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Mapping Agricultural Research on Peatlands: A Bibliometric Analysis of Trends and Gaps (2004–2024)

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ABSTRACT

Peatlands in Indonesia play a crucial role in global carbon storage and agricultural productivity. However, their use for agriculture has raised environmental concerns, particularly regarding land degradation, carbon emissions, and fire risks. This study employs a bibliometric approach using Publish or Perish (PoP) and VOSviewer to analyze research trends, dominant topics, and gaps in Indonesian peatland agriculture from 2004 to 2024. Three thousand nine hundred fifty (3,950) publications from Google Scholar were examined to identify thematic clusters and shifts in research focus. The results indicate a significant increase in research on peatland agriculture over the past two decades, with a primary focus on land management, environmental impact, and agricultural commodity adaptation. Oil palm remains the dominant research topic, while studies on alternative crops, horticulture, and sustainable peatland management strategies remain underexplored. Although fire mitigation has gained attention, long-term sustainability approaches and policy-driven land management strategies require further investigation. This study underscores the need for a multidisciplinary and collaborative approach to ensure sustainable peatland agriculture. Future research should prioritize the diversification of peat-adaptive crops, precision agriculture technologies, and ecosystem-based restoration methods. Additionally, policymakers must integrate research findings into comprehensive land-use planning to balance agricultural productivity with environmental conservation. Strengthening regulations, incentivizing sustainable practices, and fostering interdisciplinary collaboration will be essential for addressing the challenges of peatland agriculture and ensuring its long-term viability.

1. Introduction

Indonesia’s peatlands, encompassing approximately 36% of the world’s tropical peatlands (Miettinen et al., 2016; Page et al., 2011), play a critical role in global carbon storage and climate regulation. However, their conversion for agriculture has led to severe environmental challenges, including annual carbon emissions exceeding 500 Mt CO_2 due to drainage and fires (Hooijer et al., 2012), as well as the degradation of over 2.4 million hectares of peat ecosystems (Murdiyarso et al., 2019). These practices exacerbate subsidence, recurrent land fires, and biodiversity loss (Evans et al., 2019; Sumarga et al., 2016), undermining both local livelihoods and global climate targets (Couwenberg et al., 2010;

Jaenicke et al., 2010). Despite restoration initiatives—such as canal blocking and revegetation—progress remains constrained by fragmented research and insufficient integration of multidisciplinary insights (Harrison et al., 2020; Ritzema et al., 2014).

Existing studies on peatland agriculture often focus narrowly on sectoral themes (e.g., hydrology, agronomy) rather than synthesizing broader trends (Dommain et al., 2014; Uda et al., 2017). For instance, while oil palm dominates research, alternative crops like pineapple or corn remain underexplored (Handayani, 2021; Suhartawan & Sulaiman, 2024). This sectoral approach obscures opportunities for interdisciplinary collaboration, which is vital for balancing economic productivity with ecological sustainability (Dohong et al., 2018; Purnomo et al., 2019). Furthermore, limited analysis of long-term policy impacts and precision agriculture techniques hinders the development of scalable solutions (Wahyunto et al., 2013).

To address existing knowledge gaps, this study employs bibliometric analysis using Publish or Perish and VOSviewer to examine research trends, collaborations, and underexplored topics in Indonesian peatland agriculture from 2004 to 2024. By analyzing 3,950 publications from Google Scholar over the past two decades, it provides a comprehensive overview of the field's development (Ellegaard & Wallin, 2015; Mingers & Leydesdorff, 2015), highlighting dominant themes such as oil palm cultivation and fire mitigation, along with emerging opportunities in crop diversification and socio-economic policies. This analysis aims to guide future research by identifying underexplored areas, fostering cross-disciplinary collaboration (Glänzel & Schubert, 2003; Small, 2006), and promoting innovation in sustainable peatland management. Furthermore, mapping research gaps can support evidence-based policymaking (Bornmann & Daniel, 2008; Hood & Wilson, 2001), ensuring that agricultural productivity aligns with peatland conservation efforts.

