*Kempestiftelserna*

Stiftelserna J.C. Kempes och Seth M. Kempes minne

# Forskningsansökan

**JCSMK-0172**



## UPPGIFTER OM SÖKANDE

**Huvudsökande / Projektledare**


**Namn**

Hyungwoo Lim

**E-post**

hyungwoo.lim@slu.se

**Universitet**

SLU - Umeå

**Telefon**

070 212 76 54

**Institution**

SES, Skogens ekologi och skötsel


## UPPGIFTER OM PROJEKTET

**Startdatum för projektet**

2025-01-01

**Slutdatum för projektet**

2026-12-31

**Projektets längd**

24 månader

**Rubrik**

Quantifying the role of transpiration in soil nitrogen acquisition: is really transpiration “inevitable evil” for plant growth?

**Ansökan avser**

Vi ansöker om finansiering för i) en postdoc stipendiat (700 kkr) och ii) kemiska analyskostnader (440 kkr)

**Syfte och sammanfattning**


Transpiration har traditionellt ansetts vara ett slösaktigt sätt för växter att använda vatten. Vi hävdar dock att transpiration spelar en avgörande roll i växters upptag av kväve i rötterna. Jordvattnet hjälper växterna att ta upp kväve genom diffusion, medan transpiration driver den huvudsakliga transporten av löst kväve i jordlösningen via massflöde. Även om jordvattnets betydelse för kväveupptag är välkänd, har effekten av transpirationens massflöde undersökts i liten utsträckning. En stor utmaning i detta är svårigheten att separera massflöde från diffusion, eftersom dessa två processer ofta sker samtidigt.

Nya framsteg inom jordmikrodialyssystem gör det möjligt att mäta vatten- och kvädeströmmar i jorden i realtid med hjälp av tunna, rotliknande membran. Genom att kombinera detta system med isotopmärkt element i en kontrollerad laboratoriemiljö och en experimentell skog, syftar detta projekt till att undersöka både de direkta och indirekta effekterna av transpiration på tillgången till kväve i jorden.

Genom projektet förväntar vi oss att ge insikter i de faktorer som driver variationen i jordens kvävetillgång och skogens tillväxtrespons, särskilt i gödslade boreala skogar där jorden är mättad med lösligt mineralkväve.


**Nytta och relevans**

Efter Parisavtalet har samhälleliga förväntningar alltmer fokuserat på skogar som en lösning för att mildra klimatförändringar. För att kunna möta den ökande efterfrågan på träprodukter, samtidigt som ekologiska och sociala värden bevaras, måste skogarna förvaltas på ett hållbart och effektivt sätt.

Hittills har kvävegödsling i produktiva skogar varit en av de mest lönsamma åtgärderna inom operativt skogsbruk. Kvävegödsling kan dock gå från att vara ett verktyg för att öka skogstillväxten till att bli en del av problemet, eftersom det kan ha djupt negativa effekter på andra ekosystemtjänster genom ökade utsläpp av växthusgaser, eutrofiering och minskad biologisk mångfald.

Skogstillväxtens respons på kvävegödsling varierar kraftigt, från ingen effekt till en fördubbling av tillväxten, och detta beror främst på tillgången till markvatten. Att förstå vilka faktorer som ligger bakom denna stora variation kan bidra till att öka effektiviteten av gödsling i skogar. Samtidigt kan det minska ineffektiv, slösaktig och potentiellt förorenande användning av gödsel.

Projektet kommer att producera grundläggande kunskap för att bygga en robust grund för att revidera nuvarande gödslingsriktlinjer och hållbara strategier för skogsförvaltning. På lång sikt tror vi att resultaten kommer att hjälpa skogsförvaltare att säkerställa att investeringar i tid, arbetskraft och pengar är kostnadseffektiva, både ekonomiskt och ekologiskt.

**Relation till annan forskning**

Vårt projekt, som bygger på samarbetsforskning, kommer att använda en rad avancerade tekniker inom jord- och växtvetenskaperna. Det föreslagna arbetet kommer att vara till stor nytta för Skogsfakulteten vid Sveriges lantbruksuniversitet och Institutionen för skogens ekologi och skötsel. Institutionen fokuserar på kritiska aspekter av forskning kring skogsträd och ekosystem, särskilt genom Framtidens skogsbruk-programmet. Två stora forskningsmål inom programmet är: (i) att minska framtida osäkerheter kring skogstillväxt och beståndsutveckling genom att förklara rumsliga och tidsmässiga variationer över olika skalor, samt (ii) att överbrygga klyftan mellan vetenskaplig förståelse på olika nivåer, till exempel från markmikroorganismer till ekosystem och landskap.

Vårt projekt är unikt utformat för att ta itu med båda forskningsmålen. Genom att studera variationen i markens kvävedynamik syftar vi till att fördjupa förståelsen för den rumsliga och tidsmässiga variationen i skogens produktivitet. Vi kommer även att koppla experimentella resultat från kontrollerade jordmikrokosmer till verkliga fältförhållanden.

