 34 years, 11 were used for the model spin-up and 20 for completing five complete sequences, leaving 3 years with an incomplete sequence. Four seasons, including winter (January–March), spring (April–June), summer (July–September), and fall (October–December), were considered to examine temporal variability in model outputs. For SOC change, outputs were averaged annually, and variability in change in SOC among rotations within each scenario were calculated. Similarly, annual crop yield was averaged annually, and box plots were used to display the summary. Radar charts were used to assess differences in ecosystem services among various scenarios compared to baseline scenarios.

2.5. Climate

The annual average minimum and maximum temperatures from 1998 to 2020 ranged from 3.6 to 6.4 °C and 14.4 to 17.8 °C, respectively. The average temperature was higher in summer (21.5 °C) followed by spring (15.7 °C), fall (6.1 °C), and winter (−0.7 °C) (Supplementary Figure S1a). Spring was the wettest season with an average total precipitation of 297 mm followed by summer (270 mm), fall (209 mm), and winter (188 mm) (Supplementary Figure S1b).

2.6. Global Warming Potential (GWP)

GWP was calculated to measure the heat-trapping ability of GHGs including CO_2, N_2O, and CH_4 emitted under different management practices into the atmosphere. It was determined by comparing the cumulative radiative forcing of these GHGs to that of an equivalent mass of CO_2 [56]. The GWP was calculated following the Equation (1) [57].

$$\text{GWP} = CO_2 + N_2O \times 265 + CH_4 \times 28 \quad (1)$$

2.7. Land Use Change during the Study Period

Based on the crop land data layers spanning 2006 to 2022 obtained from CropScape [58], the study site had multiple crop rotations. The dominant rotation across most of the area consisted of corn, soybeans, and winter wheat, with alfalfa also included as a perennial crop in some sections from 2008 to 2010. Since a majority of the Midwest underwent significant land use change through the conversion of grasslands to row crop production [59–61], the assumption of the same crop rotation throughout the study period from 1998 to 2020 may not accurately portray the ecosystem services observed in the years prior to 2008.

3. Results

3.1. Annual and Seasonal CO_2 Emission

The yearly average CO_2 emissions ranged between 1723 kg C ha^{-1} yr^{-1} and 2738 kg C ha^{-1} yr^{-1} across all scenarios. The SC-AL scenario with three years of alfalfa (SN1) resulted in higher CO_2 emission than the SC-AL scenarios with four years of alfalfa (SN2–SN3). The inclusion of CR as winter crop in the SC-AL scenario with four years of alfalfa led to lower emissions compared to scenario involving WW as a winter crop. Among the CS scenarios, corn fertilized with manure during winter and SF application in spring under CT resulted in the greatest annual CO_2 emission (2472 kg C ha^{-1} yr^{-1}) (Figure 3a). Conversely, a reduction in CO_2 emissions was observed in the CS scenarios where corn was solely fertilized using SF, such as the baseline CS scenario. Use of 50% of total N as a side dressing to corn contributed to an increase in CO_2 emissions when compared to applying the same amount of N at the planting (i.e., C-S[PP + P]). Adoption of NT practice into the CS system in the absence of CR (i.e., C-S[NT&PP + P], C-S[NT&M + SF]) reduced

CO_2 emission compared to equivalent scenarios under CT (C-S[PP + P] and C-S[M + SF]). The greatest reduction in CO_2 emission (371 kg C ha^{-1} yr^{-1}) under NT, as compared to a similar scenario under CT, was observed when manure-based management practices were employed in CS system. When CR was integrated in CS rotation, NT seems to be less beneficial over CT, as it resulted in slightly higher CO_2 emissions (1 kg C ha^{-1} yr^{-1}).

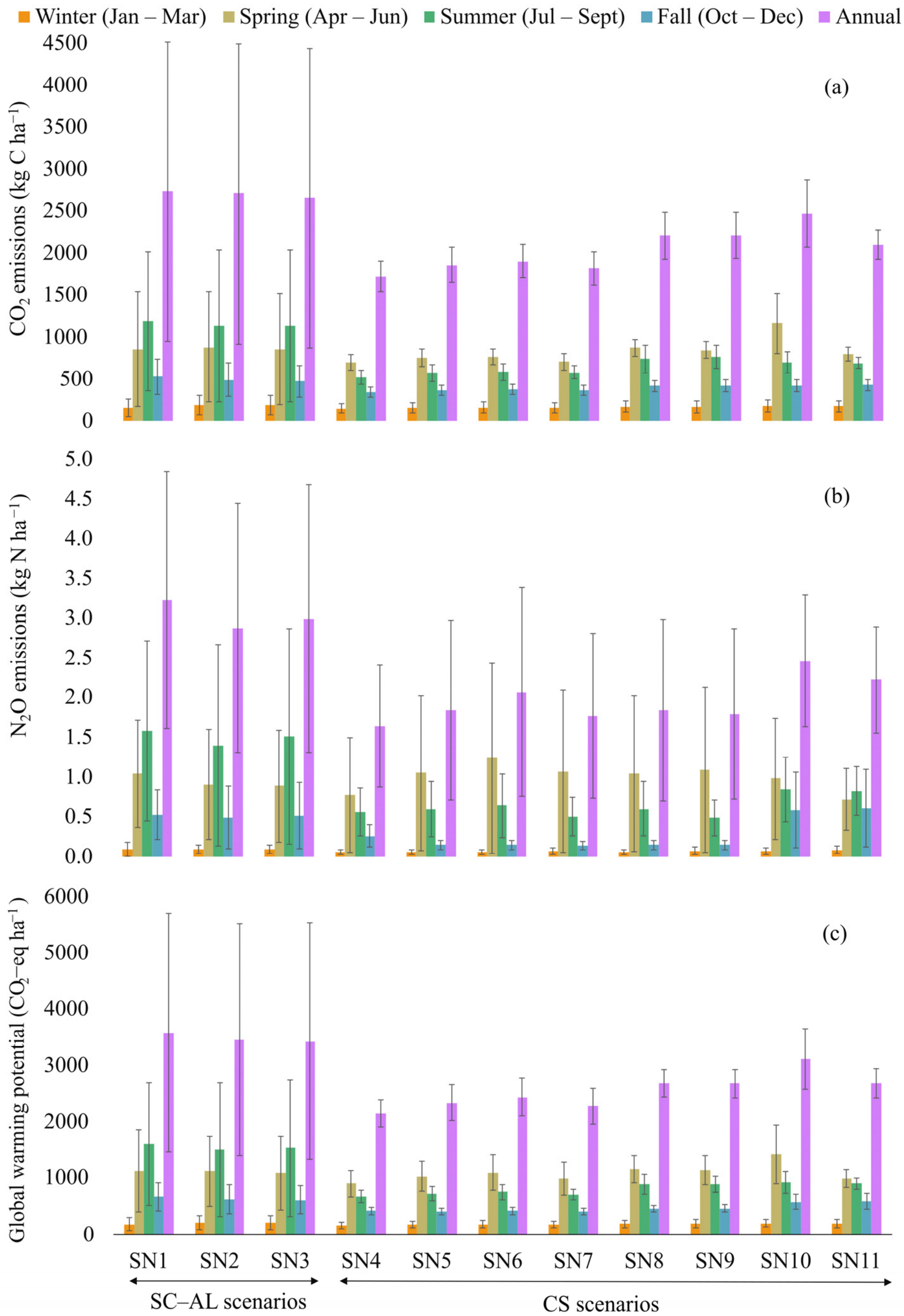

Figure 3. Seasonal and annual (**a**) CO_2 (kg C ha^{-1}) emissions, (**b**) N_2O emissions (kg C ha^{-1}), and (**c**) GWP (CO_2 eq-ha^{-1}) by scenario. Note: SN1–SN3 are silage corn and alfalfa-based scenarios, and SN4–SN11 are corn and soybean rotation-based scenarios. SN1 and SN4 are the two baseline scenarios considered in the study. Error bars represent variability.

Seasonal CO_2 emissions exhibited greater variation under SC-AL scenarios than the CS scenarios (Figure 3a). In the SC-AL scenarios, CO_2 emissions were higher in summer followed by spring, fall, and winter, with considerable interannual variability in spring and summer. However, in the CS scenario, CO_2 emissions were notably high in spring compared to summer. Across all scenarios, winter consistently exhibited the lowest CO_2 emissions, accounting for approximately 6–9% of the annual emissions, followed by the fall season (Figure 3a). In general, SC-AL scenarios contributed to more CO_2 emissions than CS scenarios. In the SC-AL scenarios, the summer season contributed approximately 42–43% of the annual CO_2 emissions, while in the CS scenarios, the spring season accounted for approximately 38–47% of the annual CO_2 emissions.

3.2. Annual and Seasonal N_2O Emission

Both average annual N_2O emissions and its interannual variability were higher in SC-AL than in CS scenarios (Figure 3b). The baseline SC-AL scenario resulted in more N_2O than other SC-based scenarios. Among the CS scenarios, when manure was applied to corn as a supplement to SF during the fall under CT, it resulted in the highest N_2O emissions. Conversely, the baseline CS scenarios exhibited the lowest levels of emissions. The application of half the total SF to corn as side dressing during spring led to increased N_2O emissions than the similar CS scenarios where the same amount of SF was applied during fall or during planting. In the CS system, NT practices resulted in reduced annual N_2O emissions relative to CT. CR did not cause any differences in N_2O emission under CT, whereas it marginally decreased emission under NT.

