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APPLICATION OF REMOTE SENSING FOR MONITORING CARBON FARMING: A REVIEW

Gustė METRIKAITYTĖ GUDELĖ *, Jūratė SUŽIEDELYTĖ VISOCKIENĖ

Vilnius Gediminas Technical University, Vilnius, Lithuania

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Abstract. This research article presents an overview of the role of carbon farming in mitigating climate change by sequestering carbon in soil and vegetation. The article highlights the potential of remote sensing technology for monitoring carbon farming practices and CO_2 absorption. Carbon farming practices, such as conservation tillage, cover cropping, crop rotation, and agroforestry, are discussed. The article explains the application of remote sensing technology, including satellite-based remote sensing, aerial photography, and ground-based sensors, in monitoring changes in carbon sequestration and CO_2 absorption. The article concludes that remote sensing technology provides a powerful tool for monitoring carbon farming and CO_2 absorption and is likely to become even more effective in the future as technology continues to advance.

Keywords: remote sensing, CO_2, tillage, strip-till, no-till, minimal-till, carbon farming.

Introduction

One of the most important environmental problems of our day is climate change, which is brought on by greenhouse gas emissions, especially carbon dioxide emissions. Carbon dioxide (CO_2) plays a significant role in global climate change (Ali et al., 2020; Punia, 2021; Zhong & Haigh, 2013). Plants absorb CO_2 through photosynthesis, which is a vital process that helps to regulate atmospheric CO_2 levels. Monitoring CO_2 absorption by plants and soil is, therefore, an essential part of understanding the global carbon cycle and its impact on the environment (Avgoustaki et al., 2021). The importance of carbon farming, which includes methods of storing carbon in soil and vegetation, has received increasing attention in recent years as a means of mitigating climate change. Remote sensing technology has become a potent tool for tracking carbon farming and CO_2 absorption in recent years (Chen et al., 2019; Lu et al., 2020; Perosa et al., 2023; Zhang et al., 2021, 2022). An overview of carbon farming, CO_2 absorption, and the use of remote sensing equipment to track carbon sequestration are all covered in this chapter.

Carbon sequestration and carbon farming play a crucial role in the reduction of greenhouse gas emissions and the enhancement of carbon storage in vegetation and soil, which is essential for mitigating climate change. The process of carbon sequestration involves the permanent storage of carbon in ecosystems, such as forests and soils. Carbon farming, on the other hand, encompasses various practices focused on sequestering carbon in vegetation and soil, including crop rotation, agroforestry, conservation tillage, and cover cropping (Ghaffar et al., 2022; Lal, 2019; Naftel, 2022; Paul et al., 2023; Reicosky & Kassam, 2021; Tiefenbacher et al., 2021).

One of the main benefits of carbon sequestration and carbon farming is their potential to reduce greenhouse gas emissions. According to a study by Schlesinger and Amundson (2019), increasing soil carbon sequestration by just 0.4% per year could offset global greenhouse gas emissions by up to 20–35%. Carbon farming practices can also reduce emissions by promoting sustainable land use practices and reducing the need for synthetic fertilizers and other inputs.

In addition to mitigating climate change, carbon sequestration and carbon farming can also provide a range of other benefits, such as improving soil health, increasing crop yields, and promoting biodiversity (Lal, 2019). For example, a study by Hati et al. (2019) found that cover cropping and reduced tillage practices not only increased carbon sequestration, but also improved soil health and increased crop yields.

*Corresponding author. E-mail: *guste.metrikaityte-gudele@vilniustech.lt*

Overall, carbon sequestration and carbon farming are important strategies for mitigating climate change and promoting sustainable land use practices.

