ELEMENTAL PROFILE AND STOICHIOMETRY OF PEATLAND TREE

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BOGOR
2025

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Bogor, September 2025

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RINGKASAN

MOH. SYUKRON ISMAIL. Profil Elemen dan Stoikiometri Pohon Lahan Gambut. Dibimbing oleh TRIADIATI, SULISTIJORINI, dan MAFRIKHUL MUTTAQIN.

Lahan gambut tropis memainkan peran penting dalam menjaga kestabilan iklim global karena kemampuannya dalam menyimpan karbon. Lahan gambut Indonesia menyimpan sekitar 28,1 gigaton karbon, dan hampir setengahnya berada di wilayah Sumatra. Namun, deforestasi, pengeringan, dan alih fungsi lahan telah menyebabkan penurunan luas lahan gambut secara drastis, terutama di Sumatra. Upaya revegetasi selama ini cenderung berfokus pada spesies lokal yang tumbuh cepat, namun pendekatan ini sering mengabaikan pentingnya karakter tumbuhan seperti stoikiometri nutrien, yang memengaruhi proses dekomposisi, siklus hara, dan penyimpanan karbon jangka panjang. Rasio unsur karbon (C), nitrogen (N), fosfor (P), dan kalium (K) dalam jaringan tumbuhan memberikan informasi penting mengenai strategi adaptasi dan fungsinya dalam ekosistem. Penelitian terkait stoikiometri nutrien sebagian besar dilakukan di wilayah beriklim sedang, sedangkan di wilayah tropis lebih berfokus pada pertumbuhan tanaman. Studi ini dilakukan untuk mengisi kekurangan tersebut. Penelitian ini menganalisis profil stoikiometri pohon-pohon gambut di Sumatra Selatan berdasarkan: (1) rasio C:N pada akar, batang, ranting, dan daun dan mengidentifikasi spesies dengan potensi tinggi dalam menyimpan karbon tanah, serta (2) stoikiometri daun N:P:K untuk mengungkap kemungkinan keterbatasan hara pada spesies tersebut.

Penelitian ini dilaksanakan pada Juli hingga November 2024 di lanskap PT Tri Pupa Jaya (TPJ), Kabupaten Musi Banyuasin, Provinsi Sumatra Selatan (1°44'16.24"S, 104°12'16.08"E). Sampel pohon berupa akar, batang, ranting, dan daun dikumpulkan dari petak hutan gambut primer seluas 1 hektar. Persiapan sampel dilakukan di Departemen Biologi, Institut Pertanian Bogor. Analisis nutrien dilakukan di Laboratorium Tanah, Tanaman, Pupuk, dan Air, Balai Penelitian Tanah. Sampel diekstraksi menggunakan metode pengabuan basah dengan H_2SO_4 untuk pengukuran N serta metode pengabuan basah dengan HNO_3 dan $HClO_4$ untuk pengukuran P dan K. Hasil ekstraksi digunakan untuk analisis nutrien meliputi N, P, dan K. Kandungan N, P, K, dan C berturut-turut diukur menggunakan metode distilasi Kjeldahl, metode pewarnaan dengan spektrofotometri, fotometri nyala, dan metode Walkley & Black. Data stoikiometri divisualisasikan menggunakan diagram violin-box dan dihitung koefisien variasinya. Analisis korelasi Pearson digunakan untuk mengevaluasi hubungan antara kadar unsur karbon dan nitrogen serta rasio C:N pada masing-masing organ. Klasterisasi hierarkis menggunakan metode Ward diterapkan untuk mengelompokkan spesies berdasarkan profil nutrisinya dan pola distribusi nutrien divisualisasikan dalam bentuk heatmap. UpSet plot digunakan untuk mengidentifikasi spesies dengan rasio C:N tinggi secara konsisten pada beberapa organ. Stoikiometri NPK daun dianalisis menggunakan diagram ternary untuk menilai potensi keterbatasan hara. Seluruh analisis dilakukan menggunakan perangkat lunak R (versi 3.5.1).

