ISSN 2582- 564X
AEXTJ
AGRICULTURAL EXTENSION JOURNAL

Available Online at www.aextj.com
Agricultural Extension Journal 2025; 9(3):1-4

RESEARCH ARTICLE

Carbon Capture and Utilization for Agriculture with Environmental Sustainability

Subhadip Rajak, Ananya Hazra, Sangita Maity, Amit Biswas

Department of Agricultural Engineering, Haldia Institute of Technology, Haldia, West Bengal, India

Received: 16-07-2025; Revised: 28-08-2025; Accepted: 16-09-2025

ABSTRACT

Increasing soil degradation teamed up adverse climate changes are serious concern on food safety for the global population. To address these various innovative and green agriculture practices, they are ongoing or are in research level. Agriculture plays both roles in the carbon cycle as a source and a potential sink for atmospheric carbon. Carbons capture and clean environment policies binds traditional agriculture with sustainability naturally as well as technologically. Carbon capture and utilization technologies integrating with agricultural systems provide route for reduced emission and higher productivity. Soil carbon sequestration by conservative tillage, crop covering, usage of internet of things (IoT) sensors, biochar production helping to reduce carbon footprints, and helps to increase production, helps to maintain soil health as well. Agro-silvi cultures and perennial crops are natural carbon absorber; maintain food production with the goal of sustainability. In the stages of energy usages, harvesting, processing the capture of carbon unlocks a new path for reducing carbon footprints, while production of bio-gas, biochar, biofertilizers, and others speeding up the sustainable agriculture. New methods like converting paddy straws into biochar instead of open burning, this biochar help to maintain soil health. Such innovations support the objectives of clean environment's goals as well as sustainable agriculture by increasing farmer's profits and integrating climate-resilient practices. AI models can be used to predict long-term carbon depository of soil and environment. IoT is also used to maintain methane levels for livestocks. Thus, carbon capture integrate agriculture emerges not only as a climate-friendly but a path of profitable, environmentally sustainable farming culture.

Key words: Carbon capture, clean environment, internet of things, sustainable agriculture, sustainablity

INTRODUCTION

Coal and petroleum are widely used as fossil fuels that release large amounts of greenhouse gases, particularly carbon dioxide.[1] This is the main reason behind climate change, global warming, that directly effects on ecosystem, food security, and human well-being. The reduction of carbon emission is a global challenge and goal of many scientists around world.[2] Furthermore, agriculture plays both roles in carbon emissions through soil management, fertilizer use, live-stock rearing, and energy-intensive practices; at the same time, agriculture holds potential sink for atmospheric carbon through sustainable practices.[3] This paper focuses on capturing carbon and the role of agriculture in controlling the discharge rate of carbon to the environment.[4]

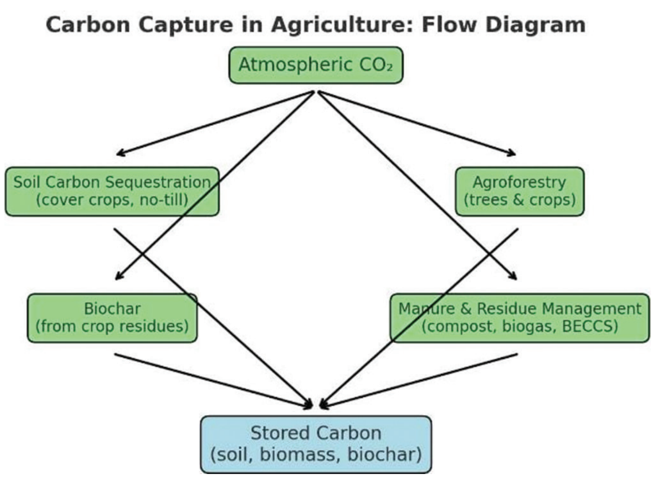
As non-carbon renewable energy currently supplies a small part of total global energy, perhaps only 13–16% and it also cost-effective for sustainable practices, so several publications have dealt with the development of non-carbon renewable energy. Hence, we focus on:

1. Carbon capture and utilization (CCU) technologies integrating with agriculture systems provide route for reduce emission and higher productivity. Carbon capture and utilization technology is raising strategy that

Address for correspondence:
Amit Biswas
E-mail: amitmbiswas@gmail.com

captures CO_2 emissions from the atmosphere or industrial sources and transforming them into biofuel, fertilizers, bioplastic, and soil amendments[5]

2. Soil carbon sequestration by conservative tillage, crop covering, and the uses of internet of things (IoT) sensors helping to mitigate carbon footprints and helps to increase production, maintain soil health as well
3. Agro-silvi cultures and perennial crops are natural carbon observer, maintain food production with the goal of sustainability[6]
4. New methods like converting paddy straws into biochar instead of open burning this biochar help to maintain soil health. AI models can be used to predict long-term carbon depository of soil, IoT is also used to maintain methane levels for live-stocks.