The seasonal patterns of N_2O flux exhibited a similar trend to that of CO_2 emissions (Figure 3b). Within the SC-AL scenarios, the summer season accounted for 49–50% of total annual N_2O emissions and exhibited greater interannual variability. However, in CS scenarios, emissions during spring shared 32–61% of annual emissions with greater interannual variability. Application of manure to corn during the fall to partially replace SF resulted in higher N_2O emissions under both tillage practices, nearly one and half times the N_2O emissions compared to the baseline CS scenario.

3.3. Annual and Seasonal Global Warming Potential

The annual GWP ranged from 2142 to 3579 CO_2-eq ha^{-1} and it followed a trend similar to that of annual CO_2 and N_2O emissions across most scenarios. The GWP of SC-AL scenarios exceeded that of all CS scenarios. Among these, the baseline SC-AL scenario resulted in the highest annual GWP, while the baseline CS scenario exhibited the lowest (Figure 3c). Among the CS scenarios where SF was exclusively applied to corn and lacked CR in rotation, the scenario involving 50% of total N as spring side dressing to corn exhibited the highest GWP. The inclusion of CR in CS systems led to an increase in GWP under both tillage conditions. Among the CS scenarios, the application of manure to corn in fall as a partial replacement for SF resulted in elevated GWP, reaching up to 968 CO_2 eq-ha^{-1} under CT compared to other CS scenarios. NT practice reduced the GWP of the CS system compared to CT (Figure 3c).

In the SC-AL scenarios, the GWP increased in the order of winter, fall, spring, and summer, with the latter season contributing 43.4% to 44.9% of the annual GWP. Similarly, in the CS scenarios, the order was winter, fall, summer, and spring, with the spring season contributing 36.8% to 45.6% of the annual GWP.

3.4. Annual Change in SOC

All scenarios resulted in higher SOC in 2020 compared to 1998 within a depth of 50 cm from the soil surface. The annual SOC change ranged between 265.7 and 809.2 kg C ha^{-1} yr^{-1} across all scenarios (Figure 4). Among the SC-AL scenarios, the scenario with WW as winter crop and four years of alfalfa in rotation retained the most SOC each year, followed by equivalent scenario with CR as winter crop.

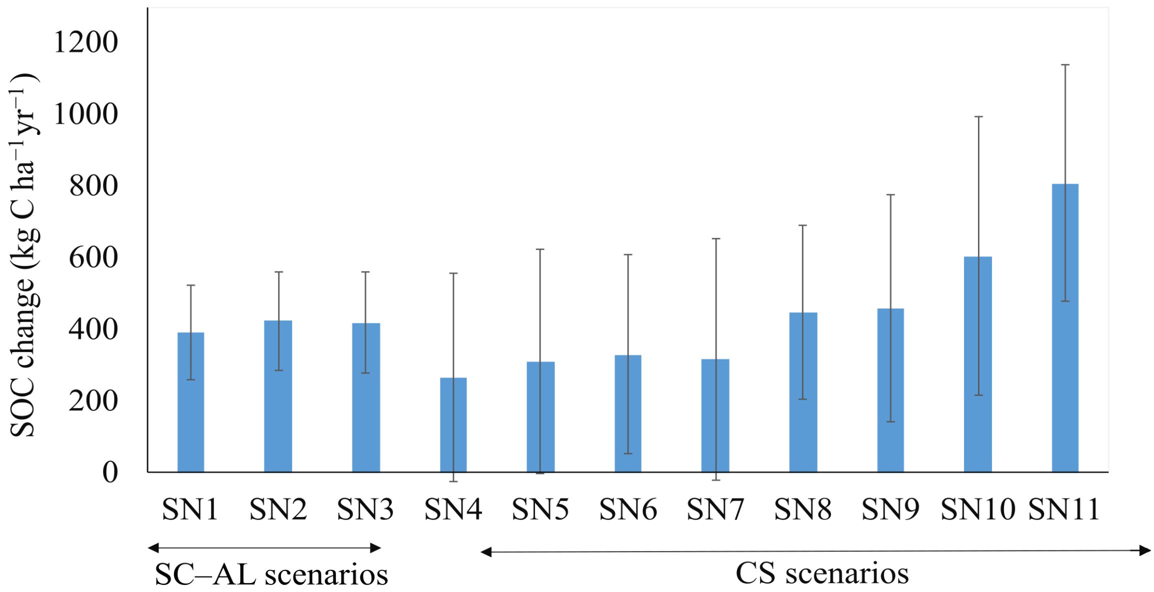

Figure 4. Annual change in SOC (kg C ha^{-1} yr^{-1}) during 1998–2020. Note: Variation represents SOC change from one complete crop rotation sequence to another.

The continuous use of NT practice increased carbon storage within a corn–soybean rotation over the 23 years period. It sequestered up to 809.2 kg C ha^{-1} yr^{-1} in the soil by 2020 when integrated with an N application that combines both manure and SF for corn compared to other CS scenarios. The use of CR in CS rotation resulted in higher SOC levels, with a more positive effect under NT. The application of 50% of the total N to corn as side dressing increased carbon sequestration (330.5 kg C ha^{-1} yr^{-1}) in comparison to other CS scenarios where corn received N solely from SF and CCs were absent. Replacing a portion of total SF required for corn to supply N with manure showed the greatest potential to sequester carbon among the CS scenarios. Specifically, under CT and NT practices, the application of manure led to SOC gains of 339.1 and 498.9 kg C ha^{-1} yr^{-1}, respectively, over the baseline CS scenario (Figure 4) for the study period. Moreover, substituting a portion of total SF required for corn with manure led to greater variations in SOC change from one complete crop rotation to another.

3.5. Dry Corn Silage and Corn Grain Yield

A SC-AL scenario with WW followed by four years of AL resulted in a higher dry silage yield than other SC-AL scenarios (Figure 5a). Likewise, in the CS scenarios, the highest corn grain yield was achieved when corn received a dual application of manure and SF as its N fertilizer source under CT practice. The side dressing was the best N management practice to get higher corn grain yield, particularly when N was exclusively supplied to corn via SF (Figure 5b). The NT practice resulted in a decrease in corn grain yield when compared to CT under equivalent management practices. CR demonstrated a minor corn yield advantage (31 kg C ha^{-1} yr^{-1}) when combined with tillage, compared to analogous management scenarios lacking CR.

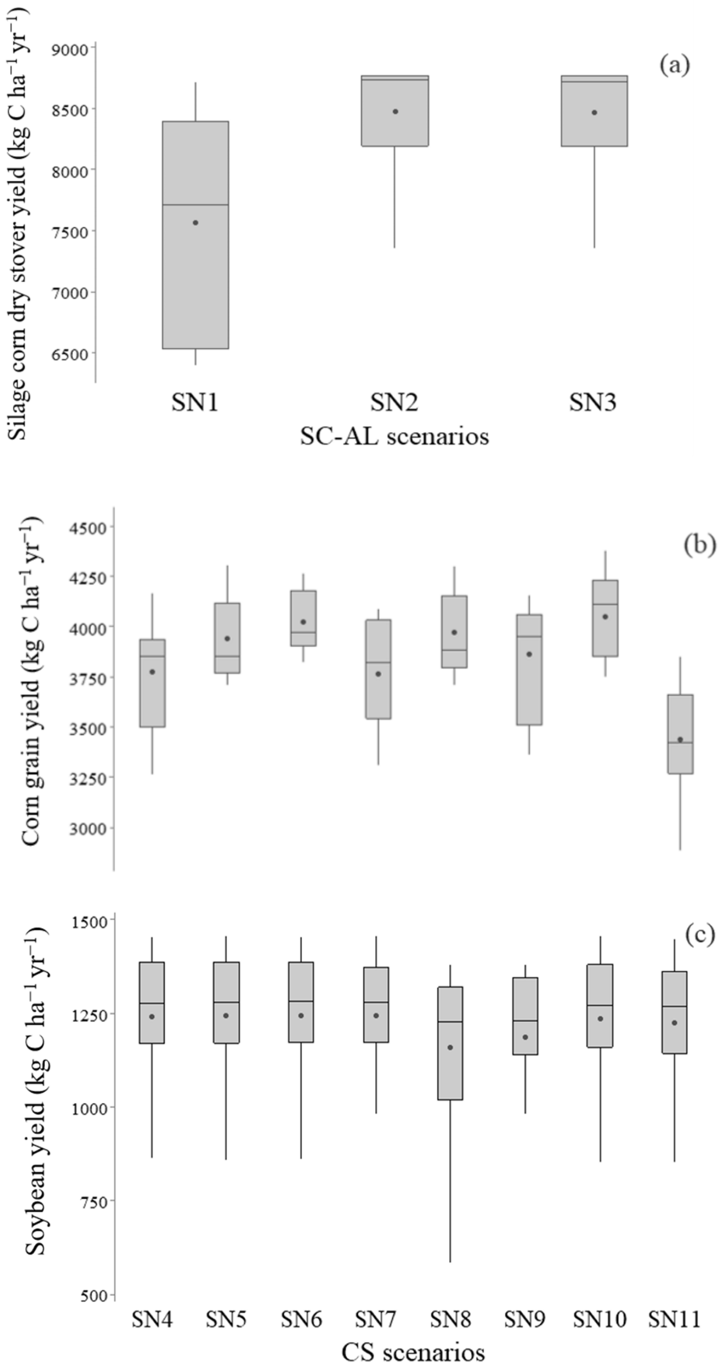

Figure 5. Simulated (**a**) corn dry stover yield (kg C ha^{-1} yr^{-1}), (**b**) corn grain yield (kg C ha^{-1} yr^{-1}), and (**c**) soybean yield (kg C ha^{-1} yr^{-1}) under different scenarios during 1998–2020. Note: A line dividing the interquartile range denotes the median, and the solid black circle inside the interquartile range denotes the mean.

