

Environmental Implications of Peat-Based Growing Media on Carbon Balance and Greenhouse Gas Emissions in Horticultural Systems

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Abstract

Peat-based growing media have long been the backbone of commercial horticulture due to their favorable physical and chemical properties, including high water-holding capacity, low bulk density, and excellent aeration. However, increasing environmental concerns regarding peat extraction and utilization have intensified scrutiny of its role in carbon balance and greenhouse gas (GHG) emissions. Peatlands are among the most significant terrestrial carbon sinks, storing vast quantities of organic carbon accumulated over millennia. Their disturbance through peat extraction leads to irreversible carbon losses and contributes substantially to atmospheric carbon dioxide emissions. In horticultural systems, peat-based substrates further influence emissions of carbon dioxide, methane, and nitrous oxide through microbial decomposition, irrigation practices, fertilization regimes, and crop management. This review synthesizes current knowledge on the environmental implications of peat-based growing media, focusing on carbon dynamics, GHG emissions across the peat life cycle, and their broader climate impacts. The article also evaluates emerging alternatives to peat, such as composts, biochar, coir, and wood-based substrates, assessing their potential to mitigate emissions while maintaining horticultural productivity. The review highlights research gaps and policy considerations, emphasizing the urgent need for sustainable substrate management to align horticultural production with global climate mitigation goals.

Keywords: peat-based substrates, carbon balance, greenhouse gas emissions, horticulture, sustainability, growing media.

1. Introduction

The global horticulture industry relies heavily on soilless growing media to achieve consistent crop quality, high yields, and efficient resource use. Among these substrates, peat-based growing media have historically dominated due to their uniform structure, high porosity, chemical stability, and compatibility with a wide range of crops. Peat moss, primarily harvested from peatlands, is widely used in nursery production, greenhouse cultivation, and containerized horticulture across Europe, North America, and parts of Asia [1]. Peatlands occupy only about 3% of the Earth's terrestrial surface, yet they store approximately 30% of the world's soil carbon, making them one of the most critical global carbon reservoirs. These ecosystems accumulate organic matter under waterlogged and anaerobic conditions, resulting in extremely slow decomposition rates and long-term carbon sequestration. However, peat extraction disrupts these ecosystems, converting long-term carbon sinks into net carbon sources [2]. The growing urgency to mitigate climate change has brought attention to the environmental footprint of horticultural inputs, including growing media. The extraction, processing, transport, and use of peat-based substrates collectively contribute to

greenhouse gas emissions, particularly carbon dioxide. Furthermore, peat-based growing media influence emissions during crop production through microbial respiration, nutrient mineralization, and interactions with irrigation and fertilization practices, climate targets set by international agreements and national sustainability policies, several countries have proposed or implemented restrictions on peat use in horticulture. These developments have accelerated research into alternative growing media and sustainable substrate formulations [3]. However, peat remains widely used, especially in high-value horticultural production systems, due to the technical challenges associated with complete replacement. This review critically examines the environmental implications of peat-based growing media in horticultural systems, with a specific focus on carbon balance and greenhouse gas emissions. It explores the carbon dynamics of peatlands, emissions across the peat life cycle, on-farm emission processes, and the comparative environmental performance of alternative substrates. By synthesizing current scientific evidence, this article aims to inform researchers, growers, and policymakers seeking sustainable pathways for horticultural production.

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Table 1. Carbon Storage Potential and Greenhouse Gas Emissions from Intact and Drained Peatlands

| Peatland Condition | Carbon Storage Capacity | Dominant Greenhouse Gas Emissions | Estimated Emission Rates | Environmental Implications |
|-----------------------|---|---|---|---|
| Intact peatlands | Very high (up to 1,500 t C ha ⁻¹) | Methane (CH ₄) (low to moderate) | 0.1–1.0 t CO ₂ -eq ha ⁻¹ yr ⁻¹ | Acts as a long-term carbon sink; supports biodiversity and hydrological stability |
| Drained peatlands | Rapidly declining carbon stocks | Carbon dioxide (CO ₂), Nitrous oxide (N ₂ O) | 20–40 t CO ₂ -eq ha ⁻¹ yr ⁻¹ | Major carbon source; land subsidence and ecosystem degradation |
| Peat extraction sites | Severely depleted carbon reserves | CO ₂ (dominant) | >40 t CO ₂ -eq ha ⁻¹ yr ⁻¹ | Irreversible carbon loss and habitat destruction |
| Rewetted peatlands | Moderate carbon recovery potential | Reduced CO ₂ , increased CH ₄ | 5–10 t CO ₂ -eq ha ⁻¹ yr ⁻¹ | Partial restoration of climate regulation functions |

