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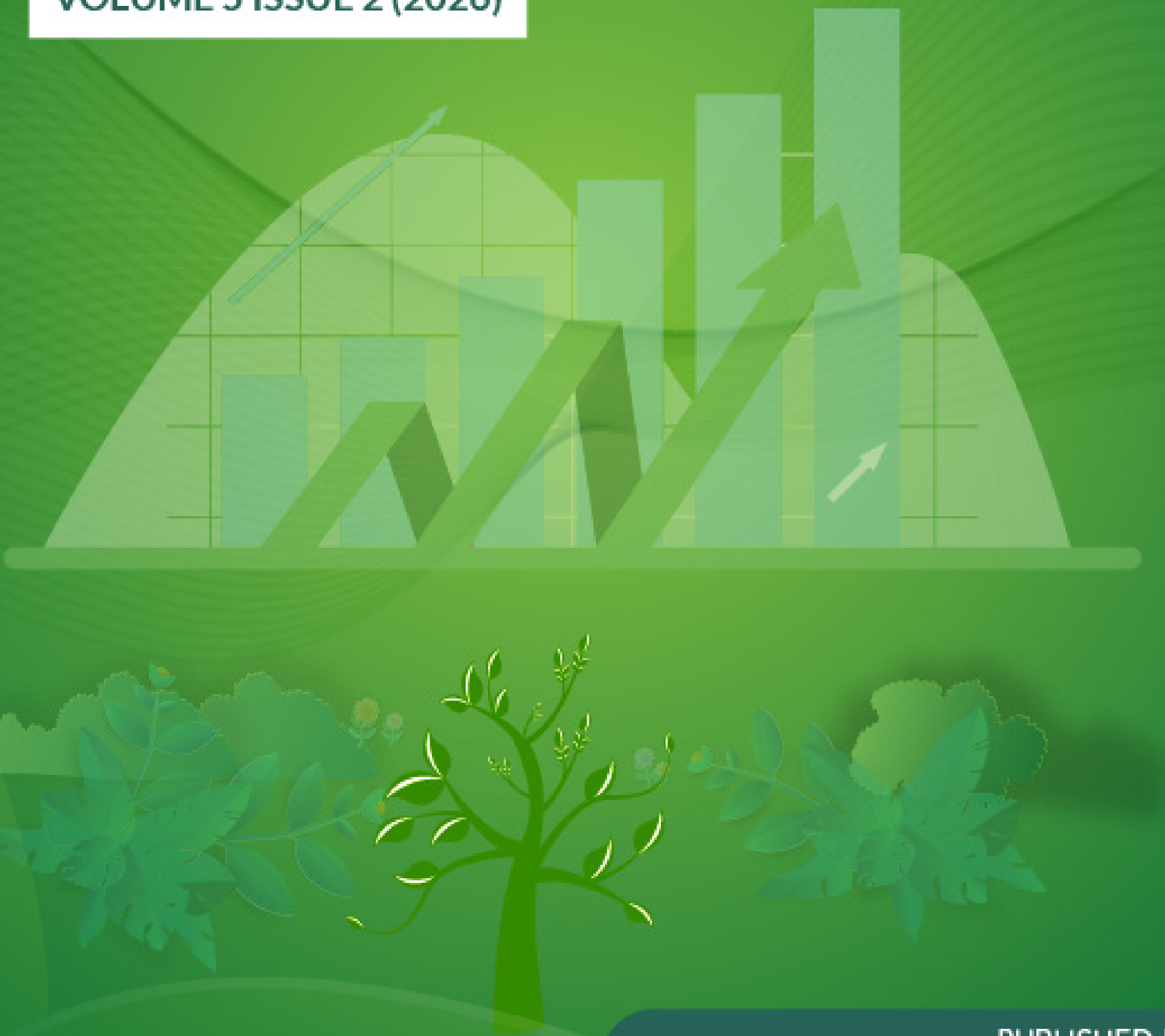

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Evaluating the Cost-Effectiveness of On-Farm Greenhouse Gas Mitigation Practices Using: COMET-Planner and USDA Data

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ABSTRACT

Agriculture serves as both a contributor and a sink of greenhouse gas (GHG) emissions. Even though the USDA promotes climate-resilient agricultural practices, farmers face a critical challenge in identifying the most cost-effective GHG reduction strategies or practices. This study assesses the cost-effectiveness of reducing agricultural GHG emissions across five strategies- cover cropping, mulching, no- tillage, crop rotation, and strip-cropping by integrating COMET Planner with USDA NRCS cost data across three Maryland counties: Caroline, Wicomico, and Somerset. Findings reveal that cover cropping provides the highest GHG reductions, with total CO2 equivalent reductions ranging from 40 to 71 t CO2 e per 100 acres, depending on species and irrigation status. Despite these reductions, the average mitigation cost remains relatively high, ranging from $190 to $211 per t CO2e. Mulching generates consistent but smaller reductions (32 t CO_2 e per 100 acres) than cover cropping, with a wide range of cost variability across material types. Natural leaf mulch offers the lowest mitigation cost at approximately $348 per t CO_2 e, whereas synthetic materials and wood chips exceed $11,000 and $83,000 per t CO_2 e, respectively. Strip cropping emerges as the most cost-effective strategy, with CO_2 equivalent reductions of 24 t CO_2 e per 100 acres and mitigation costs as low as $10.04 per t CO_2 e. Overall, the analysis indicates significant differences in cost effectiveness across several conservation practices, with strip-cropping the most economically efficient choice, while mulching exhibits comparatively high costs relative to its GHG benefits. Cumulatively, cover cropping has been shown to reduce high amounts of GHG emissions.

INTRODUCTION

Greenhouse gases (GHGs) are gases that have the potential to trap heat energy radiated from the Earth's surface, resulting in global warming. Since 1850, Earth has warmed by an average of 0.11 0 F, and if this trend continues, global temperature by the end of the century could reach 7.9 0 F, with unprecedented consequences for human civilizations such as Hurricane Helene, Typhoon Yagi, drought, rising sea levels, and habitat loss (NOAA, 2025).