2. Methodology

2.1. Research Approach

This study employs bibliometric analysis to systematically map the evolution of agricultural research on Indonesian peatlands from 2004 to 2024. Bibliometrics, a quantitative method for analyzing publication patterns, was selected due to its efficacy in identifying research trends, collaborations, and knowledge gaps through large-scale data mining (Zupic & Čater, 2015). This approach provides a structured framework to assess thematic and temporal dynamics in peatland agriculture research by leveraging metadata such as titles, abstracts, keywords, and citations.

2.2. Data Source

Data were retrieved from Google Scholar using the Boolean search query "Agriculture" AND "Peat" to ensure thematic relevance. The search spanned 2004 to 2024 to capture two decades of research evolution, with document types including journal articles, conference proceedings, theses, and dissertations in English and Indonesian. Three thousand nine hundred fifty (3,950) documents were directly analyzed after excluding duplicates and non-peer-reviewed materials (e.g., reports and newsletters). This rigorous selection prioritized academic rigor while maintaining breadth, ensuring the dataset represented credible and focused contributions to peatland agriculture.

2.3. Data Analyze

Publication metadata were extracted using Publish or Perish (PoP) and analyzed with VOSviewer (version 1.6.20). VOSviewer's association strength algorithm—which calculates term relationships based on co-occurrence frequency—was applied to generate keyword networks (Van Eck & Waltman, 2010). This method emphasizes meaningful semantic connections over random linkages, ensuring robust clustering of themes. Three visualization modes were utilized: network visualization to map keyword clusters, overlay visualization to highlight temporal trends using color gradients, and density visualization to identify high- and low-intensity research areas. A co-occurrence threshold of 10 instances per keyword was set to filter noise, and generic terms (e.g., "Agriculture" and "Peat") were excluded to avoid dominance. After filtering, 56 keywords remained, forming six thematic clusters.

2.4. Data Validation

To ensure validity, RIS-formatted data from PoP were cross-verified with seminal literature on peatland agriculture (e.g., Couwenberg et al., 2010; Evans et al., 2019). Keyword clusters were manually checked against contextually relevant studies to minimize bias from ambiguous terms (Al Husaeni & Nandiyanto, 2021). For instance, region-specific terms like "Riau" were retained only if linked to agricultural practices. This iterative refinement strengthened the reliability of network interpretations and ensured alignment with the study's focus.

3. Results and Discussion

3.1. Research Matrix

The bibliometric analysis of 3,950 publications on peatland agriculture from 2004 to 2024 (Table 1) highlights a dynamic and impactful research landscape. The total citation counts of 32,413, averaging 8.21 citations per paper and 1,543.48 annually, underscores the field's growing academic relevance. This surge aligns with global efforts to address peatland degradation, particularly after the 2015 Paris Agreement (UNFCCC, 2015) and Indonesia's enactment of peatland protection policies (Republic of Indonesia, 2016). These frameworks prioritized peat restoration and fire mitigation, catalyzing interdisciplinary studies on sustainable agricultural practices in peat-rich regions like Sumatra and Borneo (Miettinen et al., 2016; Wahyunto et al., 2013).

Table 1. Research Data Matrix

Publication years	: 2004-2024
Citation years	: 21 (2004-2025)
Paper	: 3950
Citations	: 32413
Cites/year	: 1543.48
Cites/paper	: 8.21
Cites/author	: 21403.47
Papers/author	: 2594.56
Author/paper	: 2.05/2.0/1 (mean/median/mode)
h-index	: 68
g-index	: 130
hI,norm	: 57
hI,annual	: 2.71
hA-index	: 14
Papers with ACC	: 1,2,5,10,20:760,344,97,22,8

Author productivity metrics reveal a collaborative yet concentrated research ecosystem. The average of 2.05 authors per paper reflects small-team dominance, while high citation rates per author (21,403.47) suggest influential contributions from key researchers or institutions. The h-index of 68 indicates that 68 publications have each received at least 68 citations, a benchmark of foundational impact (Bornmann & Daniel, 2008). Complementing this, the g-index 130 signals broad citation distribution across subfields like peatland hydrology and carbon dynamics (Egghe, 2006). These indices collectively illustrate a maturing field with sustained contributions, as evidenced by the stability metrics (hI, norm = 57; hI, annual = 2.71).