3.6. Soybean Yield

The average annual soybean yields over the twenty-three-year simulation ranged from 1142 to 1234 kg C ha^{-1} (Figure 5c). The CS scenarios where N was supplied to corn solely through SF in the absence of CR resulted in almost similar soybean yields. Corn fertilization with manure during fall, followed by SF in spring, resulted in lower soybean yields compared to scenarios where corn was solely fertilized with SF. The CR reduced soybean yields by 90 and 59.8 kg C ha^{-1} under CT and NT compared to the baseline CS scenario (Figure 5c).

3.7. Tradeoffs among the Ecosystem Services

The alternative SC-AL scenarios (SN2–SN3) compared to the baseline SC-AL scenario (SN1) were found to offer benefits, including lower GHG emissions and GWP, and higher corn dry silage yield and SOC sequestration (Figure 6a–f). Morover, the adoption of CR as an alternative to WW in the SC-AL scenario, with fours years of alfalfa in rotation, lowered CO_2 emission and GWP, as well as reduced the SOC. Alternative scenarios of N application in CS rotation (SN5 and SN6) were found to be beneficial for SOC sequestration and crop yield enhancement relative to the baseline (SN4). However, they also led to higher GHGs emissions and an increased GWP. No-tillage practice exhibited superior environmental benefits with lower GHG emissions and GWP, along with higher SOC sequestration compared to tillage practice. Conversely, when it comes to provisioning services, particularly crop yields, NT practice generally demonstrated inferior performance compared to tillage practice. The incorporation of CR into CS rotation led to a mixed tradeoff in ecosystem services. While it contributed to an augmentation in carbon sequestration through an increase in SOC, it also led to an elevation in GHG emissions, and thus GWP. Similarly, it had a positive impact on corn grain yield, but conversely resulted in a decrease in soybean yield. The manure use as a partial substitute for SF to provide N to corn resulted in SOC enhancement. However, concurrently, it triggered an elevation in GHG emissions and GWP. The magnitude of this escalation was more pronounced under NT practice for SOC, and under CT for GHG emissions and GWP. Notably, the application of manure demonstrated benefits through increased corn yield only when combined with CT practice.

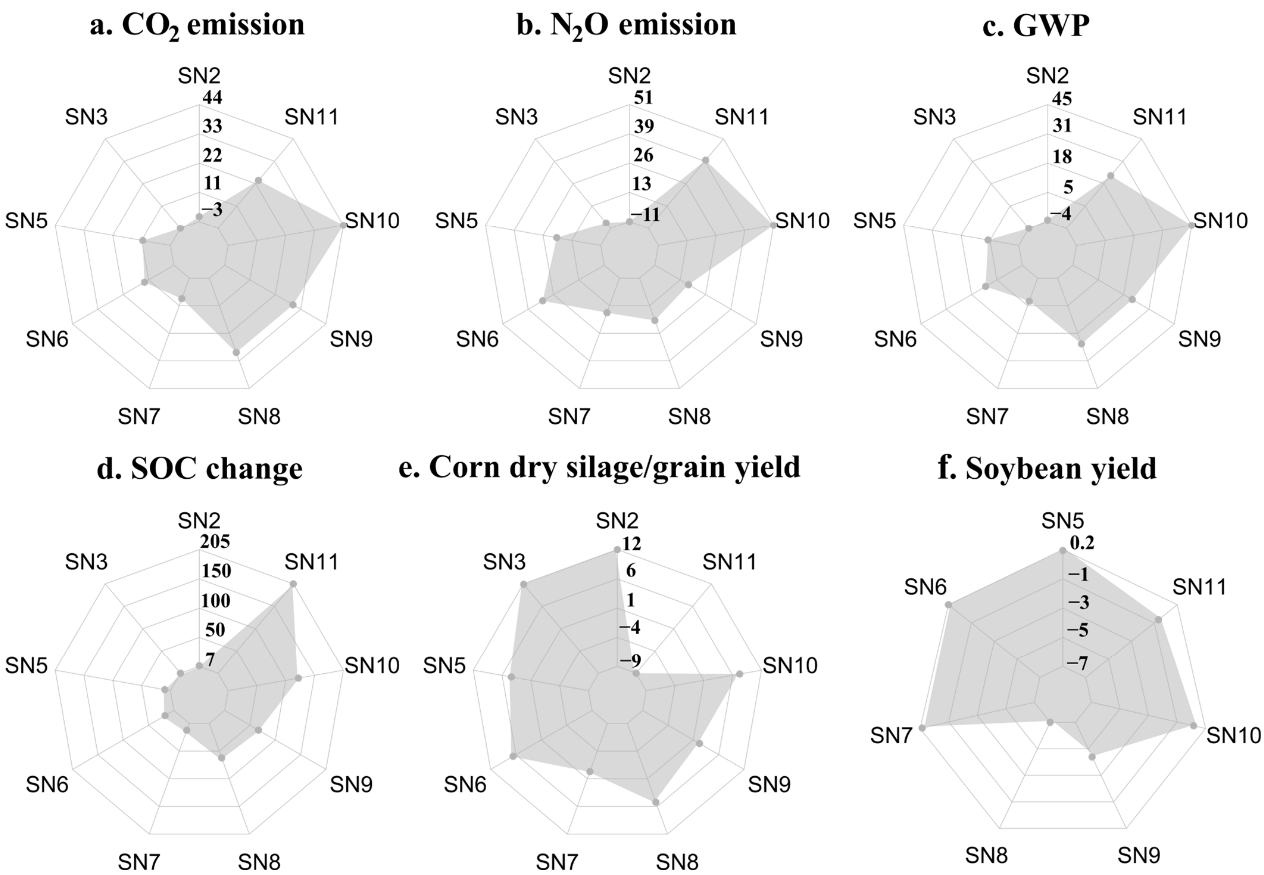

Figure 6. Percent change in average annual GHGs emissions (CO_2, N_2O), GWP, crop yield and SOC in various SC-AL and CS scenarios relative to their baseline scenarios. Note: While SN1 is the baseline scenario for SC-AL scenarios (i.e., SN2–SN3), SN4 is the baseline scenario for CS scenarios (i.e., SN5–SN11). In estimation of percent yield change, corn silage was considered for SC-AL scenarios, and corn and soybean yields were considered for CS scenarios.

4. Discussion

4.1. Seasonal Fluctuations in GHG Emissions

In SC-AL scenarios, an increase in CO_2 emissions during summer could be attributed to the use of manure in September before alfalfa planting, and to tilling in June to terminate alfalfa, followed by another round of tillage in July. Although CO_2 emissions reached the maximum in June with the termination of alfalfa, there was a consistent release of high CO_2 throughout July and August (Supplementary Figure S3a). Similar findings were observed for N_2O emissions (Supplementary Figure S3e). Generally, microbial activities tend to increase following the tillage operations, leading to a rise in soil CO_2 emissions [62]. Moreover, tillage enhances soil aeration by disturbing the soil, which consequently leads to an increase in GHG flux [63].

In CS scenarios under CT practice, the CO_2 and N_2O emissions were highest in the spring than in other seasons due to the timing of tillage practices and the application of N fertilizer (Supplementary Figure S3b–d). The initial tillage operations were performed in mid-April, followed by another round of tillage a week later. Subsequently, N fertilizer was also applied after the first tillage, and then again during the first week of May. In addition to these factors, variations in field emissions can be attributed to factors such as crop growth [64] and soil respiration, which are influenced by soil temperature and moisture levels [65] as reported by Biswas et al. [66] and Yilmaz [67]. As such, a noticeable increase in CO_2 emissions can still be observed in soybean fields with an increase in temperature in the growing season despite no-tillage and fertilizer operations (Supplementary Figure S3b–d). Similarly, during the winter season, which is characterized by lower temperatures and the absence of actively growing crops, emissions were lower.

4.2. Annual CO_2 and N_2O Emissions

All scenarios involving manure application resulted in more CO_2 than scenarios without manure. Our findings are in agreement with previous studies that have reported higher CO_2 emissions from fields treated with manure compared to fields where only SF was used [68–71]. A global meta-analysis on the impacts of manure application on soil carbon balance reported 27.6% higher CO_2 emissions associated with manure applications compared to chemical fertilizers [72]. The addition of manure as a substrate increases microbial biomass, which in turn stimulates better root growth and higher root respiration [73], contributing to increased CO_2 emissions [72,74].