## BUDGET

**Sökt belopp kkr**

1 140

**Projektets totalkostnad kkr**

1 220

| Utrustning / Material | År 1 | År 2 | År 3 | Sökt kkr | Totalt kkr |
|---|---|---|---|---|---|
| Chemical analyses of soil solution | 440 | | | 440 | 520 |
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| Summa kkr | 440 | | | 440 | 520 |

| Stipendie (post doc), max 2 år/stipendie | År 1 | År 2 | År 3 | Sökt kkr | Totalt kkr |
|---|---|---|---|---|---|
| Post doc | 350 | 350 | | 700 | 700 |
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| Summa kkr | 350 | 350 | | 700 | 700 |

Kostnader som kan uppstå, t ex: drift, resor.

| Andra kostnader | År 1 | År 2 | År 3 | Sökt kkr | Totalt kkr |
|---|---|---|---|---|---|
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| | | | | 0 | |
| Summa kkr | | | | 0 | |

| Totalt | År 1 | År 2 | År 3 | Sökt kkr | Totalt kkr |
|---|---|---|---|---|---|
| Summa kkr | 790 | 350 | | 1 140 | 1 220 |

## ÖVRIGA ANSLAGSKÄLLOR OCH INTÄKTER

**Bidrag har beviljats eller skall sökas från andra anslagskällor som har direkt koppling till ansökan (obligatorisk uppgift)**

| Fond/Stiftelse eller annan intäktskälla | Beroende av | Status | Belopp | Besked väntas |
|---|---|---|---|---|
| | | | | |

| Fond/Stiftelse eller annan intäktskälla | Beroende av | Status | Belopp | Besked väntas |
|---|---|---|---|---|
| | ▼ | ▼ | | |
| | ▼ | ▼ | | |
| | ▼ | ▼ | | |
| | ▼ | ▼ | | |

## BILAGOR

**Obligatoriska dokument**

Max 12 sidor, normalt 2-6 sidor

| | |
|---|---|
| Projektbeskrivning | **Projektbeskrivning.pdf** |
| CV | **CV.pdf** |

**Övriga relevanta dokument, ej obligatoriska**

| | |
|---|---|
| Publikationslista inklusive annan produktion (patent, software mm) | **Publikationslista.pdf** |
| Ange namn på bilaga | |
| Ange namn på bilaga | |

## SIGNATUR

| | |
|---|---|
| Signatur | **Signatur.pdf** |

# Quantifying the role of transpiration in soil nitrogen acquisition

Is really transpiration “inevitable evil” for plant growth?

Hyungwoo Lim (hyungwoo.lim@slu.se)
Department of Forest Ecology and Management, SLU, Umeå.

## Motivation and objectives

Plants open their leave stomata to absorb atmospheric carbon dioxide for photosynthesis, at the expense of water loss through the stomata – transpiration. Plants use less than 1% of the taken up water being used for growth, while the rest, 99%, is transpired back to the atmosphere. Due to this significant portion water loss, transpiration is often called as “inevitable evil” for plant function. Contrarily to this classical view, we argue that plant transpiration has an important role in the regulation of soil nitrogen availability and root nitrogen acquisition, particularly in fertilized boreal forests, where the soils are saturated with soluble mineral forms of nitrogen[1,2].

Soil nitrogen availability has long been put forward as the most growth-limiting factor in boreal forests. To date, nitrogen fertilization in productive forests is one of the most profitable measures that can be taken in operational forestry[3]. Responses of forest growth to nitrogen fertilization varies significantly from zero to doubling the growth depending largely on soil water availability[4,5]. The interactive effect with water availability is expected to become greater as the frequency of summer drought is projected to increase in the boreal regions[6]. Beyond the observations, however, the mechanisms behind the interactions are poorly understood.

Water is one of the most important factors for root uptake of nutrient including nitrogen[7]. Roots take up nitrogen that is dissolved in the soil solution and reaches their surface through two kinds of fluxes: diffusive flux and mass flow. Diffusive flux is the net movement of nutrients towards the sources of the roots along a concentration gradient, whereas mass flow is the bulk transport of nutrients together with water driven by transpiration. These two fluxes interact and influence each other[7,8]. Transpirationally driven mass flow can create concentration gradient of soil solutes, which enhances diffusive flux, while the reduced concentration gradient from diffusive flux can be quickly restored by mass flow. It can be concluded that mass flow, driven by transpiration, promotes nutrient uptake by facilitating diffusive flux[8,9].

Nitrogen exists in various chemical forms in the soil. In boreal forests, for example, organic form of nitrogen is the dominant form of plant-available nitrogen (e.g., amino acids)[10]. When nitrogen fertilization is practiced, often adding nitrate-ammonium forms, the mineral forms become dominant as plant-available nitrogen. The movement of soil nitrogen within the negatively charged soil matrix is significantly affected by the electric charge and molecular size of nitrogen compounds[11]. Water fluxes influence nitrogen delivery to the roots and its uptake, depending on the chemical forms and quantifies of dominant soil nitrogen, both of which are altered by forest fertilization[12]. Transpiration therefore affects root nitrogen acquisition both directly and indirectly through its interaction with the soil environment[13,14].