Methods for monitoring CO_2 absorption in agriculture

Analyzing various sources, there can be distinguish several methods for monitoring CO_2 absorption in agriculture (Angelopoulou et al., 2019; Balafoutis et al., 2017; Eve et al., 2014; Food and Agriculture Organization of the United Nations, 2018; Izaurralde et al., 2001; Jin et al., 2016; Loveland et al., 2014; Montaldo & Oren, 2016; Robert, 2001):

- Soil sampling and analysis: soil samples can be collected and analyzed to determine the amount of carbon stored in the soil. This method provides a direct measurement of carbon sequestration in the soil and can be used to track changes over time.
- Remote sensing: remote sensing techniques, such as satellite imagery and aerial photography, can be used to estimate the amount of vegetation cover and biomass in agricultural fields. These measurements can be used to estimate the amount of carbon stored in plants and soil.
- Carbon footprint analysis: carbon footprint analysis involves calculating the net amount of carbon emissions from a specific agricultural activity, such as crop production or livestock rearing. This method can be used to identify areas where emissions can be reduced and carbon sequestration increased.
- Gas flux measurements: gas flux measurements involve measuring the exchange of CO_2 and other greenhouse gases between the soil, plants, and atmosphere. This method provides a direct measurement of carbon uptake and release in agricultural systems.
- Modeling: modeling involves using computer models to estimate the amount of carbon sequestered in agricultural systems. These models can be used to simulate the effects of different management practices and climate scenarios on carbon sequestration.

In agricultural systems, various methods are used for monitoring carbon sequestration, each with its own advantages and disadvantages. Often, a combination of methods is employed to obtain a more complete understanding of the process. However, in this research article, only the remote sensing method for monitoring CO_2 absorption will be examined.

Remote sensing is a valuable tool for monitoring carbon farming because it provides frequent and extensive coverage of large areas, allowing for the detection of changes in vegetation cover and biomass that are crucial indicators of carbon sequestration in agricultural systems. It also provides information on the spatial and temporal patterns of carbon sequestration, which helps farmers and land managers make informed decisions about land use and management practices.

Moreover, remote sensing is useful for estimating carbon sequestration in inaccessible or sensitive regions, providing a more comprehensive understanding of carbon sequestration at the landscape level and enabling better management of these areas for carbon farming.

Overall, remote sensing plays a critical role in monitoring carbon farming by providing accurate, timely, and comprehensive information on carbon sequestration in agricultural landscapes. This information can aid the development and implementation of effective policies and management practices for carbon farming, contributing to mitigating climate change and enhancing environmental sustainability.

1. Carbon farming practices for CO_2 absorption

According to Paustian et al. (2016), carbon farming is a climate mitigation strategy that involves implementing land-use practices that increase carbon sequestration in soils and vegetation. These practices are designed to promote soil health, enhance biodiversity, and reduce greenhouse gas emissions. Carbon farming can include a variety of activities which will be discussed in the article below.

There is growing interest in carbon farming as a way to address climate change, and many countries and organizations are developing programs and policies to support its adoption. Carbon farming also involving the implementation of market-based mechanisms, such as carbon offsets and payments for ecosystem services, which provide economic incentives for farmers and land managers to adopt more sustainable land management practices.

Overall, carbon farming represents a promising approach to mitigating climate change while also promoting sustainable agriculture and improving ecosystem health.

1.1. Carbon farming practices

There can be distinguish several carbon farming practices that can be implemented to sequester carbon in the soil and vegetation. Here are some examples:

- Conservation tillage: this is a method of planting crops without tilling the soil, which can help to reduce soil disturbance and increase carbon sequestration. Conservation tillage practices include no-till, strip-till, and reduced-till (United States Department of Agriculture [USDA], 2016b, 2016a).
- Cover crops: cover crops are planted between cash crops to cover the soil and improve soil health. They can also help to sequester carbon by increasing plant biomass and soil organic matter (USDA, 2014b).
- Agroforestry: agroforestry involves integrating trees into agricultural landscapes to provide multiple benefits, such as reducing erosion, improving soil health, and sequestering carbon (USDA, 2014a).
- Conservation agriculture: conservation agriculture is a set of practices that aim to improve soil health and reduce soil erosion. It involves minimal soil disturbance, permanent soil cover, and crop rotation. These practices can help to sequester carbon and improve soil quality (Reicosky & Kassam, 2021).

- Grazing management: grazing management practices, such as rotational grazing, can help to increase carbon sequestration by promoting plant growth and soil health (Kenneth & Spaeth, 2022).
- Composting: composting organic waste can help to sequester carbon by converting it into stable soil organic matter (USDA, 2020).

These are just a few examples of carbon farming practices. Implementing these practices can help to mitigate climate change by sequestering carbon in the soil and vegetation.