Similarly, our study indicated that prolonged application of manure can lead to a gradual accumulation of C in the soil, which can result in increased N_2O emissions. Our findings are in agreement with a prior modeling study by Deng et al. [34] in which N_2O emissions from agricultural systems treated with poultry manure and inorganic fertilizer were estimated for over 100 years. The study reported that manure application can result in the highest annual N_2O emission as quickly as 40 years. This increase in N_2O emission may result from increased SOC from manure amendments, which provides more substrate, serving as an energy source for the microbial communities to thrive [75], which in turn induces denitrification [34,76].

The presence of alfalfa, which generally has a higher dinitrogen fixation capacity than soybean [77], could be the contributing factor to higher N_2O emissions in SC-AL scenarios. In addition to N fixing capacity of alfalfa, the breakdown of its fine roots after alfalfa termination enhances soil N availability, which promotes denitrification and hence higher N_2O emissions [78,79].

In this study, in most cases, both CO_2 and N_2O emissions were lower under NT than CT. The lower emissions under NT are consistent with findings from previous field studies [42,75,80]. The tillage practice impacts the decomposition of SOC and crop residues, subsequently influencing the carbon and nitrogen pools in the soil [81]. When crop residues are partially removed from the field, they tend to accumulate on the soil surface under NT. These accumulated residues decompose at a slower rate compared to when they are incorporated into the soil through tillage, which disturbs the soil, increases soil temperature and aeration, and promotes the formation of macroaggregates that favor microbial population [82]. Consequently, the decomposition rate increases [81,82], leading to higher emissions. However, with CR in CS rotation, the model predicted an equal magnitude of CO_2 emissions under both CT and NT.

Typically, tillage increases the rates of residue N mineralization and soil nitrate availability, which in turn stimulates increased denitrification processes. A minimal difference in N_2O emissions between tillage practices observed in this study may partly be attributed to the effect of tile drains on nutrient dynamics. Tile drainage improves soil drainage, which promotes aerobic conditions within the soil and increases the likelihood of soil nitrate transport down the soil layers, thereby reducing N_2O emissions [83].

CS scenarios with CR exhibited higher annual CO_2 emissions compared to similar scenarios without CR. This can be attributed to the increased soil carbon inputs resulting from the incorporation of CR residues into the soil. The higher carbon substrates, microbial activity, and soil respiration associated with CR contribute to elevated CO_2 emissions [84,85]. A global meta-analysis that examined the effects of CCs on GHG emissions, based on 41 field-based experiments (including nine in or near the Midwest region), also reported increased CO_2 emissions with the presence of CCs compared to their absence [86]. On the other hand, CR has no significant effect on N_2O emissions under tilled conditions. This can be explained by the fact that biomass with a high carbon-to-nitrogen (C:N) ratio can result in partial immobilization of N [87]. Due to this reason, the CR incorporation might have caused N_2O emissions similar to other scenarios without CR. The lower N_2O emissions observed under NT with CR residue are consistent with findings from other studies [85,86].

When chemical fertilizers were the sole N source for corn in CS scenarios with no CR, the side dressing of chemical N fertilizer led to higher CO_2 and N_2O emissions compared to other scenarios. Based on an experiment conducted in Purdue, Illinois, in 2010 and 2011, Burzaco et al. [88] observed higher N_2O-N flux by 0.6 kg with a side dressing of chemical fertilizer compared to pre-emergence applications. This difference was attributed to several factors, including higher water-filled pore spaces, higher temperature, and greater availability of mineral N. In the SN6 scenario of this study, half of the total N from SF was applied to corn on June 3rd. In other similar CS scenarios without side dressing, the same amount of N was applied to corn on May 6th, at the time of planting. However, the average maximum and minimum temperatures in June were 4.8 °C and 5.3 °C higher, respectively, compared to May. Therefore, higher temperatures and availability of mineral nitrogen might have played a major role in higher N_2O and CO_2 emissions with side dressing compared to the early application of chemical N fertilizer. Typically, the addition of N fertilizer increases microbial activities, which results in higher CO_2 fluxes [89] along with N_2O.

4.3. SOC Change

Manure application was found to be a contributor to the buildup of SOC, as evidenced by the increased SOC levels in the scenario where manure was applied compared to the scenarios where only chemical fertilizer was used to supply N to corn. This finding is consistent with prior studies. A meta-analysis reported that manure application leads to a greater increase in soil carbon stock rates when compared to other practices, such as crop residue, inorganic N fertilizers, and CCs on changes in SOC [7].

Cover crops play a significant role in increasing carbon sequestration, with sequestration rates ranging from 0.1 to 1 Mg C ha^{-1} yr^{-1} depending on factors such as initial soil carbon levels, the number of years the cover crops were planted, and biomass production [90]. In this study, CR in CS rotation was associated with increased SOC compared to similar CS scenarios without CR (Figure 3). Long-term (>20 years) simulation studies have shown a similar increase in SOC level from incorporating over-winter CCs in crop rotations [91–93]. Austin et al. [94] observed a significant portion of soil C in the top 10 cm of soil originated from mineralized C inputs after its termination, suggesting that CC incorporation in rotations every year results in soil C accumulation. Therefore, CC detritus is mainly responsible for annual changes in the SOC [17,92].

Consistent with prior studies [17,95–97], our results also demonstrated higher SOC sequestration under NT compared to CT. Under NT practices, crop residues or manure tend to accumulate on the soil surface. This accumulation has several effects, such as modifying soil temperature [62] and promoting slow [81,98] and partial [98] decomposition of the residues. As a result, carbon losses are reduced, leading to lower loss of soil C through CO_2 emissions [62].

4.4. Dry Silage, Corn, and Soybean Grain Yield

Corn grain yield in the CS scenarios was higher when manure partially substituted SF as a N source. This increase in corn grain yield is expected due to improvements in soil structure, water-holding capacity, and soil fertility status resulting from the continuous application of manure [99]. These improvements provide favorable conditions for plant growth and development, ultimately leading to enhanced crop yield. This suggests that manure could be used as a supplement to chemical N fertilizer and can be equally effective in promoting crop growth and yield as chemical N fertilizer. O'Brien and Hatfield [100], in their meta-analysis, concluded that row crops fertilized with manure can achieve similar yields to those fertilized with SF if the manure is applied based on plant available N. Furthermore, the silage corn–WW–alfalfa scenario with four years of alfalfa cultivation may be a better option compared to three years of alfalfa or replacing wheat with CR.

Prior studies have reported mixed findings regarding the impact of CCs on crop yields [20]. In our study, we observed a slight advantage of CR in corn yields under tilled conditions. Research conducted by the Iowa Learning Farms and Practical Farmers of Iowa on cooperating farms from 2009 to 2012 reported that CR did not significantly affect corn yields, and with proper management, CR does not hurt corn yield [101]. However, the incorporation of CR into the soil before soybean planting lowered the soybean yields under both tilled and NT conditions. In field conditions, rye causes allelopathic effects on the following crop [102], which reduce soybean yields. Tyler [103] also observed lower average soybean yields with CR under both CT and NT from three-year research in Stoneville, Mississippi.

The lower corn yield under NT compared to CT practices observed in this study is consistent with the number of previous studies [104–107]. There are multiple reasons for a lower corn yield under NT. These include the accumulation of residues on the soil surface, which reduces soil temperature [108] and delays seed germination and emergence, leading to poor crop establishment [109]. Additionally, poor root growth can occur due to increased penetration resistance [108,110,111]. Though NT enhances SOC levels, the nutrient supply capacity is reduced due to a higher fraction of macroaggregates that are resistant to microbial decomposition [112].

Corn plants rapidly uptake nitrogen in active growth stages in summer; therefore, splitting the total N dose before planting and after planting as a side dressing helps to improve nitrogen use efficiency [113]. Corn requires high amounts of N only after four weeks of planting as only five percent of N is required for the first four to six weeks after planting [114]. Hence, the application of chemical fertilizer as a side dressing 28 days after planting when the plant's demand for N is greatest might have improved the N uptake, leading to better crop growth and yield. Purucker and Steinke [115] have also found greater agronomic efficiency with split application of N fertilizer as pre-emergence and side dressing during the vegetative phase than with only pre-emergence application in Michigan corn fields. Similar advantages of side dressing over a single-pass N application strategy have been demonstrated by other researchers in the United States [116].