Hasil menunjukkan bahwa konsentrasi karbon dan nitrogen bervariasi antarorgan. Batang dan ranting memiliki kandungan karbon tertinggi, sedangkan daun menunjukkan konsentrasi nitrogen paling tinggi. Perbedaan ini menghasilkan pola rasio C:N yang berbeda pada setiap organ. Batang menunjukkan nilai rata-rata

C:N tertinggi sekaligus variasi paling besar, sementara daun memiliki rasio terendah dan sebaran yang paling sempit. Analisis korelasi menunjukkan hubungan negatif yang kuat antara rasio C:N dan konsentrasi nitrogen di semua organ. Sebaliknya, korelasi positif antara rasio C:N dan kadar karbon hanya signifikan pada akar dan ranting. Klasterisasi berdasarkan rasio C:N menghasilkan tiga kelompok dengan perbedaan dominan ditentuka oleh nilai rasio C:N pada batang. Klaster 1 menunjukkan rasio C:N tinggi, sedangkan Klaster 3 menunjukkan rasio rendah pada semua organ. UpSet plot menunjukkan enam spesies dengan rasio C:N tinggi secara konsisten pada akar, batang, ranting, dan daun. Tiga spesies berasal dari Klaster 1 dan tiga lainnya dari Klaster 2. Keenam spesies ini memiliki rasio C:N hampir dua kali lipat dari rata-rata semua spesies untuk setiap organ, menunjukkan potensi tinggi dalam menyimpan karbon jangka panjang.

Analisis stoikiometri daun menunjukkan pola yang berbeda pada rasio N:P, N:K, dan K:P di antara 153 spesies pohon gambut. Rasio N:P memiliki nilai rata-rata tertinggi namun koefisien variasi (CV) terendah, sedangkan rasio N:K justru memiliki CV tinggi meskipun distribusi visualnya sempit. Klasterisasi berdasarkan ketiga rasio ini menghasilkan empat kelompok spesies yang terutama dipisahkan oleh nilai N:P, mulai dari rendah (Klaster 1), rendah hingga sedang (Klaster 2), sedang hingga tinggi (Klaster 4), hingga tinggi (Klaster 3). Diagram ternary (triaxial) berdasarkan rasio NPK daun menunjukkan bahwa sebagian besar spesies berada dalam zona keterbatasan nitrogen atau kombinasi nitrogen dan fosfor (N+P). Spesies dalam Klaster 1, 2, dan 3 menunjukkan defisiensi nitrogen atau gabungan nitrogen-fosfor. Klaster 4 merupakan spesies yang mengalami defisiensi nitrogen. Klaster 1, yang terletak paling dekat dengan pusat diagram, memperlihatkan tanda keterbatasan hara paling lemah, menunjukkan status hara yang relatif seimbang di antara spesies anggotanya.

Kata kunci: lahan gambut tropis, rasio C:N, sekuestrasi karbon, stoikiometri N:P:K, stoikiometri biologis.

SUMMARY

MOH. SYUKRON ISMAIL. Elemental Profile and Stoichiometry of Peatland Tree. Supervised by TRIADIATI, SULISTIJORINI, and MAFRIKHUL MUTTAQIN.

Tropical peatlands are globally significant ecosystems due to their critical role in carbon sequestration and climate regulation. Indonesia stores an estimated 28.1 gigatons of carbon, approximately half of which is in Sumatra alone. However, widespread deforestation, drainage, and land conversion have drastically reduced peatland areas, particularly in Sumatra. While restoration efforts often prioritize fast-growing native species, these approaches frequently overlook the ecological importance of plant traits, such as nutrient stoichiometry, which influence decomposition, nutrient cycling, and long-term carbon storage. The ratios of carbon (C), nitrogen (N), phosphorus (P), and potassium (K) in plant tissues offer insights into species' adaptation and ecosystem function, yet such data remain limited. Most previous research has overlooked stoichiometric traits or focused on temperate ecosystems, leaving a critical gap in understanding tropical peatland vegetation. This study addresses that gap by analyzing the stoichiometric profiles of tree species in the peatlands of South Sumatra, based on : (1) C:N ratios across multiple organs (roots, stems, twigs, and leaves) and identify species with traits associated with high soil carbon sequestration potential, and (2) leaf N:P:K stoichiometry and determine potential nutrient limitations in peatland tree species.

The study was conducted from July to November 2024 in the PT Tri Pupa Jaya (TPJ) landscape, Musi Banyuasin Regency, South Sumatra (1°44'16.24"S, 104°12'16.08"E). Tree samples, including roots, stems, twigs, and leaves were collected from tropical peatland vegetation within 1-hectare forest plots. Sample preparation was performed at the Department of Biology, IPB University, while chemical analyses were conducted at the Soil, Plant, Fertilizer, and Water Laboratory, Balai Penelitian Tanah. Samples were digested using H_2SO_4 for N and with HNO_3 and $HClO_4$ solution for P and K. Nutrient contents were determined using the Walkley-Black method for C, Kjeldahl for N, colorimetry for P, and flame photometry for K. Violin-box plots and coefficients of variation were used to visualize and quantify variation in stoichiometric ratios. Pearson correlation analysis assessed relationships between carbon and nitrogen concentrations and their ratios across plant organs. Hierarchical clustering using Ward's method was applied to group species based on nutrient profiles. Nutrient distribution patterns were visualized using heatmaps. An UpSet plot identified species with consistently high C:N ratios across multiple organs. Leaf NPK stoichiometry data were plotted in a ternary diagram to assess nutrient limitations. All analyses were performed using R software (version 3.5.1).