However, citation disparities persist. While 760 publications received ≥1 citation, only 8 surpassed 20 citations, reflecting uneven research impact. High-impact studies likely focus on policy-relevant themes such as oil palm management and CO_2 emissions (Hooijer et al., 2012; Page et al., 2011), which dominate academic and policy discourse due to their alignment with climate agendas (IPCC, 2019). Conversely, under-cited works may address niche topics like crop diversification or socio-economic analyses, indicating untapped research potential.

Geographically, studies from Riau and Kalimantan dominate, reflecting Indonesia's peatland concentration (Wahyunto et al., 2013). This regional focus risks overlooking broader ecological and socio-economic contexts, underscoring the need for collaborative networks to address multi-scale challenges. For instance, integrating precision agriculture tools (Van Eck & Waltman, 2010) with traditional practices could enhance peatland resilience while balancing productivity and conservation (Wösten et al., 2008).

In summary, while peatland agriculture research has achieved notable academic traction, its future hinges on diversifying themes, expanding collaborations, and aligning with global sustainability frameworks.

3.2. Network Visualization

Bibliometric analysis based on keyword mapping was carried out in three forms of visualization, namely: (1) Network Visualization, (2) Overlay Visualization, and (3) Density Visualization. Although each type of visualization presents a different perspective, all three have the same goal: to map bibliometric relationships among publications based on downloaded metadata (Van Eck & Waltman, 2010).

Network Visualization in bibliometric analysis aims to describe the relationship between keywords often appearing in agricultural research on peatlands over the past 20 years. Based on VOSviewer data, this network is built from relationships between keywords that have a relationship based on simultaneous occurrences in one article. This network structure can provide insight into frequently used terms and how they relate to scientific discourse.

Each term is represented as a node in the analyzed VOSviewer data (Figure 1). In contrast, the connecting lines (edges) between the nodes reflect the relationship between two terms that often appear together in the same article. The thicker the connecting line, the stronger the relationship between the terms. In addition, the occurrence value indicates how often a word appears in the overall dataset, while link strength describes the strength of associations between terms (Cobo et al., 2011).

