Quantifying Canopy Nitrogen Content in a Soil-Acidified Temperate Forest Using Image Spectroscopy

EARSeL Valencia 2024
Abstract
Corresponding Author:
h.j.abdullah-1@utwente.nl

Haidi Abdullah*[1], Andrew K. Skidmore [1], Andjin Siegenthaler[1], Roshanak Darvishzadeh[1], Elnaz Neinavaz[1], Alejandra Torres-Rodriguez[1], Yiwei Duan[1].

[1] Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands.

Keywords (5): Canopy Nitrogen Content, Image Spectroscopy, PRISMA, Soil Acidification, PLSR

Challenge

The challenge of monitoring the impact of soil acidification on forest health is a critical ecological concern, particularly in the context of increasing nitrogen deposition, which results in decreased soil pH levels. Soil acidification, often stemming from excess nitrogen deposition from sources such as industrial emissions and agricultural runoff, has far-reaching consequences on forest ecosystems. It disrupts the delicate natural nutrient balance within these ecosystems, directly influencing nutrient availability to the forest's resident trees. The interplay of soil acidification and nitrogen deposition creates a multifaceted problem for forest management and conservation. When soil pH levels drop, it can lead to leaching of essential nutrients, like calcium and magnesium, which are vital for the health of both the soil and the trees. This nutrient imbalance negatively affects the growth and vitality of the forest ecosystem, making it imperative to monitor and mitigate these changes effectively. Traditionally, monitoring the impact of soil acidification on forest health has been a challenging task. To address this, scientists and environmental researchers have been exploring advanced technologies, one of which is the use of hyperspectral satellites like PRISMA. These newly launched satellites have the potential to revolutionize our ability to assess the effects of soil acidification on forest ecosystems.

Hyperspectral satellites like PRISMA offer a promising tool to monitor the impact of soil acidification by measuring canopy nitrogen content as a proxy for forest health. These satellites are equipped with advanced sensors capable of capturing a wide range of spectral information. Measuring canopy nitrogen content provides insights into the forest's ability to take up nutrients from the soil, which can be severely hampered by soil acidification. By monitoring these changes over time, researchers can gain a better understanding of how soil acidification impacts forest health, tree growth, and overall ecosystem resilience. This information is invaluable for developing targeted strategies to mitigate the negative consequences of soil acidification and nitrogen deposition on forests.

In conclusion, the challenges posed by soil acidification and nitrogen deposition on forest health are pressing environmental issues. The disruption of the natural nutrient balance within forest ecosystems can have profound effects on their vitality. Fortunately, recent advancements in satellite technology, particularly the launch of hyperspectral satellites like PRISMA, provide a promising avenue for monitoring these impacts by measuring canopy nitrogen content. This innovative approach enables us to better understand and address the complex ecological challenges posed by soil acidification and its consequences on forest ecosystems.

Methodology (1200 – 1500 characters incl. spaces)

In this study, our primary focus was to examine the influence of stressed forests, which have experienced nitrogen deposition and soil acidification, on the nitrogen content within the forest ecosystem. We employed hyperspectral data obtained from the PRISMA satellite, combined with on-site field measurements of nitrogen content. To accomplish this, a dedicated field campaign was carried out in 2021 to gather data on leaf nitrogen content within two distinct stressed forests in the central Netherlands, specifically Hoge Veluwe and Veluwezoom. To collect leaf samples, we followed a meticulous procedure. An average of 2–3 branches was selected from each tree. The chosen branches were all from the upper sections of the trees, where they were exposed to ample sunlight. The heights of the trees ranged from approximately 25 to 30 meters. Our method involved using a crossbow to shoot an arrow equipped with a fishing line, which was then attached to a branch with sunlit leaves. The fishing line served as a conduit for a rope, which we maneuvered over the targeted branch. Once the rope was in place, the branch was gently pulled until it separated from the tree. The needles were promptly collected from the fallen branches and placed in labeled plastic zip-lock bags. These bags were further protected by wet pulp paper and transported to the laboratory in a portable cooling box filled with frozen ice packs to ensure the samples remained cool. To assess foliar nitrogen levels, the collected needles were subjected to a 72-hour drying process within an oven set at 60°C. Subsequently, the dried needles were finely ground using a mortar and pestle until they achieved a soft, powdery consistency. The resulting material was then sifted through a 0.25 mm mesh screen. Following this, 2 mg of the powdered leaves were carefully transferred into small aluminium capsules for nitrogen content measurements, which were conducted using an organic elemental analyzer (FLASH 2000). In the final stage of our analysis, we utilized a Partial Least Square Regression (PLSR) model to estimate the canopy's nitrogen content. PLSR is a regression method that takes into consideration both the variance of the explanatory and dependent variables. It establishes a linear relationship between a set of dependent (Y) variables, in this case, canopy nitrogen content, and a set of predictor (X) variables, represented by the spectral reflectance data obtained in this study.