Despite the importance of coordinating the role of transpiration in the regulation of root nitrogen acquisition, these interactions and feedbacks have been poorly understood[15]. The likely culprit for this is that determining the effect of transpiration is challenging as is difficult to control and manipulate accurately. Instead, studies often rely on naturally observed temporal variation of air-dryness, measured by vapor pressure deficit, a metric that expresses how much additional vapor is required in the atmospheric to reach the maximum vapor pressure[16]. The problem is that soil water deficit and atmospheric vapor deficit often temporally covary in the natural condition, so co-affecting transpiration and soil water status[17]. Instead, spatially manipulated water fluxes in the field condition and controlled laboratory studies overcome this issue to address the role of transpiration[18]. In order to define limitations and possibilities of forest fertilization under the projected dry climates, the first step in boreal forests is to elucidate the distinctive role of water flux in acquisition of soil nitrogen.

**The objective of the project is to determine the role of transpiration in nitrogen acquisition, focusing on its interactions with diffusive flux of soil nitrogen.**
To achieve this, we will conduct two interconnected experiments at different scale, i) a controlled laboratory experiment, where transpirationally driven mass flow will artificially be induced, and ii) a field-based manipulative experiment, where air humidity and soil water content have been spatially manipulated alongside ambient control plots. Empirical data will be collected from both experimental setups, based on a combination of root-like thin thread membranes (soil microdialysis system) and stable isotopes of water and nitrogen. Through the project, we aim to determine the role of transpiration and offer insights into the factors driving variability of the fertilization response.

## Previous findings and preliminary results by the applicants

1. Laboratory and greenhouse experiments
En earlier study that employed the microdialysis system suggested that plant transpiration promotes diffusive fluxes by restoring a concentration gradient[9]. Despite being a frontier in the field of soil nitrogen uptake, the study provided limited insight into the inherent mobility of nitrogen within the soil matrix, as it was based on standard solution, rather than actual soil conditions. Following, we monitored soil nitrogen fluxes in seedling's growing plots using the microdialysis system where mineral nitrogen ($NH_4NO_3$) or organic nitrogen (arginine) was added (Fig. 1)[12]. Soil nitrogen flux sustained longer in the arginine pots compared with that in the mineral nitrogen added pots. This highlights the importance of chemical forms in availability and acquisition of soil nitrogen. Furthermore, in a pilot experiment, we showed a tendency of increased $NO_3$-N uptake in the seedlings with higher transpiration (Fig. 2A).

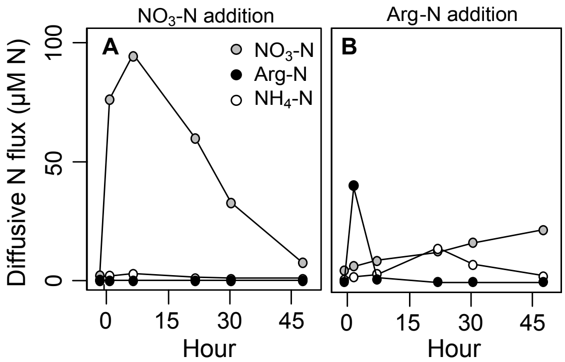


**Figure. 1. Monitoring diffusive flux of different forms of nitrogen using the microdialysis system[12]** (**A**) in the soil added with $NO_3$-N and (**B**) in that added with organic nitrogen, arginine (Arg)-N. Diffusive flux of $NO_3$-N peaked immediately after the addition of $NO_3$-N, and quickly diminished. Diffusive flux of Arg-N peaked after the addition of Arg-N but to a lesser extent than $NO_3$-N addition. A fraction of Arg was then mineralized and retained in the soil as forms of $NH_4$-N and $NO_3$-N. This study suggests the importance of the chemical form nitrogen in the nitrogen and water interactions.

2. Field-based studies
We demonstrated that fertilized forests become more water-sensitivity based on field

experiments[4,5]. Foliar nitrogen concentration and tree growth were associated with precipitation during the growing season (Fig. 2B). In response to fertilization, leaf area and stem volume production were increased, while woody density and root biomass decreased. This structural shift facilitates tree transpiration. We proposed that these structural changes may occur as a response to acquiring the most limiting resource, nitrogen, because transpiration can facilitate the acquisition of the fertilized mineral nitrogen. Findings of the proposed project will test this suggestion.

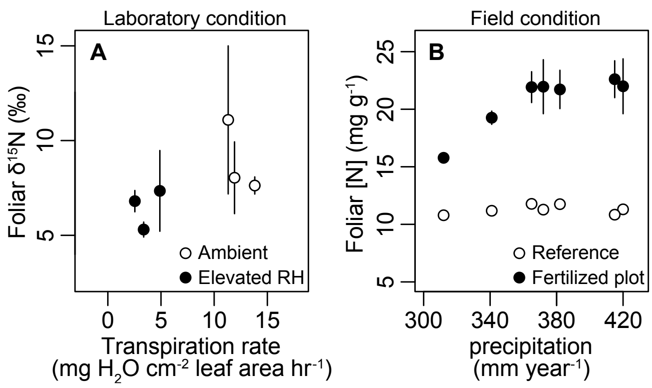


**Figure. 2. A. Foliar δ$^{15}$N of seedlings in response to transpiration rate.** Uptake of added $^{15}NO_3$-N increases with increasing transpiration rate. Elevated relative humidity (RH) reduced transpiration rate without changing other environmental variables. **B. Foliar nitrogen content in response to annual precipitation** during the vegetation growing season in reference plots and fertilized plots ($NH_4NO_3$). Foliar nitrogen content increased with increasing precipitation in the mineral nitrogen fertilized plots. This indicates that soil moisture availability increased nitrogen uptake only where mineral nitrogen supply was improved.