5. Conclusions

This study used a calibrated and validated DNDC model to assess the impacts of tillage, CCs, and fertilizer practices on SOC, GHG emissions, and crop productivity in corn-based cropping systems in the U.S. Midwest. Based on 23 years of simulation, the partial substitution of SF with manure enhanced corn yields by 7.2% compared to the baseline CS scenario under tilled conditions while causing a slight reduction in soybean yields by 0.6 and 1.3% under CT and NT practices, respectively. Additionally, continuous application of manure improved SOC levels up to 339 and 499 kg ha^{-1} yr^{-1} by year 23 under CT and NT, respectively, compared to year 1. However, this practice also resulted in higher GHGs emissions from corn–soybean systems compared to SF scenarios. The NT practice slightly reduced corn grain yields compared to CT but increased SOC levels. The fall application of SF lowered GWP. However, it was accompanied by reduced corn grain yields and a lower increase in SOC compared to alternative N fertilization methods. The CR contributed more to global warming through GHG emissions from CS rotation, but it improved SOC under two tillage practices with minimal impact on crop yield. The silage corn followed by WW and four years of alfalfa offered a comparative advantage in terms of dry silage yield over the same rotation with three years of alfalfa. While the study offers comprehensive insights into the potential agronomic and environmental benefits of adopting various management practices with and without manure and/or CR, the high spatial and temporal variability of soil, weather, and management conditions that vary from site to site could limit the applicability of these findings to other areas with different weather and soil conditions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16135622/s1, Figure S1a,b: Seasonal and annual average a) temperature (°C) and total precipitation (mm) at study location during 1998–2020; Figure S2: Seasonal and annual CH_4 emissions under each scenario. Note: SN1-SN3 are silage corn and alfalfa crop based scenarios (SC-AL scenarios), SN4-SN11 are corn and soybean rotation based scenarios (CS scenarios); Figure S3a–h: Fluctuation in CO_2 (a–d) and N_2O (e–h) from a one complete crop rotation [SC-WW-AL×4 (1st row) as representative of SC-AL scenario; C-S[F+P] (2nd row) as representative of CS scenario with half amount of N applied to corn through synthetic fertilizer during fall; C-S[PP+SD] (3rd row) as representative of CS scenario with half amount of N applied to corn as side dressing and C-S[M+SF] (4th row)] as representative of CS scenario with manure application to corn to replace synthetic fertilizer partially; Table S1: Management practices under varying scenarios with silage corn, winter wheat/ cereal rye and alfalfa in rotation; Table S2: Management practices under varying scenarios with grain corn and soybean in rotation with cereal rye as cover crop.

Author Contributions: Conceptualization, S.K. and A.S.; data curation, G.S.; formal analysis, A.P.T.; original draft, A.P.T. and G.S.; reviewing and editing, S.K. and A.S.; supervision, S.K.; funding acquisition, S.K. and A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the United States Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) through Awards 2017-67021-26141 and 2019-67019-29310, and by the Sustainability Research Seed Grant program and Hatch Project #NC1195.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Prokopy, L.S.; Gramig, B.M.; Bower, A.; Church, S.P.; Ellison, B.; Gassman, P.W.; Genskow, K.; Gucker, D.; Hallett, S.G.; Hill, J.; et al. The Urgency of Transforming the Midwestern U.S. Landscape into More than Corn and Soybean. *Agric. Hum. Values* **2020**, *37*, 537–539. [CrossRef] [PubMed]
2. Canales, E.; Bergtold, J.S.; Williams, J.R. Modeling the Choice of Tillage Used for Dryland Corn, Wheat and Soybean Production by Farmers in Kansas. *Agric. Resour. Econ. Rev.* **2018**, *47*, 90–117. [CrossRef]
3. Thompson, N.M.; Reeling, C.J.; Fleckenstein, M.R.; Prokopy, L.S.; Armstrong, S.D. Examining Intensity of Conservation Practice Adoption: Evidence from Cover Crop Use on U.S. Midwest Farms. *Food Policy* **2021**, *101*, 102054. [CrossRef]

4. Volsi, B.; Higashi, G.E.; Bordin, I.; Telles, T.S. The Diversification of Species in Crop Rotation Increases the Profitability of Grain Production Systems. *Sci. Rep.* **2022**, *12*, 19849. [CrossRef] [PubMed]
5. Sangotayo, A.O.; Chellappa, J.; Sekaran, U.; Bansal, S.; Angmo, P.; Jasa, P.; Kumar, S.; Iqbal, J. Long-Term Conservation and Conventional Tillage Systems Impact Physical and Biochemical Soil Health Indicators in a Corn–Soybean Rotation. *Soil. Sci. Soc. Am. J.* **2023**, *87*, 1056–1071. [CrossRef]
6. Yuan, M.; Bi, Y.; Han, D.; Wang, L.; Wang, L.; Fan, C.; Zhang, D.; Wang, Z.; Liang, W.; Zhu, Z.; et al. Long-Term Corn–Soybean Rotation and Soil Fertilization: Impacts on Yield and Agronomic Traits. *Agronomy* **2022**, *12*, 2554. [CrossRef]
7. Bolinder, M.A.; Crotty, F.; Elsen, A.; Frac, M.; Kismányoky, T.; Lipiec, J.; Tits, M.; Tóth, Z.; Kätterer, T. The Effect of Crop Residues, Cover Crops, Manures and Nitrogen Fertilization on Soil Organic Carbon Changes in Agroecosystems: A Synthesis of Reviews. *Mitig. Adapt. Strateg. Glob. Change* **2020**, *25*, 929–952. [CrossRef]
8. Giusti, B.; Hogue, R.; Jeanne, T.; Lucotte, M. Impacts of Winter Wheat and Cover Crops on Soil Microbial Diversity in a Corn–Soybean No-till Cropping System in Quebec (Canada). *Agrosyst. Geosci. Environ.* **2023**, *6*, e20349. [CrossRef]
9. Kovács, G.P.; Simon, B.; Balla, I.; Bozóki, B.; Dekemati, I.; Gyuricza, C.; Percze, A.; Birkás, M. Conservation Tillage Improves Soil Quality and Crop Yield in Hungary. *Agronomy* **2023**, *13*, 894. [CrossRef]
10. Yang, X.; Xiong, J.; Du, T.; Ju, X.; Gan, Y.; Li, S.; Xia, L.; Shen, Y.; Pacenka, S.; Steenhuis, T.S.; et al. Diversifying Crop Rotation Increases Food Production, Reduces Net Greenhouse Gas Emissions and Improves Soil Health. *Nat. Commun.* **2024**, *15*, 198. [CrossRef] [PubMed]
11. Cambron, T.W.; Deines, J.M.; Lopez, B.; Patel, R.; Liang, S.-Z.; Lobell, D.B. Further Adoption of Conservation Tillage Can Increase Maize Yields in the Western US Corn Belt. *Environ. Res. Lett.* **2024**, *19*, 054040. [CrossRef]
12. Chen, B.; Gramig, B.M.; Yun, S.D. Conservation Tillage Mitigates Drought-Induced Soybean Yield Losses in the US Corn Belt. *Q. Open* **2021**, *1*, qoab007. [CrossRef]
13. Lee, S.; Chu, M.L.; Guzman, J.A.; Botero-Acosta, A. A Comprehensive Modeling Framework to Evaluate Soil Erosion by Water and Tillage. *J. Environ. Manag.* **2021**, *279*, 111631. [CrossRef] [PubMed]
14. Steponavičienė, V.; Rudinskienė, A.; Žiūraitis, G.; Bogužas, V. The Impact of Tillage and Crop Residue Incorporation Systems on Agrophysical Soil Properties. *Plants* **2023**, *12*, 3386. [CrossRef] [PubMed]
15. Skaalsveen, K.; Clarke, L. Impact of No-Tillage on Water Purification and Retention Functions of Soil. *J. Soil. Water Conserv.* **2021**, *76*, 116–129. [CrossRef]
16. Li, Y.; Chen, J.; Drury, C.F.; Liebig, M.; Johnson, J.M.F.; Wang, Z.; Feng, H.; Abalos, D. The Role of Conservation Agriculture Practices in Mitigating N_2O Emissions: A Meta-Analysis. *Agron. Sustain. Dev.* **2023**, *43*, 63. [CrossRef]
17. Huang, Y.; Ren, W.; Grove, J.; Poffenbarger, H.; Jacobsen, K.; Tao, B.; Zhu, X.; McNear, D. Assessing Synergistic Effects of No-Tillage and Cover Crops on Soil Carbon Dynamics in a Long-Term Maize Cropping System under Climate Change. *Agric. For. Meteorol.* **2020**, *291*, 108090. [CrossRef]
18. Zhao, X.; Christianson, L.E.; Harmel, D.; Pittelkow, C.M. Assessment of Drainage Nitrogen Losses on a Yield-Scaled Basis. *Field Crops Res.* **2016**, *199*, 156–166. [CrossRef]
19. Elli, E.F.; Ciampitti, I.A.; Castellano, M.J.; Purcell, L.C.; Naeve, S.; Grassini, P.; La Menza, N.C.; Moro Rosso, L.; de Borja Reis, A.F.; Kovács, P.; et al. Climate Change and Management Impacts on Soybean N Fixation, Soil N Mineralization, N_2O Emissions, and Seed Yield. *Front. Plant Sci.* **2022**, *13*, 849896. [CrossRef] [PubMed]
20. Abdalla, M.; Hastings, A.; Cheng, K.; Yue, Q.; Chadwick, D.; Espenberg, M.; Truu, J.; Rees, R.M.; Smith, P. A Critical Review of the Impacts of Cover Crops on Nitrogen Leaching, Net Greenhouse Gas Balance and Crop Productivity. *Glob. Change Biol.* **2019**, *25*, 2530–2543. [CrossRef] [PubMed]
21. Blanco-Canqui, H.; Ruis, S.J. No-Tillage and Soil Physical Environment. *Geoderma* **2018**, *326*, 164–200. [CrossRef]
22. Mitchell, J.P.; Shrestha, A.; Mathesius, K.; Scow, K.M.; Southard, R.J.; Haney, R.L.; Schmidt, R.; Munk, D.S.; Horwath, W.R. Cover Cropping and No-Tillage Improve Soil Health in an Arid Irrigated Cropping System in California's San Joaquin Valley, USA. *Soil. Tillage Res.* **2017**, *165*, 325–335. [CrossRef]
23. Negassa, W.C.; Price, R.F.; Basir, A.; Snapp, S.S.; Kravchenko, A. Cover Crop and Tillage Systems Effect on Soil CO_2 and N_2O Fluxes in Contrasting Topographic Positions. *Soil. Tillage Res.* **2015**, *154*, 64–74. [CrossRef]
24. Deines, J.M.; Guan, K.; Lopez, B.; Zhou, Q.; White, C.S.; Wang, S.; Lobell, D.B. Recent Cover Crop Adoption Is Associated with Small Maize and Soybean Yield Losses in the United States. *Glob. Change Biol.* **2023**, *29*, 794–807. [CrossRef] [PubMed]
25. Bourns, M.; Manzar, E.K.; Nelson, N.; Roozeboom, K.; Kluitenberg, G.; Hettiarachchi, G.; Yeager, E.; Tomlinson, P.; Presley, D. Corn and Soybean Yield as Affected by Cover Crop and Phosphorus Fertilizer Management. *Kans. Agric. Exp. Stn. Res. Rep.* **2023**, *9*, 5. [CrossRef]
26. Kopittke, P.M.; Dalal, R.C.; Finn, D.; Menzies, N.W. Global Changes in Soil Stocks of Carbon, Nitrogen, Phosphorus, and Sulphur as Influenced by Long-Term Agricultural Production. *Glob. Change Biol.* **2017**, *23*, 2509–2519. [CrossRef]
27. Francis Clar, J.T.; Anex, R.P. Measuring Frequently during Peak Soil N_2O Emissions Is More Important than Choosing the Time of Day to Sample. *Biogeosci.Discuss.* **2019**, *2019*, 1–21. [CrossRef]
28. Lafond, G.; Walley, F.; Schoenau, J.; May, W.; Holzapfel, C.; McKell, J. Long-Term vs Short-Term Conservation Tillage. In Proceedings of the 20th Annual Meeting and Conference of the Saaskatchewan Soil Conservation Association, Regina, SK, Canada, 12–13 February 2008.
29. Myers, R. *How Conservation Practices Influence Agricultural Economic Returns*; Agree: Washington, DC, USA, 2023; pp. 1–19.