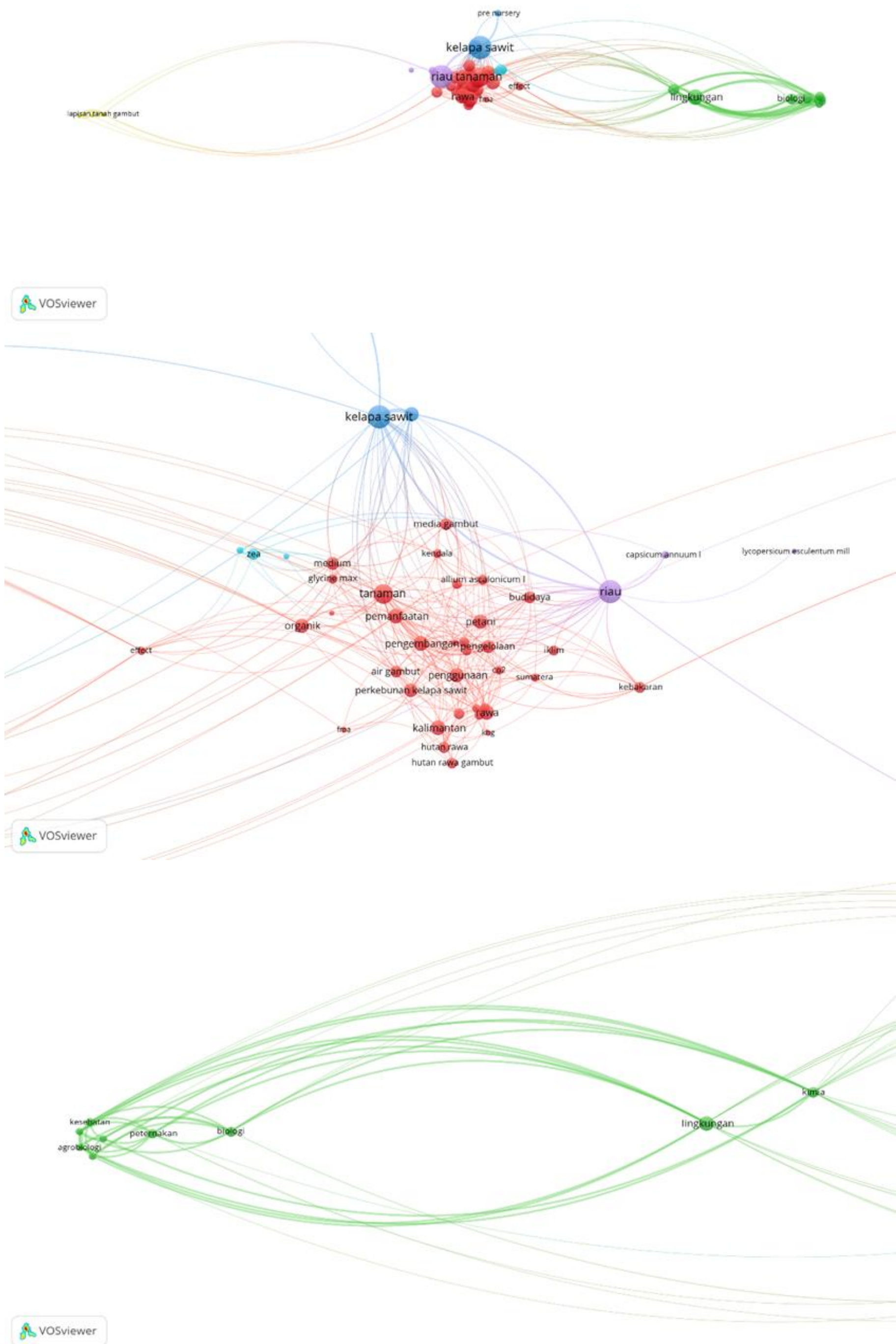

Figure 1. Network Visualization VOSviewer
Source: Analyzed Data, 2025

Figure 1 reveals six thematic clusters, delineating key trends and gaps in peatland agriculture research:

1. Cluster 1 (Red): Management, Utilization, and Characteristics of Peatlands in Agriculture: The red cluster is the largest cluster with 35 terms, covering the main topics related to the management and use of peatlands in agriculture. Some of the main terms in this cluster are peat water, swamp forest, peat media, management, utilization, oil palm plantations, and smallholders. In addition, terms such as co_2, climate, and fire indicate a

link to environmental issues, especially carbon emissions from peatlands and climate change. The existence of the terms cultivation, palm oil, oryza sativa l. (rice), and theobroma cacao l. (cocoa) indicates that the research also includes the exploration of various agricultural commodities developed on peatlands. This cluster highlights how peatlands are used for agriculture and the environmental challenges its management faces. This aligns with studies emphasizing the environmental risks of peatland conversion for oil palm (Hooijer et al., 2012).