3. Modelling studies

High demand for atmospheric water (dry air, high vapor pressure deficit) and its interactions with soil water contents have rarely been observed in boreal forests[19]. To test the hypothesis of the role of transpiration, we used data instead from tropical Eucalyptus plantation experiments, where atmospheric water demand was high while the interaction between atmospheric water demand and soil water deficit was nullified by soil irrigation[16]. Incorporating empirical data and process-based modelling, we showed the importance of atmospheric water demand and transpiration response in forest growth. Currently, we are developed an optimization model for boreal forests that incorporates nitrogen-water interactions[20,21] to contrast the effects between soil and atmospheric water demands. We expect that the current proposal will produce empirical data to refine parameters of the model.

## Methods

1. The tools

*The microdialysis system* for soil studies has opened unique opportunities in the field of soil science allowing real-time monitoring of soil water and nitrogen fluxes[22]. By enabling measurement of exchanges of water and different forms of nitrogen in soil solution, it can mimic roots' micro-environment and provide robust estimates of nitrogen and water availabilities. The technique has further been advanced by inducing lower osmotic potential by perfusing with dextran solution, a high molecular compound that does not pass through the membrane[9]. This modification allows mimicking the effects of plant transpiration on root uptake. Using this method, the role of mass flow in the nitrogen and water fluxes can be isolated and quantified. We will combine the soil microdialysis system with stable isotopic technique to precisely quantify nitrogen and water fluxes. Use of stable isotopes, particularly deuterium-enriched water ($^2H_2O$) actual amount of mass flow can be quantified[23].

*Free Air Humidity Manipulation* (FAHM) is the only free-air humidity experiment in forest stand throughout the world to include plots (sets of three 0.12 ha plots) with elevated air humidity, ambient, or ambient with soil water supply[18]. The elevated air humidity significantly reduces canopy transpiration, but it also leads to increased soil water content. To overcome this interaction, this setting includes irrigation treatment, allowing isolation and quantification of the transpiration effects. *During 2023 growing season, we have collected soil solution samples from the FAHM using combined microdialysis and labelled water, stored leaf samples for examining forest nutrition, and measured transpiration rates and other associated variables.* In this project we propose to analyze these collected samples.

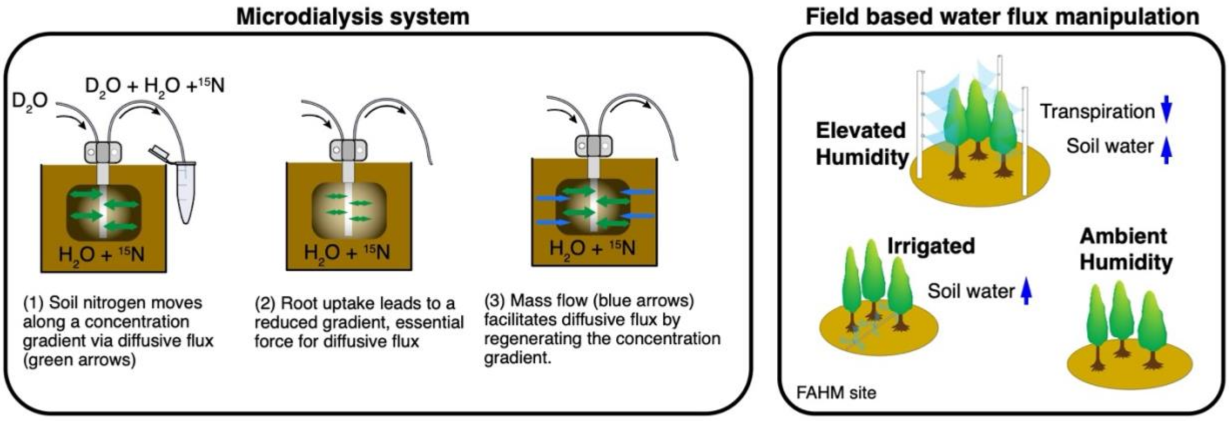


**Figure 3. The hypothesized role of the transpiration in root nitrogen acquisition.** The main role of the transpiration is to restore a concentration gradient for facilitating diffusive flux of soil nitrogen. The planned laboratory experiment is built upon a combination of the microdialysis system and isotopically labelled elements. Together with analysis of the collected soil solution samples from Free Air Humidity Manipulation (FAHM) experiment, the proposed project will directly test and quantify the role of transpiration in soil nitrogen acquisition.

2. Controlled laboratory experiment.

The effect of mass flow soil nitrogen delivery will be examined through its interaction with diffusive flux. The hypothesis is that the mass flow facilitates diffusive flux of soil nitrogen by restoring a concentration gradient around roots. To test this hypothesis, we will create artificial mass flow and diffusive flux using a soil microdialysis system. We will sample soil solution based on diffusive flux using 16 microdialysis membranes for one hour. After sampling is done, we will replace 8 membranes with mass flow by perfusing with dextran solution without changing the location of the membranes, while the other membranes operate as diffusive flux.