30. Kephe, P.N.; Ayisi, K.K.; Petja, B.M. Challenges and Opportunities in Crop Simulation Modelling under Seasonal and Projected Climate Change Scenarios for Crop Production in South Africa. *Agric. Food Secur.* **2021**, *10*, 10. [CrossRef]
31. Timilsina, A.P.; Baigorria, G.A.; Wilhite, D.; Shulski, M.; Heeren, D.; Romero, C.; Fensterseifer, C. Soybean Response under Climatic Scenarios with Changed Mean and Variability under Rainfed and Irrigated Conditions in Major Soybean Growing States of the United States. *J. Agric. Sci.* **2023**, *161*, 157–174. [CrossRef]
32. Bista, P.; Hartman, M.D.; DelGrosso, S.J.; Thapa, V.R.; Ghimire, R. Simulating Long-Term Soil Carbon Storage, Greenhouse Gas Balance, and Crop Yields in Semi-Arid Cropping Systems Using DayCent Model. *Nutr. Cycl. Agroecosyst.* **2024**, *128*, 99–114. [CrossRef]
33. Basche, A.D. *Climate-Smart Agriculture in Midwest Cropping Systems: Evaluating the Benefits and Tradeoffs of Cover Crops*; Iowa State University: Ames, IA, USA, 2015.
34. Deng, Q.; Hui, D.; Wang, J.; Yu, C.-L.; Li, C.; Reddy, K.C.; Dennis, S. Assessing the Impacts of Tillage and Fertilization Management on Nitrous Oxide Emissions in a Cornfield Using the DNDC Model. *J. Geophys. Res. Biogeosci.* **2016**, *121*, 337–349. [CrossRef]
35. Williams, M.R.; King, K.W.; Ford, W.; Fausey, N.R. Edge-of-Field Research to Quantify the Impacts of Agricultural Practices on Water Quality in Ohio. *J. Soil Water Conserv.* **2016**, *71*, 9–12. [CrossRef]
36. Smith, W.; Grant, B.; Qi, Z.; He, W.; VanderZaag, A.; Drury, C.F.; Helmers, M. Development of the DNDC Model to Improve Soil Hydrology and Incorporate Mechanistic Tile Drainage: A Comparative Analysis with RZWQM2. *Environ. Model. Softw.* **2020**, *123*, 104577. [CrossRef]
37. Gheisari, A.; Asgharipour, M.R.; Mousavi-Nik, M.; Ghanbari, A.; Javaheri, M.A. Utilization of the DNDC Model to Estimate Yield and CO_2 and CH_4 Emissions in a Cotton-Wheat Rotation under the Influence of Various Tillage Treatments. *Ecol. Model.* **2023**, *481*, 110357. [CrossRef]
38. Jiang, R.; Yang, J.Y.; Drury, C.F.; He, W.; Smith, W.N.; Grant, B.B.; He, P.; Zhou, W. Assessing the Impacts of Diversified Crop Rotation Systems on Yields and Nitrous Oxide Emissions in Canada Using the DNDC Model. *Sci. Total Environ.* **2021**, *759*, 143433. [CrossRef] [PubMed]
39. Jiang, Q.; Madramootoo, C.A.; Qi, Z. Soil Carbon and Nitrous Oxide Dynamics in Corn (*Zea Mays* L.) Production under Different Nitrogen, Tillage and Residue Management Practices. *Field Crops Res.* **2022**, *277*, 108421. [CrossRef]
40. Jiang, Z.; Yang, S.; Smith, P.; Abdalla, M.; Pang, Q.; Xu, Y.; Qi, S.; Hu, J. Development of DNDC-BC Model to Estimate Greenhouse Gas Emissions from Rice Paddy Fields under Combination of Biochar and Controlled Irrigation Management. *Geoderma* **2023**, *433*, 116450. [CrossRef]
41. Costa, C.; Galford, G.L.; Coe, M.T.; Macedo, M.; Jankowski, K.; O'Connell, C.; Neill, C. Modeling Nitrous Oxide Emissions from Large-Scale Intensive Cropping Systems in the Southern Amazon. *Front. Sustain. Food Syst.* **2021**, *5*, 701416. [CrossRef]
42. Bhattarai, A.; Steinbeck, G.; Grant, B.B.; Kalcic, M.; King, K.; Smith, W.; Xu, N.; Deng, J.; Khanal, S. Development of a Calibration Approach Using DNDC and PEST for Improving Estimates of Management Impacts on Water and Nutrient Dynamics in an Agricultural System. *Environ. Model. Softw.* **2022**, *157*, 105494. [CrossRef]
43. NADP. *2018 Annual Summary*; National Atmospheric Deposition Program: Madison, WI, USA, 2019.
44. Gridded Soil Survey Geographic (gSSURGO) Database | Natural Resources Conservation Service. Available online: https://www.nrcs.usda.gov/resources/data-and-reports/gridded-soil-survey-geographic-gssurgo-database (accessed on 22 June 2024).
45. USDA ARS SPAW. Available online: https://www.ars.usda.gov/research/software/download/?softwareid=492&modecode=80-42-05-10 (accessed on 25 March 2024).
46. PRISM. Climate Group, Oregon State U. Available online: https://prism.oregonstate.edu/ (accessed on 6 March 2023).
47. NASA POWER | Prediction of Worldwide Energy Resources. Available online: https://power.larc.nasa.gov/ (accessed on 22 June 2023).
48. USDA. NASS USDA-National Agricultural Statistics Service-Quick Stats Lite. Available online: https://www.nass.usda.gov/Quick_Stats/Lite/index.php (accessed on 30 October 2022).
49. Kalcic, M.M.; Kirchhoff, C.; Bosch, N.; Muenich, R.L.; Murray, M.; Griffith Gardner, J.; Scavia, D. Engaging Stakeholders to Define Feasible and Desirable Agricultural Conservation in Western Lake Erie Watersheds. *Environ. Sci. Technol.* **2016**, *50*, 8135–8145. [CrossRef] [PubMed]
50. Panuska, J. *The Basics of Agricultural Tile Drainage*; University of Wisconsin-Madison: Madison, WI, USA, 2018.
51. Manitoba Agriculture, Food and Rural Initiatives. *Calculating Manure Application Rates*; 2009. Available online: https://www.gov.mb.ca/agriculture/environment/nutrient-management/pubs/mmf_calcmanureapprates_factsheet.pdf (accessed on 22 May 2022).
52. Sundermeier, A. Manure and Compost: Nitrogen Availability in Organic Production. Available online: https://ohioline.osu.edu/factsheet/anr-34 (accessed on 29 May 2023).
53. Perlman, J.; Hijmans, R.J.; Horwath, W.R. Modelling Agricultural Nitrous Oxide Emissions for Large Regions. *Environ. Model. Softw.* **2013**, *48*, 183–192. [CrossRef]
54. Tabatabaie, S.M.H.; Murthy, G.S. Effect of Geographical Location and Stochastic Weather Variation on Life Cycle Assessment of Biodiesel Production from Camelina in the Northwestern USA. *Int. J. Life Cycle Assess.* **2017**, *22*, 867–882. [CrossRef]
55. Tabatabaie, S.M.H.; Bolte, J.P.; Murthy, G.S. A Regional Scale Modeling Framework Combining Biogeochemical Model with Life Cycle and Economic Analysis for Integrated Assessment of Cropping Systems. *Sci. Total Environ.* **2018**, *625*, 428–439. [CrossRef] [PubMed]