2. Cluster 2 (Green): Environmental and Health Impacts in Peatland Agriculture: The green cluster consists of 9 terms, covering topics that focus more on agriculture's environmental and health impacts on peatlands. Terms such as chemistry, biology, environment, and agrobiology show that research in this cluster discusses many ecological aspects and changes in peatland properties due to agricultural activities. In addition, freshwater fisheries and livestock indicate research linking peatland agriculture with the fisheries and livestock sectors. The existence of the term health indicates concern for the impact of the agricultural environment on human health and ecosystems. This cluster emphasizes the aspects of sustainability and ecosystem balance in peatland agriculture.
3. Cluster 3 (Blue): Key Commodities in Peatland Agriculture—Palm Oil The blue cluster consists of three terms, all related to oil palm as the main commodity in peatland agriculture. The terms in this cluster are Elaeis guineensis Jacq, oil palm, and pre-nursery. This cluster aligns with studies that underscore oil palm’s dominance, reflecting its economic significance but also the ecological trade-offs (Page et al., 2011).
4. Cluster 4 (Yellow): Soil Damage and Peatland Fires: The yellow cluster includes 3 terms, namely the impact of peat fires, soil damage, and peat soil layers. This cluster shows that soil degradation due to fire is a main research focus in peatland agriculture. The terms soil damage and peat soil layer indicate that the research in this cluster discusses a lot of how fires and agricultural activities affect the stability and productivity of peat soil. This cluster is very relevant to the discussion on sustainability and fire mitigation in peatland management for agriculture; this is in line with research from Askary & Astuti (2022), which highlights the importance of policies on environmental protection and management in maintaining the ecological function of peatlands while supporting sustainable agricultural activities.
5. Cluster 5 (Purple): Geographical Aspects and Horticultural Cultivation in Peatlands The purple cluster consists of three terms: capsicum annuum l. (chili). lycopersicum esculentum (tomato), and riau. This cluster shows that research focuses on developing horticultural crops in peatlands, especially chili peppers and tomatoes. The term Riau in this cluster indicates that much horticultural research on peatlands is carried out in this region. This shows the exploration of diversification of crops that can be cultivated in peat ecosystems outside of industrial crops such as oil palm.
6. Cluster 6 (Light Blue): Development of Alternative Crops in Peatlands The light blue cluster consists of 3 terms, namely ananas comosus (pineapple), saccharata sturt (wheat), and zea (corn). This cluster signals a gradual shift toward crop diversification, for example, the research results from Handayani (2021) on the analysis of pineapple farming on peatlands and its marketing. The existence of pineapples in this cluster indicates that horticultural plants have the potential to be developed on peatlands. The terms zea (corn) and saccharata sturt (wheat) indicate the existence of studies on

diversifying food crops in peatlands, which can be a solution to increasing agricultural productivity on these marginal lands.

The network visualization reveals that peatland agriculture research is predominantly centered on oil palm cultivation, peatland degradation, and carbon emissions. However, emerging research clusters indicate an increasing focus on sustainable farming techniques, including agroforestry and crop diversification (Handayani, 2021). This shift suggests that while oil palm remains dominant, researchers are beginning to explore alternative approaches that balance economic viability with ecological sustainability.