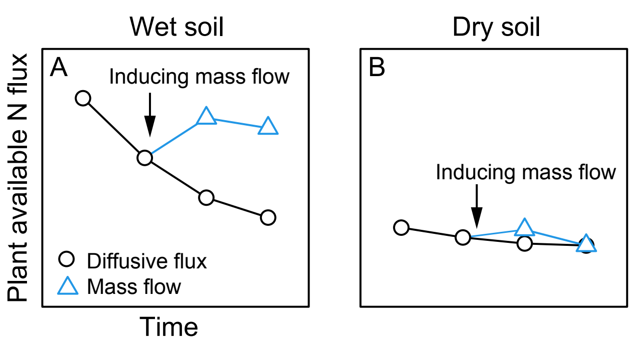


**Figure. 4. Hypothesized outcome from the proposed laboratory experiment. A.** For wet soil, plant-available nitrogen (N) flux declines over time as reduced concentration of the solute in the soil. Operating mass flow restores the concentration gradient, maintaining available nitrogen flux in the soil. **B.** For dry soil, overall availability of nitrogen is low and the role of mass flow is minimal as the mass flow is affected by soil water content.

We will apply isotopically labelled water (${}^{2}H_2O$) with mineral nitrogen (${}^{15}NO_3$-N) to soil in tubes with four levels of soil water contents (standard solution, soil with 30% water holding capacity, 100%, and 150%) in each of three soil texture types. Because extractive water at a given

pressure differs with soil texture, three types of soil texture (sandy, sandy loam, sandy clay) will be combined. Three levels of soil nitrogen availability will be simulated: no addition, addition of 100 μM N or 500 μM N. Depending on the soil mass, the addition rate can be revised so as to follow the rate of practical fertilization (150 kg N $ha^{-1}$).
We will then collect 480 samples that cover different soil types with varying water contents (3 soil types x 3 water content + 1 solution) x (2 mass flow + 1 diffusion) x 2 nitrogen levels x 8 replications.

3. Field-based experiment
In FAHM experiment, we collected soil solution samples in 2023 and stored them in the Department of Forest Ecology and Management at SLU. Therefore no field work is required for the project. As described above, samples include both diffusive flux and mass flow settings from high humidity, irrigated, and controlled ambient plots. This experiment allows quantifying the effect of actual forest transpiration on soil nitrogen flux and comparing it with artificially driven mass flow. Briefly, we operated eight membranes in each of the nine plots, on diffusive flux using labelled water. After one hour of the sampling, four membranes were perfused with water-labelled dextran solution to induce mass flow, while the rest membranes were kept for the diffusive flux sampling. The positions of the membranes were kept, untouched. As a result of the mass flow setup, we collected ~30% higher volume of soil solution compared with the diffusive flux setting. We froze all the 288 samples immediately with the dry ice to avoid any mineralization before analyzing the solute concentration (3 treatments x 3 replicated plots x 8 membrane samples x 2 sampling times x 2 fluxes).

4. Sample analysis
Collected soil samples will be analyzed based on our developed methods for isotopic ratio of water and nitrogen compounds[9,12,23]. We will first precipitate the mass flow samples with ethanol to remove dextran. Isotopic signature of water and nitrogen will be analyzed using Isotope Ratio Mass Spectrometer (TC/EA-IRMS; Thermo Fisher Scientific, Bremen, Germany), using a method[24] in SLU Stable Isotope Lab at the Department of Forest Ecology and Management. In collaboration with researchers in the FAHM infrastructure (Prof. A. Sellin, Assoc. Prof. P. Kupper), data on the plant samples will be provided.

## Project organization, collaborations, and budget justification

The research work will be carried out at Swedish University of Agricultural Sciences in Umeå (SLU). Dr. Hyungwoo Lim (the main applicant, SLU), an expert in ecophysiology and forest silviculture, specializes on forest responses to various forest management regimes. The proposed project is a follow-up research based on the findings of a previous 4-year-project (funded by Swedish Research Council Formas, 2021–2024) led by the applicant. During his career, Dr. Lim has utilized state-of-the-art isotope and microdialysis techniques, along with advanced modelling skillsets for various projects. A two-year-postdoctoral researcher will carry out the planned experiments and lead two scientific papers, under Dr. Lim’s oversight. Professor Torgny Näsholm and Dr. Sandra Jämtgård of SLU will contribute to the project. These collaborators have been at the forefront in the field of the proposed project and been instrumental in developing the soil microdialysis system.

This project presents an excellent opportunity to advance a postdoctoral researcher’s career for several reasons. First, the soil microdialysis system has received significant attention across various disciplines and is emerging as a distinct field within soil and plant sciences. The postdoctoral researcher will be equipped with this advance tool, while understanding applicability of the tool. Second, with field samples already collected (FHAM site in 2023), the laboratory experiment set up, and well-defined, testable hypotheses in place, the postdoctoral researcher will be well-positioned to generate the planned research papers within the project timeframe. We believe this project will provide a strong scientific foundation and valuable career opportunities for the postdoc.

The total budget for this project is 1 220k SEK. The current proposal requests for 1 140k SEK. The 80k SEK has been funded by Swedish Research Council Formas (used for field work and purchasing chemicals and microdialysis membranes). Of the 744k SEK, we request for 440k SEK for chemical analysis costs of 1000 soil solution samples (190k SEK for $^{13}C$, $^{15}N$ analysis, 190 SEK per sample; 250k SEK for $^{2}H_2O$, 250 SEK per sample), and 700k SEK for one two-year-postdoc.