Given that in practice farmers are increasingly encouraged to practice environmentally friendly farming, further chosen to analyze conservation tillage methods for CO_2 absorption and how remote sensing data could be involved in monitoring process.

1.2. Conservation tillage

Strip-till, reduced-till, and no-till are different types of tillage practices used in agriculture. They refer to the amount and depth of soil disturbance during planting and crop management. Below is a brief explanation of each practice (Hatfield et al., 2001; Lai, 1989):

Strip-tillage is a practice where only narrow strips of soil are tilled, leaving the remaining soil undisturbed. The tillage is usually done only in the area where the crop rows will be planted, leaving the rest of the field untouched. Strip-tillage can help to reduce soil erosion, improve soil moisture retention, and increase crop yield by maintaining a more stable soil structure.

Minimal tillage, also known as reduced tillage or conservation tillage, is a practice where only a small amount of soil is disturbed during planting and crop management. The tillage is usually done only to a shallow depth, leaving most of the soil surface undisturbed. Minimal-tillage can help to reduce soil erosion, conserve soil moisture, and increase soil organic matter content.

No-till, also known as direct drilling or zero tillage, is a practice where no soil is disturbed during planting and crop management. The seeds are planted directly into the undisturbed soil using specialized equipment. No-till can help to reduce soil erosion, conserve soil moisture, increase soil organic matter content, and sequester more carbon in the soil.

Overall, these tillage practices aim to reduce soil erosion, conserve soil moisture, increase soil organic matter content, and minimize the environmental impact of agriculture. Each practice has its advantages and disadvantages, and the choice of tillage method depends on several factors, including soil type, crop type, climate, and farm management practices (Statistics Canada, 2015).

Subsequently, this research paper intends to examine the potential applications of remote sensing to distinguish and differentiate among the three tillage methods mentioned above.

2. Remote sensing for monitoring CO_2 absorption

Remote sensing is the process of collecting and analyzing information about the environment from a distance. In agriculture, remote sensing is used to collect and analyze information about crop health, growth, and yield. This information can then be used to make decisions about crop management practices and improve productivity. Remote sensing can be done through a variety of methods, including satellites, drones, and ground-based sensors. Each method has its own advantages and disadvantages, but all are useful for collecting data about crops and the environment.

Remote sensing can be used quit widely to support carbon farming by providing accurate and efficient ways to monitor and measure changes in carbon stocks and fluxes in soil and vegetation. This can be done by using remote sensing to estimate above-ground biomass, vegetation cover, and other vegetation characteristics, which are directly related to carbon sequestration potential. In addition, remote sensing can also be used to estimate soil organic carbon content and soil properties, which are critical for understanding soil carbon dynamics.

Using remote sensing, farmers and land managers can monitor changes in carbon stocks over time and track the effectiveness of carbon farming practices, such as conservation tillage, cover cropping, and agroforestry. This can help to identify areas where carbon sequestration is occurring, as well as areas where additional management interventions may be necessary to increase carbon sequestration potential.

Furthermore, remote sensing can provide spatially explicit information about land use and land cover changes, which can be used to prioritize areas for carbon farming and to support decision-making about land management practices. By providing accurate and timely information about carbon stocks and fluxes, remote sensing can help to facilitate the development of carbon markets and other mechanisms for incentivizing carbon farming practices.

Satellite-based remote sensing is the most commonly used method for monitoring CO_2 absorption and carbon sequestration. Satellites can capture large amounts of data over large areas, making them an ideal tool for monitoring carbon sequestration on a regional or global scale. Satellite-based remote sensing can provide information on vegetation cover, biomass, and other variables related to carbon sequestration.

For example, a study by Dimobe et al. (2018) used satellite-based remote sensing to estimate the carbon sequestration potential of croplands in Semi-Arid West African Savannas. The study used data from the Copernicus Sentinel-2 satellite to identify the main land use and land cover categories (LULCc) for assessing the carbon stocks (biomass and soil) in the selected LULCc and predict the effect of clime change on the spatial distribution of the carbon stock. The authors based on model results proved that climate change might have impact on carbon stock at specific horizon and these findings highlights the importance of practicing sustainable agriculture.

Another study by Csillik et al. (2019) used satellite-based remote sensing to measure forest carbon stocksand emissions. They created a large-scale very high-resolution map of aboveground carbon stocks and emissions for the country of Peru. The authors found significant carbon emissions between 2012 and 2017 in areas aggressively affected by oil palm and cacao plantations, agricultural and urban expansions or illegal gold mining.