3.1. Overlay Visualization

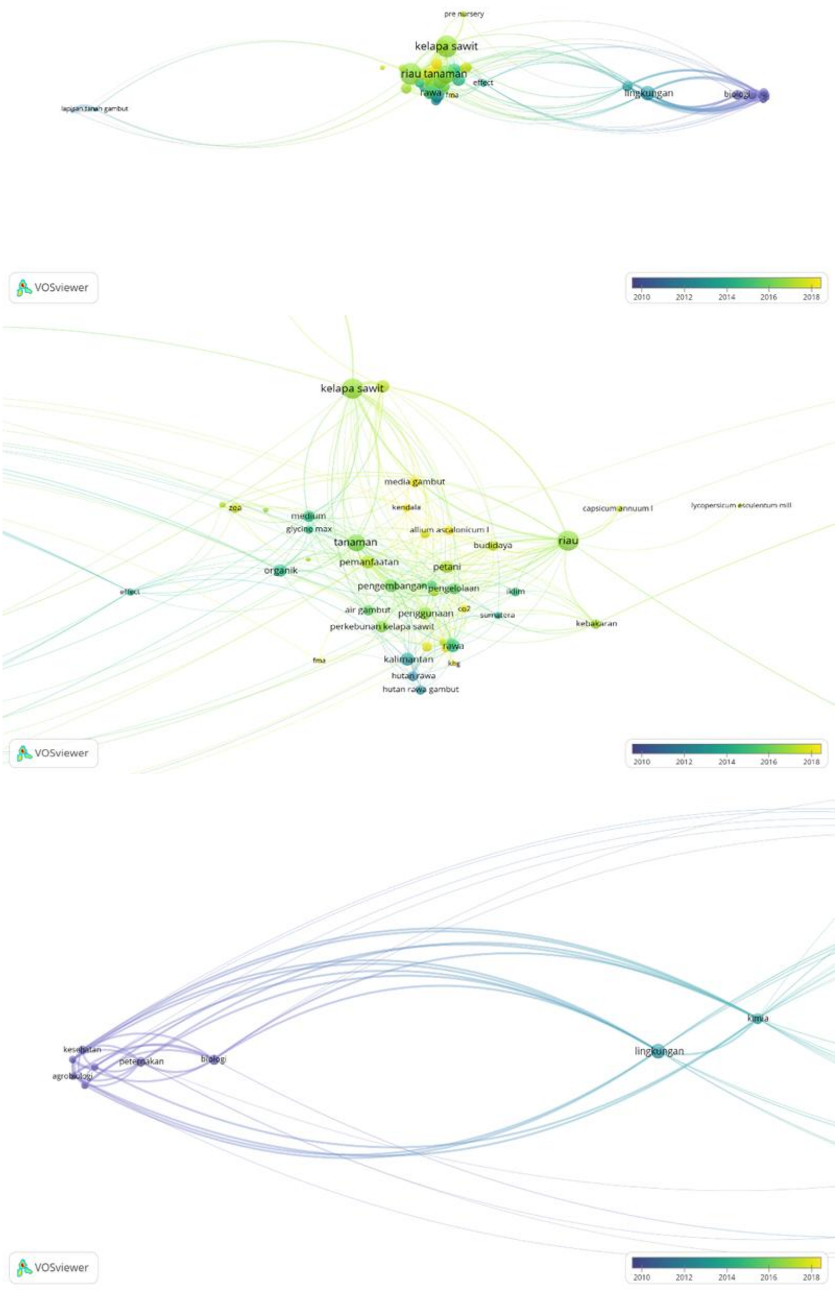

Figure 2. Overlay Visualization VOSviewer
Source: Analyzed Data, 2025

The trend of agricultural research on peatlands has experienced dynamic development from time to time, as shown in the Overlay Visualization in Figure 2. The colors in this visualization represent the temporal distribution of the research terms, with the color spectrum moving from blue (2010) to yellow (2018). This analysis shows search has shifted from environmental and ecological studies to the exploration of agricultural commodities and environmental impact mitigation strategies.

From 2010 to 2013, research focused more on environmental impacts and biological aspects in peatland ecosystems. Terms such as environment, biology, chemistry, agrobiology, and animal husbandry dominate scientific discussions in this era. The research focuses mainly on peatland degradation, soil quality, and its impact on biodiversity and freshwater. In this phase, researchers are trying to understand how ecosystem changes due to agricultural activities affect the ecological balance (IPCC, 2019).

As time went by, from 2014 to 2016, research began to shift towards peatland management for agriculture. Terms such as management, utilization, use, and oil palm plantation appear more and more frequently in the scientific literature. This indicates that many studies are beginning to explore ways to optimize peatlands for commercial agriculture, particularly in the context of oil palm plantations. During this period, research also began to highlight technical aspects such as peat media, peat water, and peat swamp forests, which showed an increased interest in understanding the characteristics of peatlands to support agricultural production, coinciding with Indonesia’s peatland protection policies (Republic of Indonesia, 2016).

Entering the period from 2017 to 2018, the research trend is increasingly developing towards diversification of crops and peatland fire mitigation. Research began to explore alternative food crops that can be cultivated in peat ecosystems, as indicated by terms such as zea (corn) and capsicum annuum l. (chili), and lycopersicum esculentum (tomato). In addition, the emergence of the terms co_2, climate, and fire in yellow indicates increased attention to environmental impact mitigation, especially concerning carbon emissions and peatland fire prevention. At this stage, researchers began to look for sustainable solutions that benefited the agricultural sector and helped reduce the risk of ecological disasters. For instance, early studies on peatland degradation (Cluster 4) evolved into practical solutions like fire mitigation and precision irrigation (Cluster 6), demonstrating a transition from problem identification to sustainable problem-solving. This aligns with global calls for climate-smart agriculture in peatlands (UNFCCC, 2015).

The results of this analysis show that research on agriculture in peatlands has undergone a significant shift in the last two decades. Initially, the study focused more on ecological impacts and environmental sustainability, then expanded towards agricultural optimization, and finally transformed into the search for more sustainable innovative solutions, including crop diversification and climate change impact mitigation. This shift reflects the growing awareness of the need to balance agricultural productivity and environmental conservation in peat ecosystems.