Expected results (1200 – 1500 characters incl. spaces)

The study's outcomes demonstrate that hyperspectral data derived from the PRISMA satellite can reliably estimate forest canopy nitrogen content, yielding a root mean square error (RMSEcv) of 20.25 and a cross-validated coefficient of determination (R2CV) of 0.60.

Furthermore, our investigations uncover significant variations within these two forests, characterized by patches exhibiting notably low soil pH levels ($pH < 3$). These acidic patches have a discernible impact, leading to a significant ($p \leq 0.05$) reduction in canopy nitrogen content, especially in coniferous stands when compared to deciduous stands. In addition, our in-situ measurements of both soil and leaf nitrogen content provide compelling evidence of variations between these two forest types (coniferous and deciduous). There's a substantial difference in nitrogen content and soil pH levels, with coniferous forests displaying lower values.

Moreover, the comparative analysis of these two national parks, Veluwezoom and Hoge Veluwe, reveals distinct differences. Veluwezoom, in particular, stands out as being more acidic and possessing lower canopy nitrogen content in contrast to Hoge Veluwe.

Outlook for the future (800 - 1000 characters incl. spaces)

This research offers a compelling illustration of the practical application of cutting-edge spaceborne hyperspectral technology in predicting canopy nitrogen content within a stressed, acidified temperate forest environment. By harnessing this advanced technology, the study has successfully generated maps and predictive models with substantial implications for both the field of forest ecology and forest management strategies. This contribution is of paramount significance not only for the scientific community but also for policymakers and forest management authorities.

The utilization of spaceborne next-generation hyperspectral data for canopy nitrogen content prediction represents a breakthrough in the field of ecological assessment. Such predictions are indispensable for understanding the health and vitality of forest ecosystems and informing appropriate management practices. Looking ahead, the promise of revolutionizing remote sensing capabilities looms on the horizon with the impending launch of the CHIME satellite. This innovative satellite technology is poised to significantly enhance the acquisition and analysis of spectral data from Earth's surface, offering novel solutions for addressing ecological challenges on a global scale. With CHIME and similar advancements, we can anticipate unprecedented progress in our ability to monitor, understand, and conserve forests and other ecosystems, ultimately contributing to the preservation of our planet's environmental health.

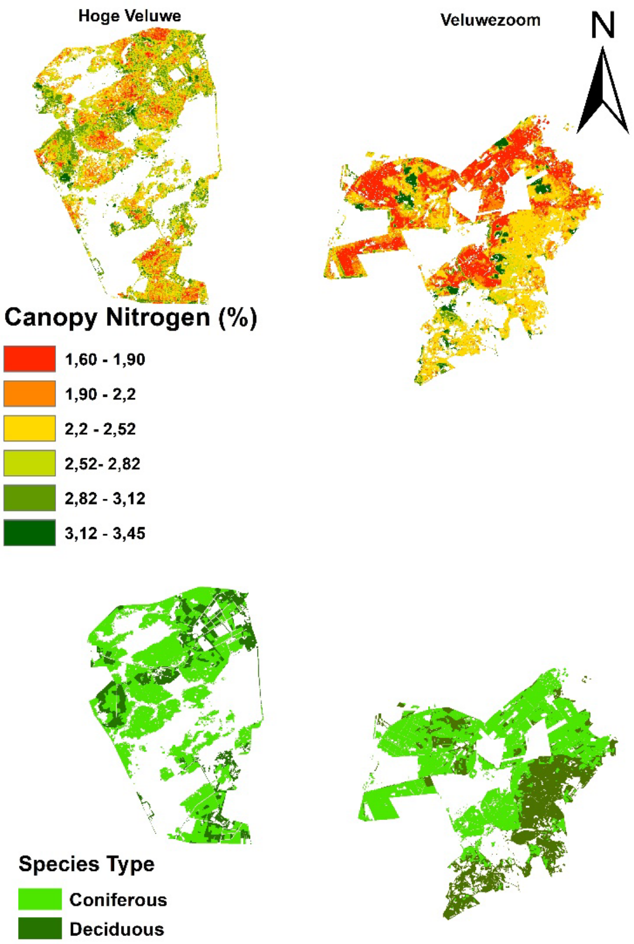

Figure Estimated maps of canopy nitrogen content using the PLSR model (top) and species distribution maps for the two national parks (bottom).