The three most significant GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The most contributing one is CO_2, followed by CH4 and N_2O. To compare the heat trapping potential of GHGs relative to CO_2, the Global Warming Potential (GWP) metric was developed. Relative to CO_2, CH_4 has a GWP of 28, and N_2O a GWP of 273, meaning methane and N2O warm the planet 28 and 273 times, respectively 1 ton of CO_2 (Greenhouse Gas Protocol, IPCC, 2024). In 2025, global monthly means 423 ppm for CO_2, 1931 ppb for CH_4, and 339 ppb for N_2O (Lan, Tans, & Thoning, 2025; Lan, Thoning, & Dlugokencky, 2025). In 2022, U.S. greenhouse gas emissions totaled 6,343 million metric tons of carbon dioxide equivalents, of which 79.7% was CO_2, 11.1% N_2O, and 3.1% HFCs, PFCs, SF6, and NF3 (EPA, 2025). The residential and commercial sectors are the largest contributors to total U.S. greenhouse gas emissions, comprising 31%, while the industry and transportation sectors contribute 30% and 29% respectively. Moreover, agriculture contributes 10.5% to total US GHG emissions (EPA, 2025; ERS, USDA, 2024).

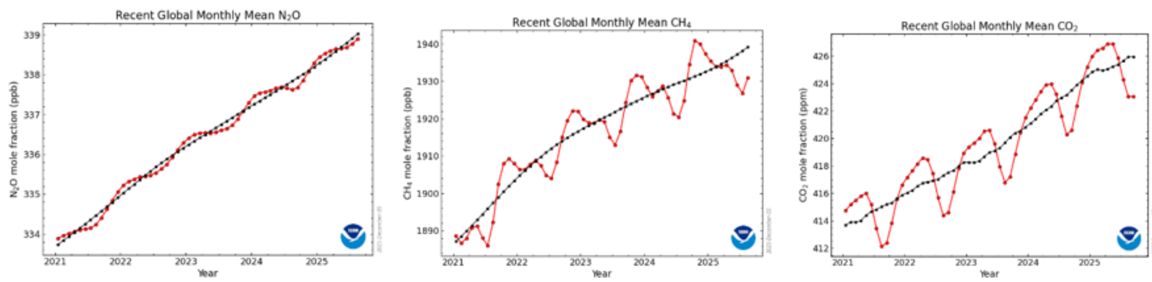

Figure 1: Global N_2O, CH4, and CO_2 monthly means
Source: Lan, Thoning, & Dlugokencky (2025)

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The Carbon Management Evaluation Tool (COMET Planner) was developed by the Natural Resources Conservation Service (NRCS), USDA, and Colorado State University to estimate potential greenhouse gas (GHG) reductions from the adoption of NRCS conservation practices in agricultural fields (on farms and ranches). NRCS conservation practices are grouped into five broad categories:

(i) Cropland management, (ii) Grazing lands, (iii) Cropland to herbaceous cover, (iv)Woody plantings, and (v) Restoration of disturbed lands.

COMET Planner is useful for conservation planning and provides generalized estimates of GHG emissions. However, for detailed site-specific analyses at the farm level, COMET Farm should be used. The value provided by COMET- Planner can be positive or negative. A decrease in GHG emissions is indicated by a positive value, while an increase due to the intervention of NRCS practices is indicated by a negative sign.

The estimates are measured in Mg CO_2 eq per acre per year, where: Mg = Megagrams (1 Megagram (Mg) = 1 Metric Tonnes)

- Megagrams or metric tonnes are equivalent to 1000 kilograms.
- An English (or 'short') ton equals 2,000 pounds; 1 Megagram (metric ton) = 1.1 English (short) tons
- CO_2 eq = Carbon Dioxide Equivalents
- CO_2 eq is used in COMET-Planner to allow users to compare emissions of carbon dioxide, nitrous oxide, and methane in standardized units.

To boost rural economies and increase the competitiveness of American agriculture, the NRCS is implementing several conservation practices based on the Agriculture Improvement Act of 2018, also known as the 2018 Farm Bill. In this study, the conservation practices evaluated include cover cropping, mulching, conservation crop rotation, no-till practices, and strip cropping in Somerset, Caroline, and Wicomico Counties in Maryland.

This study combines COMET-Planner GHG estimates with NRCS cost-share data to evaluate the cost per ton of CO_2 e reduced and to identify the most economical practices.

LITERATURE REVIEW

Sources of Agriculture Sector Emissions:

Nitrous Oxide (N_2O)

The Global N_2O emissions range from 0.5 to 4.5 Tg N_2O-N year-1 (Li *et al.*, 2024). N2O is a significant ozone-depleting substance, and one of the major GHGs, with a global warming potential 273 times greater than that of CO_2 (USDA, 2025; Ravishankara *et al.*, 2009).

The application of synthetic and organic fertilizers, fertilizer leaching, the cultivation of nitrogen-fixing crops, and irrigation practices have led to N_2O emissions from agricultural soils (EPA, USDA, 2025). The processes of nitrification and denitrification are among the processes that cause N_2O emissions. Nitrification (oxidation of ammonium to nitrate) is an aerobic process, whereas denitrification (reduction of nitrate to N_2O then to N2) is an anaerobic process (Bouwman *et al.*, 2002). Nitrogen-based fertilizers increase soil N_2O emissions by increasing mean annual temperature and precipitation, but decrease with increasing soil pH (Li *et al.*, 2024). The Emission factor (EF) for N_2O is 1%, If 100 Kg of nitrogen-based fertilizer is added to the soil, the soil yields 1 kg of N_2O; however, EFs may not be constant and depend on the types of nitrogen fertilizers and their rates (Shcherbak *et al.*, 2014).