## Time Plan

We plan to produce two scientific papers from the proposed project, led by a new postdoc.

***First year (2025)***

Conducting the laboratory experiment, and analyzing the collected samples from the field experiment, data analysis.

***Second year (2026)***

Analyzing collected data and writing and submitting planned papers.

## References

1. Tamm CO 1991 Nitrogen in terrestrial ecosystems: questions of productivity, vegetational changes, and ecosystem stability. Berlin: Springer-Verlag.
2. Högberg P et al. 2017 On the nature of the nitrogen limitation to plant growth in Fennoscandian boreal forests. For Ecol Manag 403:161–185
3. Bergh J et al. 1999 The effect of water and nutrient availability on the productivity of Norway spruce in northern and southern Sweden. For Ecol Manag 119:51–62
4. Lim H et al. 2015 Inter-annual variability of precipitation constrains the production response of boreal *Pinus sylvestris* to nitrogen fertilization. For Ecol Manag 348:31–45
5. Lim H et al. 2017 Annual climate variation modifies nitrogen induced carbon accumulation of *Pinus sylvestris* forests. Ecol Appl 27:1838–1851
6. Sheffield J et al. 2012 Little change in global drought over the past 60 years. Nature 491:435–438
7. Tinker PB, Nye PH 2000 Solute movement in the rhizosphere. Oxford University Press.
8. Oyewole OA et al. 2017 Incorporating mass flow strongly promotes N flux rates in boreal forest soils. Soil Biol Biochem 114:263–269
9. Oyewole OA et al. 2014 Direct estimation of mass flow and diffusion of nitrogen compounds in solution and soil. NewPhytol 201:1056–1064
10. Inselsbacher E, Näsholm T 2012 The below-ground perspective of forest plants: soil provides mainly organic nitrogen for plants and mycorrhizal fungi. NewPhytol 195:329–334
11. Öhlund J, Näsholm T 2002 Low nitrogen losses with a new source of nitrogen for cultivation of conifer seedlings. Env Sci Tech 36:4854–4859
12. Lim H et al. 2022 Organic nitrogen enhances nitrogen nutrition and early growth of Pinus sylvestris seedlings. Tree Physiol 42:513–522.
13. Gorska A et al. 2008 Nitrate control of root hydraulic properties in plants: translating local information to whole plant response. Plant Physiol 148:1159–1167
14. Matimati I et al. 2014 Nitrogen regulation of transpiration controls mass-flow acquisition of nutrients. J Exp Bot 65:159–168
15. McMurtrie RE, Näsholm T 2017 Quantifying the contribution of mass flow to nitrogen acquisition by an individual plant root. New Phytol 218:119–130

16. Lim H et al. 2020 Assessing the cross-site and within-site response of potential production to atmospheric demand for water in Eucalyptus plantations. For Ecol Manag 464:118068–8
17. Novick et al. 2016 The increasing importance of atmospheric demand for ecosystem water and carbon fluxes. Nature Climate Change 6:1023–1027.
18. Tullus A et al. 2012 Climate change at northern latitudes: rising atmospheric humidity decreases transpiration, N-uptake and growth rate of hybrid aspen. Plos One 7:e42648
19. Lopez JG et al. 2021 How tree species, tree size, and topographical location influenced tree transpiration in northern boreal forests during the historic 2018 drought. Global Change Biol.
20. Tian X et al. 2021 Disaggregating the effects of nitrogen addition on gross primary production in a boreal Scots pine forest. Agr Forest Meteorol 301:108337.
21. Fransson et al. bioRxiv. 2023.10. 11.561680
22. Inselsbacher E, Näsholm T 2011 A novel method to measure the effect of temperature on diffusion of plant-available nitrogen in soil. Plant Soil 354:251–257.
23. Buckley S et al. 2023 Using microdialysis with a deuterium oxide tracer to estimate water exchange, water content and active surface area of the probe. Geoderma 439:116689.
24. Gehre et al. 2004. Continuous flow 2H/1H and 18O/16O analysis of water samples with dual inlet precision. Rapid Communications in Mass Spectrometry 18, 2650-2660.

# Hyungwoo Lim (1983. Nov. 27)

**Researcher (Jan. 2021–)**

Department of Forest Ecology and Management
Swedish University of Agricultural Sciences (SLU)
SE-901 83 Umeå, Sweden

Tel: +46 70 212 76 54
hyungwoo.lim@slu.se


## EDUCATION

**Dec. 2017. PhD in Biology (forest ecophysiology)**, SLU, Umeå, Sweden
Thesis: *Interactive effects on biomass production between nitrogen and water availabilities in boreal forests* (supervisors: Torgny Näsholm at SLU & Ram Oren at Duke Univ.)
**Feb. 2011. Msc in Forestry**, Chonnam Nat'l Univ., South Korea
Thesis: *Thinning effects on ecosystem respiration in a red pine forest*
**Feb. 2009. Bsc in Forest Science**, Chonnam Nat'l Univ.