Table 2. Life Cycle Greenhouse Gas Emissions Associated with Peat-Based Growing Media in Horticultural Systems

| Life Cycle Stage | Major Emission Sources | Key Greenhouse Gases | Relative Contribution to Total Emissions (%) | Environmental Impact |
|---------------------------------|---|------------------------------------|--|--|
| Peat extraction and drainage | Oxidation of organic carbon, land disturbance | CO ₂ , N ₂ O | 60–75 | Largest contributor to climate impact |
| Processing and packaging | Fossil fuel use, drying operations | CO ₂ | 10–15 | Energy-intensive phase |
| Transportation and distribution | Fuel combustion during transport | CO ₂ | 5–10 | Increases with transport distance |
| Cultivation and use | Microbial respiration, fertilizer-induced emissions | CO ₂ , N ₂ O | 5–10 | Continuous emissions during crop growth |
| End-of-life management | Composting, disposal, reuse | CO ₂ | <5 | Limited potential for carbon sequestration |

2. Peatlands as Major Carbon Reservoirs and Their Ecological Significance

Peatlands are among the most important terrestrial ecosystems in terms of carbon storage and climate regulation. Formed under waterlogged, anaerobic conditions, peatlands accumulate partially decomposed plant biomass over thousands of years, resulting in thick organic soil layers rich in carbon. Although peatlands cover only about 3–4% of the global land surface, they store an estimated 500–600 gigatons of carbon, which is approximately twice the amount of carbon stored in the world's forests [4]. This disproportionate contribution underscores their critical role in the global carbon cycle.

The carbon sequestration function of peatlands is maintained through a delicate balance of hydrology, vegetation, and microbial activity. High water tables restrict oxygen diffusion, slowing microbial decomposition and allowing organic matter to accumulate. However, when peatlands are drained for agricultural use or peat extraction, this balance is disrupted. Aeration accelerates microbial oxidation of stored organic carbon, leading to rapid and often irreversible release of carbon dioxide into the atmosphere. Studies indicate that drained peatlands can emit 20–40 t CO₂ ha⁻¹ yr⁻¹, transforming these ecosystems from carbon sinks into major carbon sources [5]. Beyond carbon dioxide emissions, drained peatlands also contribute to nitrous oxide emissions due to enhanced nitrification and denitrification processes, particularly when fertilizers are applied. Methane emissions, typically high in intact peatlands, decrease upon drainage, but this reduction does not compensate for the substantial increase in carbon dioxide and nitrous oxide emissions [6], peatland degradation results in significant ecological consequences, including loss of biodiversity, alteration of hydrological regimes, increased fire susceptibility, and land subsidence. These environmental costs raise serious concerns regarding the sustainability of peat extraction for horticultural growing media, particularly in the context of global climate change mitigation efforts.

3. Life Cycle Greenhouse Gas Emissions of Peat-Based Growing Media

The environmental impact of peat-based growing media must be evaluated across its entire life cycle, from extraction to end use and disposal. Life cycle assessment (LCA) studies have become an essential tool for quantifying the cumulative greenhouse gas emissions associated with peat utilization in horticulture.

3.1 Emissions from Peat Extraction and Processing

Peat extraction is the most emission-intensive phase of the peat life cycle. The process involves drainage of peatlands, removal of surface vegetation, milling or block cutting, and drying of peat material. Drainage exposes previously anaerobic peat layers to oxygen, triggering rapid microbial decomposition and oxidation of organic carbon. This results in substantial carbon dioxide emissions that continue long after extraction ceases [7]. Mechanical operations during extraction and processing also contribute to emissions through fossil fuel combustion. Milling, drying, and packaging require significant energy inputs, further increasing the carbon footprint of peat-based substrates. Estimates suggest that emissions from extraction and processing alone can account for over 70% of the total life cycle emissions of peat-based growing media.

3.2 Transportation and Distribution Emissions

Peat is frequently transported over long distances from extraction sites to horticultural production areas, particularly in regions where local peat resources are limited. Transportation emissions depend on distance, transport mode (road, rail, or sea), and substrate bulk density. Imported peat-based substrates can substantially increase greenhouse gas emissions associated with horticultural production systems, especially when transported internationally.