Irrigation increases N_2O emissions by affecting the nitrification and denitrification processes through the regulation of soil aerobic conditions. Nitrifiers oxidize ammonium under aerobic conditions while denitrifiers reduce nitrate under anaerobic conditions (Li, Ma, *et al.*, 2023). Thus, deficit irrigation reduces soil N_2O emissions, but lowers crop yield (Li *et al.*, 2024).

However, for tillage, the effects on GHG emissions are ambiguous. This is largely due to reduced gas exchange, which can reduce emissions when soil disturbance is minimized (Sánchez-Navarro *et al.*, 2022). Peister *et al.* (2024) found higher variability in GHG emissions between conventional and minimum tillage operations. In climates where growing season precipitation (GSP) exceeds 600 mm, minimum tillage was found to emit more N_2O than conventional tillage; however, in other climates, minimum tillage has 12% lower N_2O emissions than conventional tillage (Peister *et al.*, 2024).

Soil amendment activities such as biochar application do not have a significant impact on reducing GHG emissions but help increase yield by increasing total N, total C, the C/N ratio, and exchangeable K (Basalirwa *et al.*, 2020).

Methane (CH_4)

Methane, with a GWP of 28, is emitted from livestock farming and contributes to extreme weather variability (Morsy *et al.*, 2025). The management and storage of slurry are the major activities that release GHGs during livestock production. Mismanaged slurry, along with enteric fermentation, accounts for 80% of global agricultural methane (Ruiz *et al.*, 2022). Although organic manure from livestock excreta provides plant nutrients to the soil, only about 52% of the Nitrogen is recycled in the form of plant nutrients, while the rest is lost as NH_3, N2O, and CH_4 (Webb *et al.*, 2011). When organic matter degrades under anaerobic conditions, CH_4 emissions occur (Ruiz *et al.*, 2022). Eighty-one percent of total ruminant GHG emissions are associated with cattle, while 11% and 8% of production are associated with buffalo and small ruminant production (Opio *et al.*, 2013). Change in diet composition is positively related to fermentation patterns in ruminants; thus, dietary changes not only boost production but also reduce GHG emissions (Morsy *et al.*, 2025; Haque, 2018).

Flooded paddy fields are the major source of CH_4 and N_2O (Aklyama, 2025; Linquist *et al.*, 2012). Flooding in rice fields creates anaerobic conditions in the soil. During the decomposition of organic matter under anaerobic conditions, methane is produced as the ultimate product (Conrad, 2022). As paddy fields release CH_4, the global warming potential of rice cultivation is much higher, i.e., 467% higher than that of wheat and 169% higher than that of maize. Although replacing urea with ammonium sulfate increases N_2O emissions, CH_4 emissions decrease by 40% (Linquist *et al.*, 2012). Thus, to reduce GHG emissions, minimizing the duration of soil submergence and reducing carbon-based inputs should be adopted.

Carbon-dioxide (CO_2)

Carbon dioxide emissions from agriculture are mainly driven by urea application and liming operations. Urea contributed 5.3 MMt CO_2 equivalent while liming accounted for 3.3 MMT CO_2 equivalent, together totaling 8.6 MMt CO_2 equivalent in 2022 (EPA, 2024). Cumulatively, soil carbon disruption from tillage in cropland also contributes to the oxidation of soil organic carbon, thus releasing significant CO_2 emissions from the soil. Similarly, converting forests or grasslands to cropland or farmland also releases stored carbon from the soil (EPA, 2024).

NRCS Cost Data

The Agriculture Improvement Act of 2018 is legislation that addresses the needs of Historically Underserved (HU) producers, including socially disadvantaged, beginning, limited resource, and veteran farmers and ranchers, by empowering the Natural Resources Conservation Service (NRCS) to offer cost incentives for adopting agricultural conservation practices.

The cost is divided into materials, equipment installation, labor, mobilization, acquisition of technical knowledge, foregone income, and risk. A sample cost categorization for alley cropping is shown in Table 1:

Table 1: NRCS Cost categorization for alley cropping practice in Maryland (10 acres)

Cost Category	Total Cost ($)	Scenario Cost/Unit ($)
Materials	20,991.09	5.83
Equipment Installation	8,513.02	48.93
Labor	9,105.13	32.52
Mobilization	0.00	0.00
Acquisition of Technical Knowledge	0.00	0.00
Foregone Income	837.65	335.06
Risk	0.00	0.00
Total	39,446.89	43.83

NRCS conservation Practices

Cover cropping

Cover cropping is a sustainable agricultural practice that aims to improve soil health and enhance crop productivity. Ma *et al.* (2025) found that cover crops increased total nitrogen (13%), total phosphorus (15.6%), organic matter (11.7%), and microbial biomass carbon (41.1%). This increase contributes to supplying higher nutrient levels in the soil, minimizing farm production costs, and maximizing farm income. Cover crops belonging to the Poaceae family, such as rye, help improve soil structure by increasing soil porosity and improving water infiltration. Similarly, cover crops of the Brassicaceae family, such as radish, improve soil aeration and water drainage through their taproot systems that extend into the soil (Wick *et al.*, 2017). Thus, by enhancing soil health and soil organic carbon, cover crops contribute to climate change adaptation and mitigation (Schon *et al.*, 2024).

Mulching

The protective cover placed on the soil surface to grow crops is Mulch (Khamare & Marble, 2023). Mulching is a sustainable conservation practice that enhances crop production through efficient water/nitrogen use. In agriculture, the most used mulch is plastic in comparison to other products (Koitabashi *et al.*, 2012). Mulching enhances soil health by preserving soil moisture, decreasing evaporation, and strengthening nutrient status (Kader *et al.*, 2017, Wang *et al.*, 2022). In paddy fields, the use of plastic film increased crop yield and reduced the net GWP by reducing CH_4 emissions; however, mulching reduced the soil organic carbon and contributed to N_2O emissions (Yu *et al.*, 2021). Plastic film had the highest CO_2 equivalent in the soils compared with crop residues, reflecting low Net Global Warming Potential and Greenhouse gas intensity for plastic film mulching (Malghani & Liao, 2022). CO_2 equivalent C inputs in the soil were also reported to be higher under plastic film mulch systems than in crop residues, suggesting relatively low NGWP and GHGI for plastic film mulching.