56. US EPA. Understanding Global Warming Potentials. Available online: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials (accessed on 15 May 2023).
57. Myhre, G.; Shindell, D.; Bréon, F.-M.; Collins, W.; Fuglestvedt, J.; Huang, J.; Koch, D.; Lamarque, J.-F.; Lee, D.; Mendoza, B.; et al. Anthropogenic and Natural Radiative Forcing. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group. I to the Fifth Assessment Report. of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Doschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK, 2013; pp. 659–740.
58. USDA. NASS CropScape-NASS CDL Program. Available online: https://nassgeodata.gmu.edu/CropScape/ (accessed on 14 February 2024).
59. Lark, T.J.; Salmon, J.M.; Gibbs, H.K. Cropland Expansion Outpaces Agricultural and Biofuel Policies in the United States. *Environ. Res. Lett.* **2015**, *10*, 044003. [CrossRef]
60. Zhang, X.; Lark, T.J.; Clark, C.; Yuan, Y.; LeDuc, S.D. Grassland-to-Cropland Conversion Increased Soil, Nutrient, and Carbon Losses in the US Midwest between 2008 and 2016. *Environ. Res. Lett.* **2021**, *16*, 054018. [CrossRef] [PubMed]
61. Wright, C.K.; Wimberly, M.C. Recent Land Use Change in the Western Corn Belt Threatens Grasslands and Wetlands. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 4134–4139. [CrossRef] [PubMed]
62. Al-Kaisi, M.M.; Yin, X. Tillage and Crop Residue Effects on Soil Carbon and Carbon Dioxide Emission in Corn-Soybean Rotations. *J. Environ. Qual.* **2005**, *34*, 437–445. [CrossRef] [PubMed]
63. Reicosky, D.C.; Lindstrom, M.J. Fall Tillage Method: Effect on Short-Term Carbon Dioxide Flux from Soil. *Agron. J.* **1993**, *85*, 1237–1243. [CrossRef]
64. Flynn, N.E.; Stewart, C.E.; Comas, L.H.; Del Grosso, S.J.; Schnarr, C.; Schipanski, M.; von Fischer, J.C.; Stuchiner, E.R.; Fonte, S.J. Deficit Irrigation Impacts on Greenhouse Gas Emissions under Drip-Fertigated Maize in the Great Plains of Colorado. *J. Environ. Qual.* **2022**, *51*, 877–889. [CrossRef]
65. Ding, W.; Cai, Y.; Cai, Z.; Yagi, K.; Zheng, X. Soil Respiration under Maize Crops: Effects of Water, Temperature, and Nitrogen Fertilization. *Soil. Sci. Soc. Am. J.* **2007**, *71*, 944–951. [CrossRef]
66. Biswas, J.C.; Haque, M.M.; Hossain, M.B.; Maniruzzaman, M.; Zahan, T.; Rahman, M.M.; Sen, R.; Ishtiaque, S.; Chaki, A.K.; Ahmed, I.M.; et al. Seasonal Variations in Grain Yield, Greenhouse Gas Emissions and Carbon Sequestration for Maize Cultivation in Bangladesh. *Sustainability* **2022**, *14*, 9144. [CrossRef]
67. Yılmaz, G. Seasonal Variations in Soil CO_2 Emissions under Continuous Field Crop Production in Semi Arid Southeastern Turkey. *Appl. Ecol. Environ. Res.* **2019**, *17*, 6563–6579. [CrossRef]
68. Sherman, J.F.; Young, E.O.; Jokela, W.E.; Cavadini, J. Impacts of Low-Disturbance Dairy Manure Incorporation on Ammonia and Greenhouse Gas Fluxes in a Corn Silage–Winter Rye Cover Crop System. *J. Environ. Qual.* **2021**, *50*, 836–846. [CrossRef] [PubMed]
69. Shimizu, M.; Marutani, S.; Desyatkin, A.R.; Jin, T.; Hata, H.; Hatano, R. The Effect of Manure Application on Carbon Dynamics and Budgets in a Managed Grassland of Southern Hokkaido, Japan. *Agric. Ecosyst. Environ.* **2009**, *130*, 31–40. [CrossRef]
70. Verdi, L.; Marco, M.; Napoli, M.; Orlandini, S.; Marta, A.D. Soil Carbon Emissions from Maize under Different Fertilization Methods in an Extremely Dry Summer in Italy. *Ital. J. Agrometeorol.* **2019**, *2*, 3–10. [CrossRef]
71. YunFa, Q.; XiaoZeng, H.; Doane, T.A.; ShuJie, M. Emission of CO_2 and N_2O from Maize-Soybean Rotations under Five Long-Term Fertilizer Regimes in Northeastern China. *J. Food Agric. Environ.* **2014**, *12*, 492–497.
72. Xia, L.; Lam, S.K.; Yan, X.; Chen, D. How Does Recycling of Livestock Manure in Agroecosystems Affect Crop Productivity, Reactive Nitrogen Losses, and Soil Carbon Balance? *Environ. Sci. Technol.* **2017**, *51*, 7450–7457. [CrossRef] [PubMed]
73. Liu, L.; Greaver, T.L. A Global Perspective on Belowground Carbon Dynamics under Nitrogen Enrichment. *Ecol. Lett.* **2010**, *13*, 819–828. [CrossRef] [PubMed]
74. Ozlu, E.; Kumar, S. Response of Surface GHG Fluxes to Long-Term Manure and Inorganic Fertilizer Application in Corn and Soybean Rotation. *Sci. Total Environ.* **2018**, *626*, 817–825. [CrossRef] [PubMed]
75. Weidhuner, A.; Zandvakili, O.R.; Krausz, R.; Crittenden, S.J.; Deng, M.; Hunter, D.; Sadeghpour, A. Continuous No-till Decreased Soil Nitrous Oxide Emissions during Corn Years after 48 and 50 Years in a Poorly-Drained Alfisol. *Sci. Total Environ.* **2022**, *838*, 156296. [CrossRef] [PubMed]
76. Deng, J.; Zhou, Z.; Zhu, B.; Zheng, X.; Li, C.; Wang, X.; Jian, Z. Modeling Nitrogen Loading in a Small Watershed in Southwest China Using a DNDC Model with Hydrological Enhancements. *Biogeosciences* **2011**, *8*, 2999–3009. [CrossRef]
77. Russelle, M.P.; Birr, A.S. Large-Scale Assessment of Symbiotic Dinitrogen Fixation by Crops: Soybean and Alfalfa in the Mississippi River Basin. *Agron. J.* **2004**, *96*, 1754–1760. [CrossRef]
78. Brophy, L.S.; Heichel, G.H. Nitrogen Release from Roots of Alfalfa and Soybean Grown in Sand Culture. *Plant Soil.* **1989**, *116*, 77–84. [CrossRef]
79. Osterholz, W.R.; Kucharik, C.J.; Hedtcke, J.L.; Posner, J.L. Seasonal Nitrous Oxide and Methane Fluxes from Grain- and Forage-Based Production Systems in Wisconsin, USA. *J. Environ. Qual.* **2014**, *43*, 1833–1843. [CrossRef] [PubMed]
80. Rutkowska, B.; Szulc, W.; Szara, E.; Skowrońska, M.; Jadczyszyn, T. Soil N_2O Emissions under Conventional and Reduced Tillage Methods and Maize Cultivation. *Plant Soil. Environ.* **2017**, *63*, 342–347. [CrossRef]
81. Zuber, S.M.; Behnke, G.D.; Nafziger, E.D.; Villamil, M.B. Multivariate Assessment of Soil Quality Indicators for Crop Rotation and Tillage in Illinois. *Soil. Tillage Res.* **2017**, *174*, 147–155. [CrossRef]