## RESEARCH EXPERIENCES

**2022 – 2023. Visiting researcher.** International Institute for Applied Systems Analysis, Austria
**2021 – 2022. Visiting researcher.** University of Tartu, Estonia
**2018 – 2020. Postdoc.** SLU, Umeå, Sweden (supervisor: Prof. Tomas Lundmark)
**2014 – 2015**. **Guest Scholar.** Duke University, USA (8 months)

## AWARDED RESEARCH GRANTS

**2024–2025.** Anna och Håkanssons Stiftelse (100 000 SEK; Main PI)
*Nutrient Optimization Fertilization: Can the enhanced forest nutrition and production be sustained?*
**2024–2025.** Skogssällskapet (181 383 SEK; Co-PI)
*Långsiktigt kvarvarande markeffekter av tidigare intensiv gödsling i ung tallskog*
**2024–2025.** Åforsk (1 126 100 SEK; Main PI)
*Will forest fertilization benefit carbon sequestration in the future climate?*
**2022.** Stiftelsen Fonden för skogsvetenskaplig forskning (SLU internal) (120 000 SEK; Main PI)
*The impact of bark beetle outbreaks on forest carbon accumulation*
**2022–2024.** Kempestiftelserna (1 100 000 SEK, JCK 3137; Main PI)
*Managing boreal soil carbon stock in a changing climate*
**2021–2024.** Swedish Research Council Formas (4 467 189 SEK; Main PI)
*Linking nitrogen and water – spatiotemporally optimizing forest fertilization for balancing forest productivity and ecosystem services.*

## SUPERVISION

Postdoc.
2024 – present. Gwang-Jung Kim (SLU, main supervisor)
2023 – present. Jasmin Danzberger (SLU, main supervisor)

PhD students
2023 – present. Alexina Brännlund (SLU, secondary supervisor)
2019 – 2021. Jenny Dahl (SLU, PhD-licentiate, secondary supervisor)

## TEACHING

***Graduate course***
Forest Ecosystem Ecology (BI1396, HT2022, HT2023)
Lecturer: Forest carbon allocation

Silviculture – the Science of Forest Stand Management (SG0272)
Lecturer: Ecophysiological principles for modelling forest stand development (light, nutrient and water use)

***PhD level course***
Ecophysiological Concepts and Applications in Managed Forests (PFS0146, F0007)
Participating course organization and lecturer
Subject: Forest management, Biomass production, Modelling, Carbon budgets, Experimental Design

*Original articles* (Journal Impact Factor in the Web of Science)

In print

**H Lim**, D Medvigy, A Mäkelä, D Kim, TJ Albaugh, A Knier, R Blaško, O Campoe, R Deshar, O Franklin, N Henriksson, K Littke, R Lutter, CA Maier, S Palmroth, K Rosenvald, R Slesak, A Tullus, R Oren. Overlooked branch turnover creates a widespread bias in forest carbon accounting. *Proc. Natl. Acad. Sci. U.S.A.* **(JIF: 11.1)**

2024

V Oikonomou, M Huerta, A Sandéhn, T Dreier, Y Daguerre, **H Lim**, M Berggren, E Pavlopoulou, T Näsholm, M Bech, E Stavrinidou. eSoil: Low power bioelectronic growth scaffold enhances crop seedlings growth. *Proc. Natl. Acad. Sci. U.S.A.* 121:e2304135120 **(JIF: 11.1)**

R Lutter, H Hepner, A Tullus, **H Lim**, T Tullus, E Õunapuu-Pikas, R Sopp, M Kaivapalu, K Täll, K Ots, H Tullus. Ecosystem carbon and nutrient balances in short-rotation hybrid aspen coppice under different thinning methods. BioEnergy Research **(JIF: 3.1)**

2023

S Buckley, **H Lim**, JD Marshall, D Randewig, OA Oyewole, T Näsholm, S Jämtgård. Using microdialysis with a deuterium oxide tracer to estimate water exchange, water content and active surface area of the probe. *Geoderma* 439:116689 **(JIF: 6.1)**

*G Baek, ***H Lim**, NJ Noh, C Kim. No impact of nitrogen fertilization on carbon sequestration in a temperate *Pinus densiflora* forest. *Scientific Reports* 13:1743 *Equal contribution **(JIF: 4.6)**

JD Marshall, L Tarvainen, P Zhao, **H Lim**, G Wallin, T Näsholm, T Lundmark, S Linder, M Peichl. Components explain, but do eddy fluxes constrain? Carbon budget of nitrogen-fertilized boreal Scots pine forest. *New Phytologist* 239:2166–2179 **(JIF: 9.4)**

M Domevscik, B Häggström, **H Lim**, J Öhlund, A Nordin. Large-scale assessment of artificially coated seeds for forest regeneration across Sweden. *New Forests* 54:255–267 **(JIF:2.2)**

2022

**H Lim**, S Jämtgård, R Oren, L Gruffman, S Kunz, T Näsholm. Organic nitrogen enhances nitrogen nutrition and early growth of *Pinus sylvestris* seedlings. *Tree Physiology* 42:513–522 **(JIF: 4.0)**

R Blaško, B Forsmark, MJ Gundale, **H Lim**, T Lundmark, A Nordin. The carbon sequestration response of aboveground biomass and soils to nutrient enrichment in boreal forests depends on baseline site productivity. *Science of the Total Environment* 838:156327 **(JIF: 9.8)**

RK Magh, B Gralher, B Herbstritt, A Kübert, **H Lim**, T Lundmark, J Marshall. Technical note: Conservative storage of water vapour – practical *in situ* sampling of stable isotopes in tree stems. *Hydrology and Earth System Sciences* 26, 3573–3587 **(JIF: 6.3)**