Crop- Rotation

Growing different crops in the same field in a systematic and sequential order over several growing seasons is called crop rotation (Al-musawi *et al.*, 2025). Crop rotation helps improve soil quality by increasing organic carbon and microbial biomass (Karlen *et al.*, 2006). The incorporation of legumes into crop rotation increases nitrogen cycling, ultimately enhancing plant growth (Gou *et al.*, 2023). Diversified Crop rotation with a higher diversity of crops, was found to have a 15% higher net ecosystem exchange (NEE) in comparison to conventional rotation (Ranathunga *et al.*, 2025). The net ecosystem exchange explains whether an ecosystem is a carbon source or a carbon sink. A higher or more negative NEE in diversified crop rotation indicates better carbon sequestration than conventional rotation.

No-Till Practice

Non-disruption of cropland is called no-till practice. This enables agriculture to adapt and mitigate change compared to conventional tillage. Shakkor *et al.* (2024) found that even though no-till practice did not increase crop yield, it decreased soil CO_2 by 8% and N_2O emissions by 12%. Similarly, Huang *et al.* (2018) found that NT enhances barley yield by 49% in dry environmental conditions and reduces the GWP of rice fields by 22% of CO_2 and CH_4 emissions. In addition, Zeng *et al.* (2025) also concluded that the most favorable condition in the no-till system for reducing CO_2 and N_2O emissions was dry and cold climatic conditions with low silt and high sand % concentrations

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Strip Cropping

The practice of maize and legume strip inter-cropping has been widely adopted to enhance land and resource use efficiency (Zhang et al, 2025). The practice results in diverse crop combinations and wider strip widths, which facilitate mechanization and other intercultural operations. (Yang *et al.*, 2024). Zhang *et al.* (2025) also found that maize and legume strip intercropping increases the crop yield by 15-24%, along with a reduction of N_2O emissions by 15-22%. Similarly, reducing N fertilizers and incorporating straw reduced CO_2 emissions and improved N uptake and nitrogen use efficiency, which lowers fertilizer costs and increases profitability (Zheng *et al.*, 2022).

MATERIALS AND METHODS

The COMET-Planner tool was used to evaluate the potential for carbon sequestration and greenhouse gas (GHG) reductions through the adoption of NRCS conservation practices in Somerset County, Maryland, in the U.S. This tool is intended for initial planning purposes and provides generalized estimates of the greenhouse gas impacts of conservation practices. It offers an overview of a large area, limited to the county level. For farm-level emissions estimation, COMET Farm is used, which requires evaluators to provide complete historical management information. Positive values indicate carbon sequestration or GHG emissions reduction, while negative values indicate carbon loss or increased GHG emissions.

To ensure consistency, emissions and reductions from 100 acres were measured. Under evaluations, CO_2, N_2O, and CH_4 were quantified in terms of tonnes of CO2 -eq per year.

The conservation practices studied under land use and cropland management include cover crops, mulching, conservation crop rotation, no-till practice, and strip cropping. The scenarios studied are:

i. **Crop Rotation:**

- Decrease Fallow Frequency or Add Perennial Crops to Rotations

ii. **Cover Cropping:**

- Add Legume Seasonal Cover Crop to Intensive till Irrigated Cropland
- Add Legume Seasonal Cover Crop to Intensive till Non-Irrigated Cropland
- Add Non-Legume Seasonal Cover Crop to Intensive till Irrigated Cropland
- Add Non-Legume Seasonal Cover Crop to Intensive till Non-Irrigated Cropland

iii. **Strip Cropping:**

- Add Perennial Cover Grown in Strips with Irrigated Annual Crops
- Add Perennial Cover Grown in Strips with Non-Irrigated Annual Crops

iv. **Mulching**

- Add Mulch to Croplands

v. **No- Tillage Practice**

- Intensive Till to No till or Strip till on Irrigated Cropland
- Intensive Till to No till or Strip till on Non-Irrigated Cropland

To assess the cost of adopting NRCS practices, the USDA (NRCS) estimated the expenses associated with implementing such conservation practices. It includes a breakdown of costs for materials, equipment installation, labor, mobilization, acquiring technical knowledge, foregone income, and costs associated with the risks. For consistency, the given cost rate is evaluated on a per-100-acre basis. These estimates differ from those practices used by states and NRCS.

To evaluate the cost required to establish and implement each conservation practice for the minimization of GHGs, the cost per ton of CO_2 emissions reduction can be calculated.

$$\text{Cost per ton } CO_2 \text{ emissions reduction} = \frac{\text{Total Costs}}{\text{CO2 equivalent}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

RESULTS AND DISCUSSIONS

Cover Cropping

This table highlights GHG emissions from four cover cropping systems across three counties along the eastern shores- Caroline, Kent, and Somerset. It also shows the total CO_2 equivalent, which combines CO_2, CH_4, and N_2O emissions. Leguminous cover crops, such as clover, vetch, alfalfa, and berseem, are shown to sequester significantly more carbon than non-leguminous cover crops such as rye and oats. While legume cover crops release nitrous oxide into the atmosphere through denitrification, non-legumes are found to reduce N_2O emissions. Additionally, legumes exhibit a greater reduction in CO_2 emissions due to their deep root systems and lower C: N ratios, which accelerates soil microbial activity and thus increases carbon stabilization.

Hu *et al.* (2025) also found that legume cover crops made a significant increase in organic soil (23%) compared with non-legumes (2%) and the control. This is because legume cover crops influence bacterial and fungal microbial biomass C across all components of SOC, whereas non-legume cover crops affect only fungal necromass C in bulk soil and mineral-associated organic matter (Hu *et al.*, 2025). Additionally, as the microbial necromass C increases, SOC accumulation also increases.