3.3 Emissions During Cultivation and Use

Once incorporated into horticultural systems, peat-based growing media continue to emit greenhouse gases through microbial respiration and organic matter mineralization.

Carbon dioxide emissions dominate during cultivation due to aerobic decomposition, particularly under warm and moist conditions typical of greenhouse environments. Nitrous oxide emissions may also occur following nitrogen fertilization, especially under fluctuating moisture regimes that favor denitrification [8]. Methane emissions from peat-based substrates are generally low in containerized horticulture due to well-aerated conditions; however, localized anaerobic microsites may still contribute small amounts. Overall, emissions during the cultivation phase, although lower than extraction-related emissions, add to the cumulative climate impact of peat use.

4. Carbon Balance in Peat-Based Horticultural Production Systems

The carbon balance of peat-based horticultural systems is determined by the relationship between carbon inputs through plant growth and carbon losses through substrate decomposition and respiration. While crops grown in peat-based media assimilate atmospheric carbon dioxide via photosynthesis, this carbon is largely stored in short-lived biomass and is rapidly returned to the atmosphere through respiration, harvest, and post-harvest decomposition [9], the carbon stored in peat represents millennia of accumulation that is rapidly lost upon extraction and use. As a result, peat-based horticultural systems are typically net carbon sources rather than sinks. Even high-yielding horticultural crops are unable to offset the carbon emissions associated with peat degradation and oxidation. Containerized horticulture further limits opportunities for long-term carbon sequestration, as growing media are frequently replaced after one or a few production cycles. Although spent peat-based substrates may be reused in landscaping or composted, these practices generally result in continued carbon mineralization rather than stable sequestration [10]. Carbon balance assessments consistently demonstrate that reducing peat content in growing media is one of the most effective strategies for lowering the carbon footprint of horticultural production. Partial substitution with renewable or recycled materials can significantly decrease net emissions while maintaining acceptable physical and chemical properties for crop growth. Understanding and improving the carbon balance of horticultural systems is essential for aligning the sector with climate-neutral or climate-positive production goals. This requires not only alternative substrates but also improved management practices, such as optimized irrigation, precise nutrient application, and extended substrate reuse where feasible.

5. Alternative Growing Media and Their Environmental Performance

Growing concerns over peat sustainability have driven the development of alternative substrates, including composted green waste, coconut coir, wood fibers, bark, and biochar. Each alternative presents unique environmental advantages and limitations. Composts can reduce waste and recycle nutrients but may emit nitrous oxide during decomposition.

Coir is renewable and has favorable physical properties, yet long-distance transport increases its carbon footprint. Wood-based substrates are locally available in many regions but may require nitrogen supplementation. Biochar shows promise for carbon sequestration and emission reduction, though large-scale adoption remains limited [11]. Blended substrates combining peat with renewable components are increasingly used as transitional solutions to reduce peat dependency while maintaining crop performance.

7. Future Perspectives

Future research should prioritize the development of low-emission growing media with consistent performance across diverse crops and production systems. Improved life cycle assessments, including long-term field studies, are needed to quantify emissions under real-world conditions. Innovations in substrate management, such as optimized irrigation and fertilization, may further reduce emissions associated with peat-based and alternative media. Policy support, coupled with grower education and economic incentives, will be critical in accelerating the transition toward climate-smart horticulture.

8. Conclusion

Peat-based growing media have played a pivotal role in the development of modern horticulture, yet their environmental costs are increasingly incompatible with global climate mitigation goals. The extraction and use of peat disrupt carbon-rich ecosystems, contribute significantly to greenhouse gas emissions, and undermine long-term carbon sequestration. While peat-based substrates offer agronomic advantages, their carbon footprint outweighs the limited carbon gains achieved through horticultural production. The transition toward sustainable growing media is both a challenge and an opportunity for the horticulture sector. Renewable and recycled alternatives, when carefully formulated and managed, can substantially reduce emissions while maintaining crop quality and productivity. Moving forward, an integrated approach combining scientific innovation, policy intervention, and industry collaboration is essential to align horticultural practices with environmental sustainability. Reducing reliance on peat-based growing media represents a critical step toward climate-resilient and environmentally responsible horticultural systems.

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