3.2. Density Visualization

The changes in research trends shown in the overlay visualization provide an overview of how the focus of agricultural research on peatlands has evolved. Initially, research focused more on environmental and ecological aspects, but over time, attention shifted towards land optimization for agriculture and commodity diversification. In recent years, the issue of fire mitigation and the impact of climate change has also been increasingly studied. To complete this understanding, density analysis was used to show the level of intensity and concentration of the topics most frequently studied by researchers. This visualization plays a role in identifying high-density research areas and uncovering key topics that are the focus of agribusiness research networks, as shown in Figure 3.

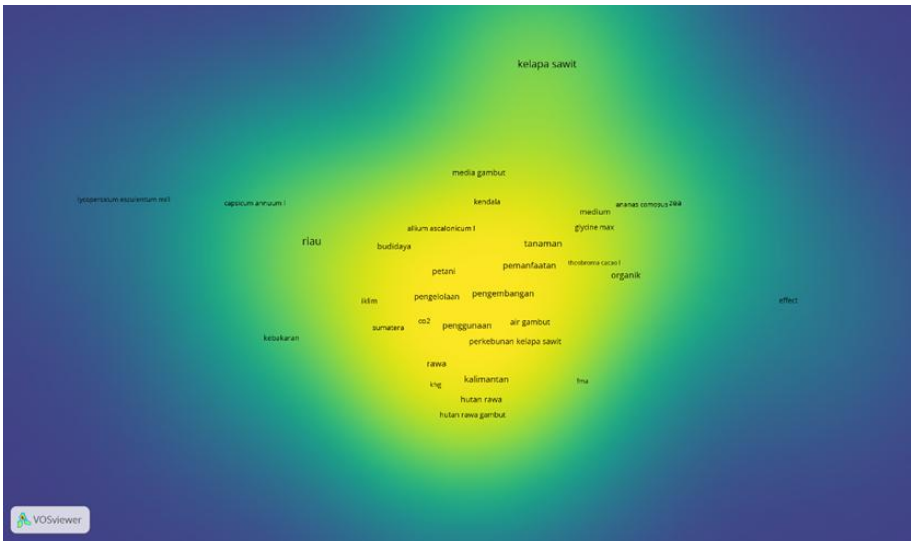

Figure 3. Density Visualization VOSviewer
Source: Analyzed Data, 2025

A lighter color (yellow) indicates a high-density research area, while a darker color (blue-green) indicates a less studied field. The results of this analysis show that research on peatlands is still heavily focused on oil palm, land management strategies, and exploration of peat planting media. Meanwhile, emerging fields such as agricultural diversification and climate adaptation are gaining traction but remain underexplored.

In high-density areas, terms such as palm oil, use, development, utilization, and management dominate research. This reflects the persistent emphasis on optimizing peatlands for industrial-scale oil palm cultivation, often at the expense of ecological sustainability. However, terms like peat media and aquaculture also appear frequently, indicating parallel efforts to characterize peat soil properties and explore alternative land-use systems.

In medium-density zones, themes like Riau and Kalimantan highlight region-specific studies, particularly in Indonesia's peat-rich provinces. Fire, climate, organic, and Zea (corn) signal a gradual shift toward environmental mitigation and crop diversification. For instance, research on allium ascalonicum l. (shallots) Moreover, organic farming underscores attempts to adapt traditional crops to peatland conditions while reducing chemical inputs.

These trends highlight critical opportunities for bridging research gaps into actionable solutions. For example, the co-occurrence of peat media and aquaculture in medium-density clusters underscores the potential for integrated farming systems, where fish farming in peat canals can coexist with organic vegetable cultivation. A study by Nurhidayah et al. (2023) demonstrated that such systems reduced fire risks by 40% and increased farmer incomes by 25% in Riau, Indonesia. Additionally, the link between organic and climate terms emphasizes the role of precision technologies, such as IoT-enabled moisture sensors, which Evans et al.