Table 2: GHG reduction per 100 acres from cover cropping

Implementation	Gas	Caroline	Wicomico	Somerset
Legume – Irrigated	CO_2	66	66	66
	N_2O	–7	–7	–7
	CH_4	0	0	0
Total CO_2 Equivalent		59	59	59
Legume – non-irrigated	CO_2	76	68	68
	N_2O	–5	–6	–6
	CH_4	0	0	0
Total CO_2 Equivalent		71	62	62
Non Legume – Irrigated	CO_2	46	37	37
	N_2O	5	4	4
	CH_4	0	0	0
Total CO_2 Equivalent		51	41	41
Non Legume – Non Irrigated	CO_2	41	37	37
	N_2O	3	3	3
	CH_4	0	0	0
Total CO_2 Equivalent		44	40	40

Table 3: Cost per tCO2 e reduced ($) through cover cropping

Cover Cropping Categories	Cost per 100 acres of establishment ($)	Average Cost per t CO2 e reduced ($)		
		Caroline	Wicomico	Somerset
Single Species	8,511.00	189.83	211.45	211.45
Multispecies	10,486.00			
Single species (Organic)	13,038.00			
Average	10,678.00			

According to NRCS, planting a single species of cover crops costs about $8,511 per 100 acres. This cost increases to $10,486 when multispecies cover crops are used and to $13,038, for organic cover crops are sown. Therefore, the average cost per 100 acres for establishment is $10,678.

A comparison across counties shows that the average cost per t CO2 e reduction in Caroline and Kent counties is $195.86, while it is $220.15 in Somerset counties. This indicates a higher cost per t CO_2 e reduction in Somerset County compared to Kent and Caroline counties. Therefore, cover cropping should be promoted in Caroline and Kent counties to minimize the GHG emissions in the Maryland's eastern shore areas.

Table 4: GHG reduction per 100 acres from Mulching

Implementation	Gas	Caroline	Wicomico	Somerset
Adding mulch to the croplands	CO_2	32	32	32
	N_2O	0	0	0
	CH_4	0	0	0
	Total CO_2 Equivalent	32	32	32

Mulching

Adding mulch to cropland significantly reduces greenhouse gas emissions by 32 CO2 equivalents, mainly through a decrease in CO2, with no effect on other gases, across 3 counties of Maryland's eastern shore. Mulching increases soil organic carbon in croplands by adding plant residues to the soil. He *et al.* (2025) found that full film mulch improves aggregate stability, while straw mulch influences aggregate formation, with better performance when applied at a rate of 5–10 t ha−1. Because straw is mainly composed of complex polysaccharides such as cellulose, hemicellulose, and lignin, it serves as a source of carbon and organic matter, boosting microbial growth and resulting in higher soil organic carbon.

Mulching appears to be the least cost-effective GHG mitigation conservation method, primarily due to high establishment costs averaging $855,541 per 100 acres. Costs vary from $11,124 for leaf mulch to $2,657,160 for synthetic materials, according to NRCS cost estimates for adopting mulching practices. Although mulching reduces 32 tons of CO2 equivalent, the cost per tCO2 equivalent reduction ranges from $347.63 to $83,036.25, depending on the nature of materials used. This exceeds the cost-effectiveness of crop rotation, no- till, or strip cropping. While mulching offers agronomic benefits like moisture retention, weed control, and erosion prevention, this practice is not economically feasible for carbon farming aimed at reducing GHG emissions from cropland.

Table 5: Cost per t CO2 e reduced ($) through mulching

Mulching Categories	Cost per 100 acres of establishment ($)	Average Cost per t CO2 e reduced ($)		
		Caroline	Wicomico	Somerset
Natural	64,698	2,021.81	2,021.81	2,021.81
Natural Material, Leaves	11,124	347.63	347.63	347.63
Erosion control blanket	1,176,120	36,753.75	36,753.75	36,753.75
Synthetic Material	368,607	11,518.97	11,518.97	11,518.97
Wood chips	2,657,160	83,036.25	83,036.25	83,036.25
Average	855,541			

Crop Rotation

Due to crop rotation, the total CO_2 equivalent reduction across all 3 counties (Caroline, Wicomico, and Somerset) is 22 with 21 CO_2 equivalent from CO_2 reduction and 1 CO_2 equivalent from N_2O. The value of CO_2 reduction in these three counties was found to be equal when assessed for a 100-acre cropland.

Crop rotation is found to increase the yield by up to 38%, while reducing N_2O emissions by 39% (Yang *et al.*, 2024). The integration of legumes into crop rotations boosts soil microbial activity and increases soil organic carbon stock by 8% (Yang *et al.*, 2024). Rotating with cover crops improves the net ecosystem carbon budget and reduces GHG emissions compared with conventional rotations (Ranathunga *et al.*, 2025). Zong *et al.* (2025) found that diversified crop rotations reduced N_2O emissions by 23%-49% compared with conventional rotations, accompanied by an increase in soil organic carbon and soil C: N ratio. Attia *et al.* (2025) found that rotating with cover crops reduces the direct-on-farm carbon footprint (DCFP) by 60% compared with business-as-usual (BAU) and by 30% compared with improved rotations without cover crops.

Crop rotation results in a 21-ton reduction in CO_2 equivalent per year. The cost per ton of reduced CO_2 equivalent is $129.72. Specialty crops cost $4151.12, more than basic crops, which cost $1556.67. The average cost of establishment per 100 acres is $2853.90. According to the USDA, Specialty crops are high-value crops, including fruits and vegetables such as apples, berries, lettuce, tomatoes, tree nuts, dried fruits, and herbs and spices such as culinary herbs and medicinal plants. Basic crop types include commodity crops like corn, wheat, and soybeans.