Overall, satellite-based remote sensing is a powerful tool for monitoring carbon sequestration and CO_2 absorption in agricultural landscapes and can provide valuable insights for carbon farming practices.

3. Challenges and limitations of monitoring CO_2 absorption using remote sensing

Remote sensing technologies have the potential to provide valuable information for monitoring CO_2 absorption in agricultural systems, but there are several challenges and limitations that need to be considered, which are also mentioned by other authors (Abdul-Jabbar et al., 2023; Angelopoulou et al., 2019).

Spatial resolution. Remote sensing data may not have sufficient spatial resolution to detect small-scale changes in CO_2 absorption. This can be a limitation when monitoring carbon sequestration at the farm or field level.

Spectral resolution. The spectral resolution of remote sensing data can also be a limitation. Different types of vegetation and soil have different spectral signatures, which can make it challenging to accurately estimate CO_2 absorption in heterogeneous landscapes.

Cloud cover. Cloud cover can limit the availability of remote sensing data, which can affect the frequency and duration of monitoring.

Data availability. The availability of high-quality remote sensing data can be a challenge, particularly in developing countries or areas with limited resources.

Calibration and validation. The accuracy of remote sensing data depends on the calibration and validation of the instruments used. This can be a challenge, as ground-based measurements are often limited in spatial and temporal coverage.

Cost. Remote sensing technologies can be expensive, which can be a limitation for some applications.

These challenges and limitations highlight the need for careful consideration of the strengths and weaknesses of remote sensing technologies when monitoring CO_2 absorption in agricultural systems. Despite these challenges, remote sensing has the potential to provide valuable information for carbon sequestration monitoring and management.

Taking into account the possible challenges, further research is planned to analyze the combined application of different remote sensing data for the determination and monitoring of carbon stock. It is also planned to analyze which resolution images are too coarse to be able to make conclusions about effective carbon farming practices at the farmer level based on the results.

Conclusions

Carbon farming practices have the potential to sequester large amounts of carbon and mitigate climate change. Remote sensing technology provides a powerful tool for monitoring carbon sequestration and CO_2 absorption, which is critical for understanding the effectiveness of carbon farming practices. Satellite-based remote sensing is the most commonly used method for monitoring carbon sequestration, and several studies have demonstrated its effectiveness in monitoring changes in carbon sequestration over time. As remote sensing technology continues to advance, it will likely become an even more powerful tool for monitoring carbon farming and CO_2 absorption in the future. Also, taking into account the potential challenges mentioned in the article using specific remote sensing data, further studies decided to analyze the synthesis of different data, that is, the combined application of different remote sensing data.

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NUOTOLINIŲ TYRIMŲ TAIKYMAS ANGLIES ŪKININKAVIMO STEBĖSENAI: APŽVALGA

G. Metrikaitytė Gudelė, J. Sužiedelytė Visockienė

Santrauka

Šiame moksliniame straipsnyje apžvelgiamas anglies ūkininkavimo vaidmuo švelninant klimato kaitą, kaupiant anglį dirvožemyje ir augmenijoje. Straipsnyje pabrėžiamas nuotolinio stebėjimo technologijos potencialas stebint anglies ūkininkavimo praktiką ir CO_2 absorbciją. Aptariamos anglies dioksido ūkininkavimo praktikos, pvz., tausojantis žemės dirbimas, dengiamųjų augalų auginimas, sėjomaina ir agrarinė miškininkystė. Nagrinėjamas nuotolinio stebėjimo technologijų, įskaitant palydovinius vaizdus, aerofotografiją, antžeminius jutiklius, taikymas, stebint anglies kaupimo ir CO_2 absorbcijos pokyčius. Straipsnyje daroma išvada, kad nuotolinio stebėjimo technologija yra galingas įrankis anglies kaupimui ir CO_2 absorbcijai stebėti, o, technologijoms tobulėjant, ateityje greičiausiai taps dar veiksmingesnis.

Reikšminiai žodžiai: nuotoliniai tyrimai, palydoviniai vaizdai, CO_2, anglies ūkininkavimas, beariminė žemdirbystė.