METHODOLOGY

Carbon capture and clean environment processes in agriculture have many sides which combine with biological, chemical, and technological method. Its primary objectives are to raise natural carbon storage, bring down greenhouse gas pollutions from agriculture, and enhance ecological balance.

Soil Carbon Segregation

Lesser amount of tillage decreases the chances of soil erosion land degradation, and grow biological material, boost soil carbon storage.[7] Here, cover cropping and crop rotation play an important roles, tilling legume family crops, for example, pulses, clover, rye, etc. Increase carbon storage by photosynthesis and upgrade organic carbon level in soil. Using organic substances such as biofertilizer, farmyard manure, and post-harvest residues (stubble, stocks, husks) adds extra carbon to the soil while increasing the soil structure.[8]

Agroforestry System

Perennial crops such as fruit trees, herbs, shrubs, and agrosilvicultures have natural carbon absorption ability. Usual processes include silvopasture, alley cropping, and wind breaks. Those sustainable ways AQ3
are helping a lot.[9]

Biochar Application

Manufacturing of biochar from burned agricultural wastes (rice husk, straw, and woody waste) in oxygen-limited conditions helps to store carbon in soil for a long time period and also maintains carbon sustainability. In addition, increase productivity of soil and maintain water capacity also prevents nutrient loss, keeping the environment clean. Moeove, biomass production also helps to sustain.[10]

Precision Farming

In modern times, the uses of GPS, drones, and sensors is rising day by day. It helps to apply fertilizer accurately which can decrease nitrous oxide emissions. Implement of digital gadget can monitor crop well-being and reduce overuse of pesticides. Smart irrigation technology brings down methane outflow by reducing waterlogging in rice fields.[8]

Livestock and Manure Management

From livestock manure, methane gas is generated. This methane gas can be harvested through biogas plants to generate renewable energy. A balanced feed reduces methane emissions in the gut of ruminants. Manuring in a controlled manner instead of storing it in the open reduces methane and nitrous oxide emissions.[7]

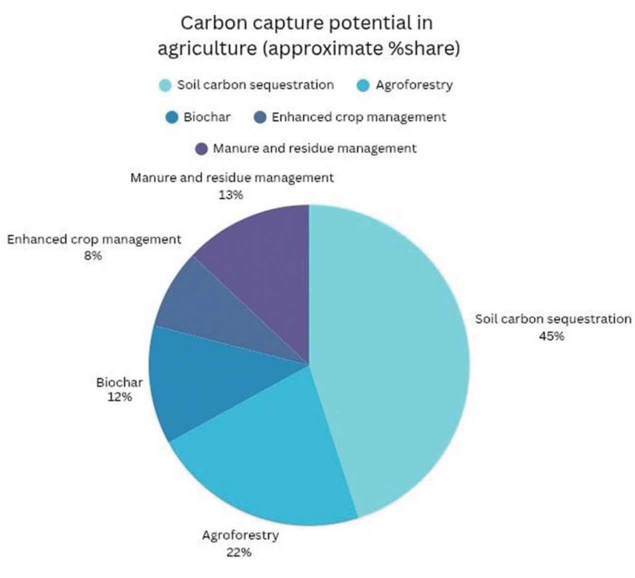
Circular Agriculture Approaches

Utilize crop residues, manure, and organic waste to make fertilizer or biochar exclude the require of slash-and-burn agriculture, and improve soil quality. Using renewable energy (solar, wind, or biogas) can reduce dependence on fossil fuels in agriculture.[8]

Policy and Community-Based Implementation

Farmer education programs develop knowledge about eco-friendly agriculture practices also encourage them to adopt carbon-smart practices. Community-level interventions, such as shared biochar units or cooperative agroforestry projects, enhance adoption.[10]

Together, these methods form a comprehensive framework for sustainable carbon management in agriculture, providing a foundation for further research, scaling, and policy integration. Through the integration of on-farm practices, modern technologies, and enabling policies, this methodology outlines a pathway for farmers and communities to pursue climate-smart agriculture that balances productivity with long-term resilience.[11]