Table 6: GHG reduction per 100 acres from crop rotation

Implementation	Gas	Caroline	Wicomico	Somerset
Decrease Fallow Frequency or Add Perennial Crops to Rotations	CO_2	21	21	21
	N_2O	1	1	1
	CH_4	0	0	0
	Total CO2 Equivalent	22	22	22

Table 7: Cost per t CO2 e reduced ($) through crop rotation

Crop Rotation Categories	Cost per 100 acres of establishment ($)	Average Cost per t CO2 e reduced ($)		
		Caroline	Wicomico	Somerset
Basic crop types	1,556.67	129.72	129.72	129.72
Specialty Crops	4,151.12			
Average	2,853.90			

No-Tillage

Non-physical disruption of soil is called tillage. Caroline County is found to reduce more CO_2 equivalent when adopting non-tillage practices compared to Wicomico and Somerset counties, under irrigated conditions. However, under non-irrigated conditions, Wicomico and Somerset outperform Caroline County. Similarly, the irrigated condition resulted in a greater CO_2 equivalent reduction compared to the non-irrigated condition. However, in both irrigated and non-irrigated cases, there is no effect on CH_4 emissions, while CO_2 reduction is the highest, followed by N_2O emissions, across all three counties.

Reduced tillage was found to increase N_2O and CH_4 emissions by 31% and 24.7%, respectively, with no effect on CO_2 emissions, whereas no tillage decreased CO_2, N_2O, and CH4 emissions by 15.1%, 7.5%, and 19.8%, respectively (Yue *et al.*, 2023). Yue *et al.* (2023) also concluded that although reduced tillage decreases crop yield, no tillage (NT) had no crop yield tradeoff and was associated with a significant reduction in GHG emissions. Similar results were reported by Li *et al.* (2023), who state that NT reduced GWP by 14.4% but had no effect on crop yields. However, in dry climates, NT was found to increase barley yield by 49% (Huang *et al.*, 2018).

Table 8: GHG reduction per 100 acres from no-tillage practice

Implementation	Gas	Caroline	Wicomico	Somerset
Tillage in a irrigated condition	CO_2	59	37	37
	N_2O	8	6	6
	CH_4	0	0	0
Total CO2 Equivalent		67	43	43
Tillage in a non-irrigated condition	CO_2	33	35	35
	N_2O	4	4	4
	CH_4	0	0	0
Total CO2 Equivalent		37	39	39

Table 9: Cost per t CO2 e reduced ($) through no-tillage practice

No Tillage scenarios	Average cost per 100 acres of establishment ($)	Average Cost per t CO2 e reduced ($)		
		Caroline	Wicomico	Somerset
No Till on Irrigated Cropland	2,406.45	35.92	55.96	55.96
No Till on Non-Irrigated Cropland		65.03	61.70	61.70

Table 9 compares the economic and environmental aspects of adopting no-till farming practices across three Maryland counties: Caroline, Wicomico, and Somerset. According to NCRS, the average cost of implementing no till practices was $2,406.45 per 100 acres, for both irrigated and non-irrigated cropland. Under irrigated conditions, Caroline had the lowest cost per ton of CO_2 equivalent reduction at $35.92, while Wicomico and Somerset had a higher estimated cost of $55.96 per ton of CO_2 equivalent reduction. In contrast, for non-irrigated conditions, the costs were consistently higher, with Caroline at $65.03 and both Wicomico and Somerset at $61.70. These higher values suggest that no till adoption on non-irrigated cropland is less cost-effective for carbon reduction than under irrigated conditions.

Strip Cropping

Regardless of location, strip cropping consistently reduces total CO_2 equivalent emissions. With the adoption of such practice, it reduces by 11 tons of CO_2 and 13 tons of N_2O, with no significant change in CH_4 value. This shows the uniform effect of strip cropping in reducing GHG emissions across different regions along Maryland's eastern shore.

Maize and legume strip cropping was found to reduce N_2O emissions by 15-22% and increase yields by 15-24% compared to intercropping (Zhang *et al.*, 2025). Zheng *et al.* (2022) found that the maximum nitrogen use efficiency with reduced CO_2 emissions was controlled by straw incorporation, and reduced nitrogen inputs were used in the soybean strip cropping system. Ullah *et al.* (2025) studied the potential of intercropping to reduce GHG emissions by 15-25% through enhanced biological nitrogen fixation, improved soil fertility and nutrient cycling, and increased microbial activity, while increasing yields by 20-40% across diverse agroecosystems. A similar study on grass buffer strips found that they improved soil health by increasing soil carbon components and led to decreased CO_2 and N_2O emissions from corn strips (Salehin *et al.*, 2020).

Table 10: GHG reduction per 100 acres from strip cropping

Implementation	Gas	Caroline	Wicomico	Somerset
Strip cropping	CO_2	11	11	11
	N_2O	13	13	13
	CH_4	0	0	0
	Total CO2 Equivalent	24	24	24

Table 11: Cost per t CO2 e reduced ($) through strip cropping

Strip cropping scenarios	Average cost per 100 acres of establishment ($)	Cost per t CO2 e reduced ($)		
		Caroline	Wicomico	Somerset
Add Perennial Cover Grown in Strips	241	10.04	10.04	10.04

Strip cropping delivers GHG reductions of 24 tons of CO2 equivalent per year, with a total establishment cost of $241 per 100 acres. The cost per ton of CO2 equivalent reduction is $10.04, making it the most cost-effective among the conservation practices under study. The value remains consistent and uniform across all three counties- Caroline, Wicomico, and Somerset.

CONCLUSION

In terms of cost-effectiveness for reducing a ton of CO2 equivalent, strip cropping was found to be the most cost-effective, followed by no-till, crop rotation, cover cropping, and mulching. However, on average, cover cropping results in higher CO2 equivalent emissions compared with the other practices. Among cover crops, legume-based cover cropping is identified as particularly effective at reducing high levels of CO2 equivalents. Therefore, from a cost-effective standpoint, strip cropping is recommended, while from an ecosystem service perspective, legume-based cover cropping is preferred in Maryland to promote farm sustainability and support carbon farming, ultimately aiding in the reduction of GHG emissions.