JRM Tuyishime, GA Adediran, BA Olsson, TS Zetterberg, L Högbom, M Spohn, **H Lim**, W Klysubun, CN Borca, T Huthwelker, JP Gustafsson. Phosphorus speciation in the organic layer of two Swedish forest soils 13–24 years after wood ash and nitrogen application. *Forest Ecology and Management* 521:120432 **(JIF: 3.7)**

P Zhao, J Chi, MB Nilsson, …, M Peichl. Long-term nitrogen addition raises the annual carbon sink of a boreal forest to a new steady-state. *Agricultural and Forest Meteorology* 324:109112 **(JIF: 6.2)**

2021

R Lutter, G Stål, LA Ceder, **H Lim**, A Padari, H Tullus, A Nordin, T Lundmark. Climate benefit of different tree species on former agricultural land in northern Europe. *Forests* 12:1810 **(JIF: 2.9)**

JD Marshall, M Peichl, L Tarvainen, **H Lim**, T Lundmark, T Näsholm, M Öquist, S Linder. Causes of the nitrogen-induced increase in soil carbon in a boreal forest: a carbon-budget approach. *Forest Ecology and Management* 502:119750 **(JIF: 3.7)**

R Lutter, N Henriksson, **H Lim**, R Blaško, RK Magh, T Näsholm, A Nordin, T Lundmark, JD Marshall. Belowground resource utilization in monocultures and mixtures of Scots pine and Norway spruce. *Forest Ecology and Management* 500:119647 **(JIF: 3.7)**

N Henriksson, **H Lim**, JD Marshall, O Franklin, RE McMurtrie, R Lutter, RK Magh, T Lundmark, T Näsholm. Three water uptake enhances nitrogen acquisition in a fertilized boreal forest – but not under nitrogen poor conditions. *New Phytologist* 10.1111/nph.17578 **(JIF: 9.4)**

X Tian, F Minunno, P Schiestl-Aalto, J Chi, P Zhao, M Peichl, JD Marshall, T Näsholm, **H Lim**, M Peltoniemi, S Linder, A Mäkelä. Disaggregating the effects of nitrogen addition on gross primary production in a boreal Scots pine forest. *Agricultural and Forest Meteorology* 301:108337 **(JIF: 6.2)**

2020

**H Lim**, BA Olsson, T Lundmark, J Dahl, A Nordin. Effects of whole-tree harvesting at thinning and subsequent compensatory nutrient additions on carbon sequestration and soil acidification in a boreal forest. *GCB bioenergy* 12:992–1001 **(JIF: 5.6)**

**H Lim**, CA Alvares, MG Ryan, D Binkley. Assessing the cross-site and within-site response of potential production to atmospheric demand for water in Eucalyptus plantations. *Forest Ecology and Management* 464:118068 **(JIF: 3.7)**

2019

18. **H Lim**, R Oren, T Näsholm, M Strömgren, T Lundmark, H Grip, S Linder. Boreal forest biomass accumulation is not increased by two decades of soil warming. *Nature Climate Change* 9:49–52 **(JIF: 30.7)**

2018

**H Lim**, K-H Lee. Estimates of annual biomass production in a *Pinus densiflora* and a *Styrax japonica* stands in the Yeochon coastal area. *The Journal of Korean Island* 30:165–175

L Tarvainen, G Wallin, **H Lim**, S Linder, R Oren, MO Löfvenius, M Räntfors, P Tor-ngern, JD Marshall. Photosynthetic refixation varies along the stem and reduces $CO_2$ efflux in mature boreal *Pinus sylvestris* trees. *Tree Physiology* 38:558–569 **(JIF: 4.0)**

G-U Kim, K-S Jang, **H Lim**, E-H Kim, K-H Lee. Genetic diversity of *Quercus gilva* in Je-ju Island. *Journal of Korean Society of Forest Science* 107:151–157

2017

**H Lim**, R Oren, S Linder, F From, A Nordin, N Fahlvik, T Lundmark, T Näsholm. Annual climate variation modifies nitrogen induced carbon accumulation of *Pinus sylvestris* forests. *Ecological Applications* 27:1838–1851 **(JIF: 5.0)**

2015

**H Lim**, R Oren, S Palmroth, P Tor-ngern, T Mörling, T Näsholm, T Lundmark, H Helmisaari, J Leppälammi-Kujansuu, S Linder. Inter-annual variability of precipitation constrains the production response of boreal *Pinus sylvestris* to nitrogen fertilization. *Forest Ecology and Management* 348:31–45 **(JIF: 3.7)**

N Henriksson, L Tarvainen, **H Lim**, P Tor-ngern, S Palmroth, R Oren, JD Marshall, T Näsholm. Stem compression reversibly reduces phloem transport in *Pinus sylvestris* trees. *Tree Physiology* 35:1075–1085 **(JIF: 4.0)**

**Projektstart:** 2025-01-01

**Projektslut:** 2026-12-31

**Sökt summa:** 1 140

**Total projektkostnad:** 1 220

Denna signatur bekräftar att uppgifterna är korrekt och att institutionens prefekt ställer sig bakom ansökan.

Umeå 2024-09-19

Ort och datum Hyungwoo Lim