RESULTS

CCU is increasingly admitted as a path of linking climate protection with sustainable agriculture. From the recent studies, it has been observed that uses of captured CO_2 can manufacture biochar, biofertilizers, and algae-based products, which can enhance soil health and crop yields while lowering emissions. For example, biochar improves soil structure and nutrient maintenance.[11] Whereas CO_2-derived fertilizers reduce reliance on fossil fuel-based production. Fresh research indicates biochar application contributes 0.3–1.8 Gt CO_2-eq per year in global sequestration potential. The technical potential for soil carbon sequestration in crop lands is estimated at 0.5–6.7 Gt CO_2 per year worldwide.[8] At the farm level, sequestration rates range lays between 0.12-1.90 t C/ha/year. Agroforestry's mitigation potential ranges between 0.4 and 1.1 Gt CO_2-eq per year, with additional co-benefits such as productivity improvements under degraded soil conditions. No-till farming, often integrated with precision methods, can reduce N_2O emissions by 50–80%, depending on crop rotations.[8] California's dairy biodigester program cut 25% of dairy methane emissions annually, an effect comparable to removing nearly 500,000 cars from the road. Feed additives like Bovaer (3-NOP) reduce enteric methane by roughly 30% in dairy cows and 45% in feedlot beef cattle. Estimates suggest sustainable biochar usage could reduce annual global GHG emissions (CO_2, CH_4, N_2O) by 1.6 to 3.2 billion tonnes CO_2-eq. Modeling studies indicate U.S. agricultural carbon markets could enable 17–75 million metric tonnes CO_2-eq of annual sequestration if properly incentivized, though profitability varies considerably.[11]

DISCUSSION

By combining on-farm practices with modern technology and supportive policies, this process offers a pathway for farmers and communities to achieve climate-smart agriculture while maintaining productivity and resilience.[7] Practices like biochar application have shown potential for rapid cost recovery, especially when paired with carbon credits. Transforming agriculture into a net carbon sink through these practices can significantly contribute to achieving global climate goals.[9] CCU technologies can create new employment opportunities in the agricultural and bio-based industries.

CONCLUSION

Climate change is mainly caused by carbon dioxide emitted from the usage of fossil fuels, which holds the greatest challenge for humanity, ecosystem, agriculture, and global food security. Agriculture plays a very interesting role in this matter one side, it produces a significant amount of the yield mission on other side, it offers one the most promising viable solution for carbon mitigation. The incorporation of CCU technologies with agriculture gives a unique combination which not only reduces the emissions but increased yield as well. Likely soil carbon sequestration, conservative tillage, IoT-based monitoring systems are reducing carbon footprints and helps to keep soil fertility for more sustainable yields. Agro-silivicultural, Agro-silivipastoral systems, perennial crops are acting as natural carbon sinks while balancing food production with environmental conservation in mind.

Innovation such as converting paddy straws into biochar, then biofertilizers is amazing because previously those paddy straws were burnt and caused huge smog issues(Delhi in each winter season), now these biochars helping to produce long-lasting ecological benefits. New ai and IoT-based monitoring helps to keep in check of the methane produce by the livestock and crop management.

By positioning those technologies, policy and on-farm practice will reduce carbon footprints in high number and help becoming more sustainable for a better future.

REFERENCES

1. Makepa DC, Chihobo CH. Sustainable pathways for biomass production and utilization in carbon capture and storage-a review. Biomass Convers Biorefin 2025;15:11397-419.
2. Dass A. Carbon capture and sequestration for sustainable land use-a review. Indian J Agric Sci 2023;93:11-8.
3. Ravichandran M, Kumar TT, Dineshkumar R. Carbon dioxide capture, sequestration, and utilization models for carbon management and transformation. Environ Sci Pollut Res 2024;31:55895-916.
4. Nijnik M, Miller D. Targeting sustainable provision of forest ecosystem services with special focus on carbon sequestration. In: Developments in Environmental Science. Netherlands: Elsevier; 2013. p. 547-68.
5. Govaerts B, Verhulst N, Castellanos-Navarrete A, Sayre KD, Dixon J, Dendooven L. Conservation agriculture and soil carbon sequestration: Between myth and farmer reality. Crit Rev Plant Sci 2009;28:97-122.
6. Liu X, Zhang S, Bae J. The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. J Clean Prod 2017;164:1239-47.
7. Tariq G, Chen Z, Zhao M. Techno-economic and life cycle assessment of integrated bio-and e-methanol production from biomass with carbon capture and utilization. Chem Eng J 2025;515:163850.
8. Rasheed MQ, Haseeb A, Adebayo TS, Ahmed Z, Ahmad M. The long-run relationship between energy consumption, oil prices, and carbon dioxide emissions in European countries. Environ Sci Pollut Res 2022;29:24234-47.
9. Abdalqadir M, Hughes D, Rezaei Gomari S, Rafiq U. A state of the art of review on factors affecting the enhanced weathering in agricultural soil: Strategies for carbon sequestration and climate mitigation. Environ Sci Pollut Res 2024;31:19047-70.
10. Powlson DS, Stirling CM, Thierfelder C, White RP, Jat ML. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? Agric Ecosyst Environ 2016;220:164-74.
11. Bhagat R, Walia SS, Sharma K, Singh R, Singh G, Hossain A. The integrated farming system is an environmentally friendly and cost-effective approach to the sustainability of agri-food systems in the modern era of the changing climate: A comprehensive review. Food Energy Secur 2024;13:e534.

Author Query???

AQ3: Please check the edit made.