REFERENCES

Al-Musawi, Z. K., Vona, V., & Kulmány, I. M. (2025). Utilizing different crop rotation systems for agricultural and environmental sustainability: A review. *Agronomy, 15*(8), 1966. https://doi.org/10.3390/agronomy15081966

Attia, A., Woli, P., Long, C. R., Rouquette Jr., F. M., Smith, G. R., Datta, A., & Rajan, N. (2025). Unlocking climate resilience by exploring the mitigation potential of improved rotation with cover cropping. *Journal of Environmental Management, 391*, 126352. https://doi.org/10.1016/j.jenvman.2025.126352

Basalirwa, D., Sudo, S., Wacal, C., Akae, F., Oo, A. Z., Koyama, S., Sasagawa, D., Yamamoto, S., Masunaga, T., & Nishihara, E. (2020). Assessment of crop residue and palm shell biochar incorporation on greenhouse gas emissions during the fallow and crop growing seasons of broccoli (*Brassica oleracea* var. *italica*). *Soil and Tillage Research, 196*, 104435. https://doi.org/10.1016/j.still.2019.104435

Basalirwa, D., Sudo, S., Wacal, C., Akae, F., Oo, A. Z., Koyama, S., Sasagawa, D., Yamamoto, S., Masunaga, T., & Nishihara, E. (2020). Assessment of crop residue and palm shell biochar incorporation on greenhouse gas emissions during the fallow and crop growing seasons of broccoli *(Brassica oleracea* var. *italica). Soil and Tillage Research, 196,* 104435. https://doi.org/10.1016/j.still.2019.104435

Bouwman, A. F., Boumans, L. J. M., & Batjes, N. H. (2002). Emissions of N_2O and NO from fertilized fields: Summary of available measurement data. *Global Biogeochemical Cycles, 16*(4), 1058. https://doi.org/10.1029/2001GB001811

Colorado State University, & U.S. Department of Agriculture, Natural Resources Conservation Service. (2024). *COMET-Planner*. Retrieved March 15, 2026, from https://comet-planner.com/

Conrad, R. (2002). Control of microbial methane production in wetland rice fields. *Nutrient Cycling in Agroecosystems, 64*(1), 59–69. https://doi.org/10.1023/A:1021178713988

Gou, X., Reich, P. B., Qiu, L., Shao, M., Wei, G., Wang, J., & Wei, X. (2023). Leguminous plants significantly increase soil nitrogen cycling across global climates and ecosystem types. *Global Change Biology, 29*(14), 4028–4043. https://doi.org/10.1111/gcb.16742

Greenhouse Gas Protocol. (2024, August 7). *IPCC global warming potential values* (Version 2.0). https://ghgprotocol.org/sites/default/files/2024-08/Global-Warming-Potential-Values%20%28August%202024%29.pdf

Haque, M. (2018). Dietary manipulation: A sustainable way to mitigate methane emissions from ruminants. *Journal of Animal Science and Technology, 60,* 15. https://doi.org/10.1186/s40781-018-0175-7

He, F., Zhang, H., Shi, D., Li, G., Song, Y., Pang, Y., Meng, Y., Shen, P., & Wen, X. (2026). A meta-analysis of impacts of mulching under different agricultural environments on soil aggregates and organic carbon. *Plant and Soil, 518*, 1413–1430. https://doi.org/10.1007/s11104-025-08082-2

Hiroko Akiyama. (2024). Methane and nitrous oxide emissions from agricultural fields in Japan and mitigation options: A review. *Soil Science and Plant Nutrition, 70*(2), 79–87. https://doi.org/10.1080/00380768.2023.2298782

Hu, Q., Jiang, T., Thomas, B. W., Chen, J., Xie, J., Hu, Y., & Shi, X. (2023). Legume cover crops enhance soil organic carbon via microbial necromass in orchard alleyways. *Soil and Tillage Research, 234*, 105858. https://doi.org/10.1016/j.still.2023.105858

Huang, Y., Ren, W., Wang, L., Hui, D., Grove, J. H., Yang, X., & Goff, B. (2018). Greenhouse gas emissions and crop yield in no-tillage systems: A meta-analysis. *Agriculture, Ecosystems & Environment, 268*, 144–153. https://doi.org/10.1016/j.agee.2018.09.002

Karlen, D. L., Hurley, E. G., Andrews, S. S., Cambardella, C. A., Meek, D. W., Duffy, M. D., & Mallarino, A. P. (2006). Crop rotation effects on soil quality at three northern corn/soybean belt locations. *Agronomy*

Journal, 98(3), 484–495. https://doi.org/10.2134/agronj2005.0098

Khamare, Y., & Marble, S. C. (2023). *Mulching as a weed management tool in container plant production: Review.* Frontiers in Agronomy, 5, Article 1235196. https://doi.org/10.3389/fagro.2023.1235196

Lan, X., Dlugokencky, E. J., & Thoning, K. W. (2025). *Trends in globally averaged CH4, N2O, and SF6 determined from NOAA Global Monitoring Laboratory measurements* (Version 2025-12). https://doi.org/10.15138/P8XG-AA10

Lan, X., Tans, P., & Thoning, K. W. (2025). *Trends in globally averaged CO2 determined from NOAA Global Monitoring Laboratory measurements.* https://doi.org/10.15138/9N0H-ZH07

Li, L., Hong, M., Zhang, Y., & Paustian, K. (2024). Soil N_2O emissions from specialty crop systems: A global estimation and meta-analysis. *Global Change Biology, 30*(3), e17233 https://doi.org/10.1111/gcb.17233

Li, L., Ma, L., Qi, Z., Fang, Q., Harmel, R. D., Schmer, M. R., & Jin, V. L. (2023). Measured and simulated effects of residue removal and amelioration practices in no-till irrigated corn (*Zea mays* L.). *European Journal of Agronomy, 146*, 126807. https://doi.org/10.1016/j.eja.2023.126807