(2019) found could reduce peat subsidence by 30% while maintaining crop yields. Furthermore, despite limited attention to legume crops, nitrogen-fixing plants like soybeans, as Dohong et al. (2018) proposed, offer a natural solution to peat soil infertility, reducing dependence on chemical fertilizers. These findings align with IPCC's (2019) recommendations for climate-resilient agriculture, urging policymakers and practitioners to prioritize adaptive, multi-functional land-use models that balance productivity with ecological preservation. While significant progress has been made in peatland research, the current landscape remains uneven, with certain topics receiving extensive attention while others are still underexplored. In particular, the predominance of oil palm studies has overshadowed the need for broader agricultural diversification and sustainable land-use strategies.

However, these research gaps present valuable opportunities for further exploration, especially in areas with low research density. Addressing these underdeveloped topics is crucial for expanding the scientific understanding of peatland agriculture and informing more holistic policy interventions. Future research should focus on emerging fields such as precision agriculture, alternative crop cultivation, and socio-economic analyses to enhance both productivity and environmental sustainability. The following research topics have been identified as promising avenues for further investigation based on the findings of this analysis:

1. Technology and Methods of Sustainable Cultivation in Peatlands
   a. Application of biochar and bioremediation techniques as a strategy to improve the fertility and stability of peat soil.
   b. Hydroponic and aeroponic systems overcome peat soil fertility constraints in producing vegetables and other horticultural crops.
   c. Study the use of organic fertilizers and microbial-based biostimulants to increase the availability of nutrients in peat soil.
   d. Development of precision irrigation and sensor-based water management systems to optimize peat soil moisture.
2. Socio-Economic Impacts and Peatland Management Policies
   a. A study on the relationship between the expansion of oil palm plantations on peatlands and the social and economic impacts on local communities.
   b. A peatland management policy study that focuses on incentives for smallholders to implement sustainable agricultural practices.
   c. Evaluation of peatland agricultural supply chains, including marketing strategies and increasing the competitiveness of agricultural products from peatland areas.
   d. Analysis of the institutional role of farmers in supporting sustainable agricultural practices and adaptation to climate change.
3. Environmental Impact Mitigation and Adaptation to Climate Change
   a. A study on carbon emission mitigation strategies due to the conversion of peatlands into agricultural areas.
   b. Research on the impact of peatland use change on biodiversity and ecosystem balance.
   c. Development of methods for restoration of peatlands that fires or long-term agricultural practices have degraded.
   d. Evaluation of the effectiveness of the canal barrier system and groundwater level management in reducing the risk of peatland fires.
4. Exploration of Alternative Commodities for Peatlands

a. A study on the productivity of food crops such as corn (Zea mays) and wheat in peatlands.
b. Exploration of tropical fruit crops such as pineapple (Ananas comosus) and bananas that can be developed as superior commodities for peatlands.
c. Further studies on legume and legume plants can increase peat soil fertility through nitrogen fixation mechanisms.
d. Study the potential of herbal and medicinal plants that can be developed on peatlands.

4. Conclusion

This study highlights the rapid growth of research on peatland agriculture in Indonesia, with an increasing focus on land management, environmental impact, and oil palm cultivation. However, despite this progress, significant research gaps remain, particularly in alternative crop diversification, long-term sustainability strategies, and policy-driven land management approaches. The dominance of oil palm research reflects its economic significance but also underscores the need for more balanced agricultural development that integrates ecological sustainability. Future research should prioritize adaptive agricultural models that promote resilience in peatland ecosystems. Precision farming technologies, agroforestry systems, and ecosystem-based restoration strategies offer promising solutions for enhancing productivity while mitigating environmental risks. Additionally, socio-economic assessments are crucial to understanding the broader implications of peatland agriculture, particularly about smallholder livelihoods and rural economies. From a policy perspective, integrating research findings into comprehensive land-use planning is essential to ensure both agricultural productivity and environmental conservation. Policymakers must establish incentives for sustainable practices, strengthen peatland protection regulations, and support interdisciplinary collaborations that bridge scientific insights with practical applications. Future research can contribute to a more sustainable and equitable approach to peatland agriculture by addressing these challenges.

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