Carbon and nitrogen concentrations differed substantially among plant organs. Stems and twigs contained the highest carbon concentrations, whereas leaves had the highest nitrogen levels. These nutrient differences resulted in distinct patterns of C:N ratios across organs. Stems had the highest average C:N ratio and the greatest variability, while leaves consistently displayed the lowest ratios and narrowest distribution. Correlation analysis showed strong negative relationships between C:N ratios and nitrogen concentrations across all organs. In contrast, positive correlations between carbon concentrations and C:N ratios were weaker

and only significant in roots and twigs. Hierarchical clustering based on C:N ratios across organs identified three distinct species groups, primarily differentiated by stem C:N values. Cluster 1 was characterized by consistently high C:N ratios, while Cluster 3 exhibited uniformly low C:N ratios. An UpSet plot further identified six species with consistently high C:N ratios in roots, stems, twigs, and leaves. These species included three from Cluster 1 and three from Cluster 2. They exhibited C:N ratios nearly twice the species mean for each organ, suggesting exceptional potential for long-term carbon storage through slower tissue decomposition.

Leaf nutrient stoichiometry among 153 peatland tree species showed distinct patterns across N:P, N:K, and K:P ratios. Among the three ratios, N:P had the highest mean and the lowest CV, indicating relatively stable values despite the data distribution appearing visually broad in the violin-box plots. In contrast, the N:K ratio exhibited a narrower range in visual distribution but a higher CV, suggesting greater relative variability. Hierarchical clustering based on N:P, N:K, and K:P ratios resulted in four species groups, primarily distinguished by their N:P values. The N:P ratio of these clusters ranges from low (Cluster 1), low to moderate (Cluster 2), moderate to high (Cluster 4), to high (Cluster 3). Differences in N:K and K:P ratios contributed further to the distinction between clusters. Evaluation using a ternary (triaxial) diagram based on leaf NPK ratios suggested that the majority of species experienced nitrogen or combined nitrogen+phosphorus (N+P) limitation. Clusters 1, 2, and 3 were generally positioned in zones indicating either nitrogen or combined nitrogen and phosphorus (N+P) limitation. Cluster 4 was dominated by species under clear nitrogen limitation. Cluster 1, positioned closest to the center of the diagram, showed the weakest nutrient limitation signals, indicating potentially more balanced nutrient status among its member species.

Keywords: biological stoichiometry, carbon sequestration, C:N ratio, N:P:K stoichiometry, tropical peatland.

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Thesis
Submitted in partial fulfillment of the requirements for a
Master Degree in
Plant Biology Study Program

PLANT BIOLOGY STUDY PROGRAM
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
IPB UNIVERSITY
BOGOR
2025

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FOREWORDS

Praises and gratitude to Allah SWT for the blessings and His mercy so I could finish this thesis. The title of my research is “Elemental Profile and Stoichiometry of Peatland Tree”.

I would like to express my gratitude to Prof. Dr. Dra. Triadiati, M.Si, Dr. Ir. Sulistijorini, M.Si, and Dr. Mafrikhul Muttaqin, S.Si., M.Si, for their guidance and support as my research supervisors. Dr. Hirmas Fuady Putra, S.Si., M.Si. as the examiner for offering revisions and recommendations to enhance my thesis. My thanks also go to Dr. Ir. Aris Tjahjoleksono, DEA, Head of the Plant Biology Study Program, for his leadership and encouragement. I extend my appreciation to all the lecturers and educational staff in the Department of Biology, particularly those in the Plant Biology Study Program, for their dedication and assistance throughout my studies. I am also grateful for the research and publication funding provided through the collaborative project between IPB University and the National University of Singapore (NUS) under the Integrated Tropical Peatland Research Program (INTPREP), which greatly supported the completion of this thesis.

I would also like to extend my sincere gratitude to all my friends in the 2023 Plant Biology batch for the shared experiences and togetherness we’ve had. My deepest appreciation goes to my parents, my younger sibling, and my extended family for their constant support and prayers. The writer would also like to thank all friends, whose names cannot be mentioned individually, for their prayers, help, and support throughout this journey.

I hope this scientific work will be beneficial to for those who need it and contribute to the advancement of science.

Bogor, September 2025

Moh. Syukron Ismail

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