Li, Z., Zhang, Q., Li, Z., Qiao, Y., Du, K., Yue, Z., & Li, F. (2023). Responses of soil greenhouse gas emissions to no-tillage: A global meta-analysis. S*ustainable Production and Consumption, 36*, 479–492. https://doi.org/10.1016/j.spc.2023.02.003

Linquist, B. A., Adviento-Borbe, M. A., Pittelkow, C. M., van Kessel, C., & van Groenigen, K. J. (2012). Fertilizer management practices and greenhouse gas emissions from rice systems: A quantitative review and analysis. *Field Crops Research, 135*, 10–21. https://doi.org/10.1016/j.fcr.2012.06.007

National Oceanic and Atmospheric Administration. (n.d.). *What are greenhouse gases and why do they matter*? Retrieved March 15, 2026, from https://www.climate.gov/ghg/what-are-greenhouse-gases-and-why-do-they-matter

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B., & Steinfeld, H. (2013). *Greenhouse gas emissions from ruminant supply chains: A global life cycle assessment.* Food and Agriculture Organization of the United Nations (FAO).

Pelster, D. E., Matteau, J.-P., Farrell, R., & Hernandez Ramirez, G. (2024). Tillage effects on growing season nitrous oxide emissions in Canadian cropland soils. *Canadian Journal of Soil Science, 104*(1), 1-10. https://doi.org/10.1139/cjss-2023-0075

Ranathunga, K. N., Evans, J., Toth, N., Brown, S., Van Eerd, L. L., & Wagner-Riddle, C. (2025). Net ecosystem carbon budget and net greenhouse gas emissions under diverse crop rotation using cover crops compared to a conventional crop rotation. *Agriculture, Ecosystems & Environment, 381,* 109418. https://doi.org/10.1016/j.agee.2024.109418

Ravishankara, A. R., Daniel, J. S., & Portmann, R. W. (2009). Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. *Science, 326*(5949), 123–125. https://doi.org/10.1126/science.1176985

Salehin, S. M. U., Ghimire, R., Angadi, S. V., & Idowu, O. J. (2020). Grass buffer strips improve soil health and mitigate greenhouse gas emissions in center-pivot irrigated cropping systems. *Sustainability, 12*(15), 6014. https://doi.org/10.3390/su12156014

Salehin, S. M. U., Ghimire, R., Angadi, S. V., & Idowu, O. J. (2020). Grass buffer strips improve soil health and mitigate greenhouse gas emissions in center-pivot irrigated cropping systems. *Sustainability, 12*(15), 6014. https://doi.org/10.3390/su12156014

Sánchez-Navarro, V., Shahrokh, V., Martínez-Martínez, S., Acosta, J. A., Almagro, M., Martínez-Mena, M., Boix-Fayos, C., Díaz-Pereira, E., & Zornoza, R. (2022). Perennial alley cropping contributes to decrease soil CO2 and N2O emissions and increase soil carbon sequestration in a Mediterranean almond orchard. *Science of the Total Environment, 845,* 157225. https://doi.org/10.1016/j.scitotenv.2022.157225

Schön, J., Gentsch, N., & Breunig, P. (2024). Cover crops support the climate change mitigation potential of agroecosystems. *PLOS ONE, 19*(5), e0302139. https://doi.org/10.1371/journal.pone.0319516

Shakoor, A., Pendall, E., Arif, M. S., Farooq, T. H., Iqbal, S., & Shahzad, S. M. (2024). Does no-till crop management mitigate gaseous emissions and reduce yield disparities: An empirical US-China evaluation. *Science of the Total Environment, 917*, 170310. https://doi.org/10.1016/j.scitotenv.2024.170310U.S. Department of Agriculture, Natural Resources Conservation Service. (n.d.). *NRCS*. https://www.nrcs.usda.gov/

U.S. Environmental Protection Agency. (2024). *Inventory of U.S. greenhouse gas emissions and sinks: 1990–2022, Chapter 5*: Agriculture. https://www.epa.gov/system/files/documents/2024-02/us-ghg-inventory-2024-chapter-5-agriculture.pdf

Yang, S., Li, H., Xu, Y., Wang, T., Hu, Y., Zhao, Y., & Chen, Y. (2024). The yield performance of maize-soybean intercropping in the North China Plain: From 172 sites empirical investigation. *Field Crops Research, 315*, 109467. https://doi.org/10.1016/j.fcr.2024.109467

Yang, X., Xiong, J., Du, T., Ju, X., Gan, Y., Li, S., & Butterbach-Bahl, K. (2024). Diversifying crop rotation increases food production, reduces net greenhouse gas emissions and improves soil health. *Nature Communications, 15*(1), 198. https://doi.org/10.1038/s41467-023-44464-9

Zeng, J., Wang, X., Li, Y., Xing, L., Li, X., Zhang, Q., & Han, X. (2025). Optimizing fertilization rate can maintain the greenhouse gas mitigation effect of no-tillage: A global-scale meta-analysis. *Field Crops Research, 322*, 109720. https://doi.org/10.1016/j.fcr.2024.109720

Zhang, J., Yao, W., Wen, Y., Qian, X., Peixoto, L., Yang, S., & Zang, H. (2025). Temporal and spatial patterns of N2O emissions in maize/legume strip intercropping: Effects of straw incorporation and crop interactions. *Field Crops Research, 326*, 109850. https://doi.org/10.1016/j.fcr.2025.109850

Zheng, B., Chen, P., Du, Q., Yang, H., Luo, K., Wang, X., & Yang, W. (2022). Straw incorporation and nitrogen reduction effect on the uptake and use efficiency of nitrogen as well as soil CO2 emission of relay strip intercropped soybean. *Frontiers in Plant Science, 13,* 1036170. https://doi.org/10.3389/fpls.2022.1036170