82. Álvaro-Fuentes, J.; Cantero-Martínez, C.; López, M.V.; Arrúe, J.L. Soil Carbon Dioxide Fluxes Following Tillage in Semiarid Mediterranean Agroecosystems. *Soil. Tillage Res.* **2007**, *96*, 331–341. [CrossRef]
83. Grossel, A.; Nicoullaud, B.; Bourennane, H.; Lacoste, M.; Guimbaud, C.; Robert, C.; Hénault, C. The Effect of Tile-Drainage on Nitrous Oxide Emissions from Soils and Drainage Streams in a Cropped Landscape in Central France. *Agric. Ecosyst. Environ.* **2016**, *230*, 251–260. [CrossRef]
84. Haque, M.d.M.; Kim, S.Y.; Ali, M.A.; Kim, P.J. Contribution of Greenhouse Gas Emissions during Cropping and Fallow Seasons on Total Global Warming Potential in Mono-Rice Paddy Soils. *Plant Soil.* **2015**, *387*, 251–264. [CrossRef]
85. Sanz-Cobena, A.; García-Marco, S.; Quemada, M.; Gabriel, J.L.; Almendros, P.; Vallejo, A. Do Cover Crops Enhance N_2O, CO_2 or CH_4 Emissions from Soil in Mediterranean Arable Systems? *Sci. Total Environ.* **2014**, *466–467*, 164–174. [CrossRef] [PubMed]
86. Muhammad, I.; Sainju, U.M.; Zhao, F.; Khan, A.; Ghimire, R.; Fu, X.; Wang, J. Regulation of Soil CO_2 and N_2O Emissions by Cover Crops: A Meta-Analysis. *Soil. Tillage Res.* **2019**, *192*, 103–112. [CrossRef]
87. Gentile, R.; Vanlauwe, B.; Chivenge, P.; Six, J. Interactive Effects from Combining Fertilizer and Organic Residue Inputs on Nitrogen Transformations. *Soil. Biol. Biochem.* **2008**, *40*, 2375–2384. [CrossRef]
88. Burzaco, J.P.; Smith, D.R.; Vyn, T.J. Nitrous Oxide Emissions in Midwest US Maize Production Vary Widely with Band-Injected N Fertilizer Rates, Timing and Nitrapyrin Presence. *Environ. Res. Lett.* **2013**, *8*, 035031. [CrossRef]
89. Phillips, R.L.; Tanaka, D.L.; Archer, D.W.; Hanson, J.D. Fertilizer Application Timing Influences Greenhouse Gas Fluxes over a Growing Season. *J. Environ. Qual.* **2009**, *38*, 1569–1579. [CrossRef] [PubMed]
90. Blanco-Canqui, H.; Shaver, T.M.; Lindquist, J.L.; Shapiro, C.A.; Elmore, R.W.; Francis, C.A.; Hergert, G.W. Cover Crops and Ecosystem Services: Insights from Studies in Temperate Soils. *Agron. J.* **2015**, *107*, 2449–2474. [CrossRef]
91. Basche, A.D.; Archontoulis, S.V.; Kaspar, T.C.; Jaynes, D.B.; Parkin, T.B.; Miguez, F.E. Simulating Long-Term Impacts of Cover Crops and Climate Change on Crop Production and Environmental Outcomes in the Midwestern United States. *Agric. Ecosyst. Environ.* **2016**, *218*, 95–106. [CrossRef]
92. Nash, P.R.; Gollany, H.T.; Liebig, M.A.; Halvorson, J.J.; Archer, D.W.; Tanaka, D.L. Simulated Soil Organic Carbon Responses to Crop Rotation, Tillage, and Climate Change in North Dakota. *J. Environ. Qual.* **2018**, *47*, 654–662. [CrossRef] [PubMed]
93. Poeplau, C.; Don, A. Carbon Sequestration in Agricultural Soils via Cultivation of Cover Crops–A Meta-Analysis. *Agric. Ecosyst. Environ.* **2015**, *200*, 33–41. [CrossRef]
94. Austin, E.E.; Wickings, K.; McDaniel, M.D.; Robertson, G.P.; Grandy, A.S. Cover Crop Root Contributions to Soil Carbon in a No-till Corn Bioenergy Cropping System. *GCB Bioenergy* **2017**, *9*, 1252–1263. [CrossRef]
95. Bai, X.; Huang, Y.; Ren, W.; Coyne, M.; Jacinthe, P.-A.; Tao, B.; Hui, D.; Yang, J.; Matocha, C. Responses of Soil Carbon Sequestration to Climate-Smart Agriculture Practices: A Meta-Analysis. *Glob. Change Biol.* **2019**, *25*, 2591–2606. [CrossRef] [PubMed]
96. Li, Y.; Li, Z.; Chang, S.X.; Cui, S.; Jagadamma, S.; Zhang, Q.; Cai, Y. Residue Retention Promotes Soil Carbon Accumulation in Minimum Tillage Systems: Implications for Conservation Agriculture. *Sci. Total Environ.* **2020**, *740*, 140147. [CrossRef] [PubMed]
97. Lembaid, I.; Moussadek, R.; Mrabet, R.; Douaik, A.; Bouhaouss, A. Modeling the Effects of Farming Management Practices on Soil Organic Carbon Stock under Two Tillage Practices in a Semi-Arid Region, Morocco. *Heliyon* **2021**, *7*, e05889. [CrossRef] [PubMed]
98. Curtin, D.; Wang, H.; Selles, F.; McConkey, B.G.; Campbell, C.A. Tillage Effects on Carbon Fluxes in Continuous Wheat and Fallow–Wheat Rotations. *Soil. Sci. Soc. Am. J.* **2000**, *64*, 2080–2086. [CrossRef]
99. Butler, T.J.; Muir, J.P. Dairy Manure Compost Improves Soil and Increases Tall Wheatgrass Yield. *Agron. J.* **2006**, *98*, 1090–1096. [CrossRef]
100. O'Brien, P.L.; Hatfield, J.L. Dairy Manure and Synthetic Fertilizer: A Meta-Analysis of Crop Production and Environmental Quality. *Agrosystems Geosci. Environ.* **2019**, *2*, 190027. [CrossRef]
101. Reports. Available online: https://www.iowalearningfarms.org/reports (accessed on 15 May 2024).
102. Kessavalou, A.; Walters, D.T. Winter Rye Cover Crop Following Soybean under Conservation Tillage: Residual Soil Nitrate. *Agron. J.* **1999**, *91*, 643–649. [CrossRef]
103. Tyler, H.L. Winter Cover Crops and No till Management Enhance Enzyme Activities in Soybean Field Soils. *Pedobiologia* **2020**, *81–82*, 150666. [CrossRef]
104. Pittelkow, C.M.; Linquist, B.A.; Lundy, M.E.; Liang, X.; van Groenigen, K.J.; Lee, J.; van Gestel, N.; Six, J.; Venterea, R.T.; van Kessel, C. When Does No-till Yield More? A Global Meta-Analysis. *Field Crops Res.* **2015**, *183*, 156–168. [CrossRef]
105. Daigh, A.L.M.; Dick, W.A.; Helmers, M.J.; Lal, R.; Lauer, J.G.; Nafziger, E.; Pederson, C.H.; Strock, J.; Villamil, M.; Mukherjee, A.; et al. Yields and Yield Stability of No-till and Chisel-Plow Fields in the Midwestern US Corn Belt. *Field Crops Res.* **2018**, *218*, 243–253. [CrossRef]
106. Wilhelm, W.W.; Wortmann, C.S. Tillage and Rotation Interactions for Corn and Soybean Grain Yield as Affected by Precipitation and Air Temperature. *Agron. J.* **2004**, *96*, 425–432. [CrossRef]
107. Randall, G.W.; Iragavarapu, T.K. Impact of Long-Term Tillage Systems for Continuous Corn on Nitrate Leaching to Tile Drainage. *J. Environ. Qual.* **1995**, *24*, 360–366. [CrossRef]
108. Fabrizzi, K.P.; García, F.O.; Costa, J.L.; Picone, L.I. Soil Water Dynamics, Physical Properties and Corn and Wheat Responses to Minimum and No-Tillage Systems in the Southern Pampas of Argentina. *Soil. Tillage Res.* **2005**, *81*, 57–69. [CrossRef]
109. Halvorson, A.D.; Mosier, A.R.; Reule, C.A.; Bausch, W.C. Nitrogen and Tillage Effects on Irrigated Continuous Corn Yields. *Agron. J.* **2006**, *98*, 63–71. [CrossRef]

110. Cid, P.; Carmona, I.; Murillo, J.M.; Gómez-Macpherson, H. No-Tillage Permanent Bed Planting and Controlled Traffic in a Maize-Cotton Irrigated System under Mediterranean Conditions: Effects on Soil Compaction, Crop Performance and Carbon Sequestration. *Eur. J. Agron.* **2014**, *61*, 24–34. [CrossRef]
111. Vyn, T.J.; Raimbult, B.A. Long-Term Effect of Five Tillage Systems on Corn Response and Soil Structure. *Agron. J.* **1993**, *85*, 1074–1079. [CrossRef]
112. Six, J.; Elliott, E.T.; Paustian, K. Soil Macroaggregate Turnover and Microaggregate Formation: A Mechanism for C Sequestration under No-Tillage Agriculture. *Soil. Biol. Biochem.* **2000**, *32*, 2099–2103. [CrossRef]
113. Ji, J.; Li, J.; Luo, J.; Shi, Y.; Lindsey, S.; Liu, S.; Li, Y.; Zhao, C. How N Fertilizer Side-Dressing Timings Mediates Fertilizer N Fates in Maize Grown in a Mollisol. *Arch. Agron. Soil. Sci.* **2021**, *67*, 1231–1241. [CrossRef]
114. Bender, R.R.; Haegele, J.W.; Ruffo, M.L.; Below, F.E. Modern Corn Hybrids' Nutrient Uptake Patterns. *Better Crops* **2013**, *97*, 7–11.
115. Purucker, T.S.; Steinke, K. Comparing Nitrogen Timing and Sidedressing Placement Strategies on Corn Growth and Yield in Michigan. *Crop Forage Turfgrass Manag.* **2020**, *6*, e20033. [CrossRef]
116. Randall, G.W.; Vetsch, J.A.; Huffman, J.R. Corn Production on a Subsurface-Drained Mollisol as Affected by Time of Nitrogen Application and Nitrapyrin. *Agron. J.* **2003**, *95*, 1213–1219. [CrossRef]