Can ammoniacal nitrogen from gold mining effluent be a promising alternative in the fertilization of natural forests?

Anoj Subedi[1,2], Émilie Robert[3], Flavia Lega Braghiroli[1], Miguel Montoro Girona[1,2]

[1]Institut de recherche sur les forêts (IRF), Université du Québec en Abitibi-Témiscamingue (UQAT), Rouyn-Noranda, QC J9X 5E4
[2]Groupe de recherche en écologie de la MRC Abitibi (GREMA), 341 Rue Principale N, Amos, QC J9T 2L8
[3]Centre Technologique des Résidus Industriels (CTRI), Cégep de l'Abitibi-Témiscamingue, Rouyn-Noranda, QC J9X 5E5

CONTEXT

- Abitibi-Témiscamingue, a resource region
- Major economic sources:
  - **Gold mining** and
  - **Forestry activities**

CONTEXT

- Issues with mining activities
- Ammoniacal nitrogen (N-NH3) is a pollutant (effluent) often present in operating mines
- Relatively toxic to the environment

(Zuttah, 2001)

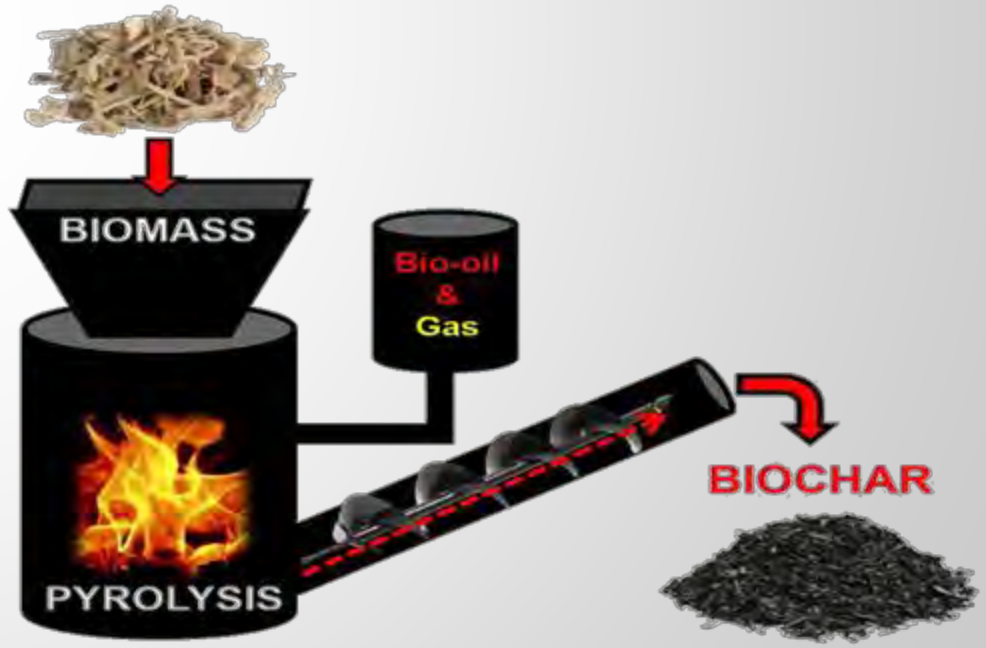
CONTEXT

- The management of these effluents is, therefore, necessary
- Approaches of mining companies: using sulfuric acid as a fixator
- **Conversion into ammonium sulfate**
- **Long-distance disposal**

(Robert and Braghiroli, 2021; Spokas et al. 2012)

CONTEXT

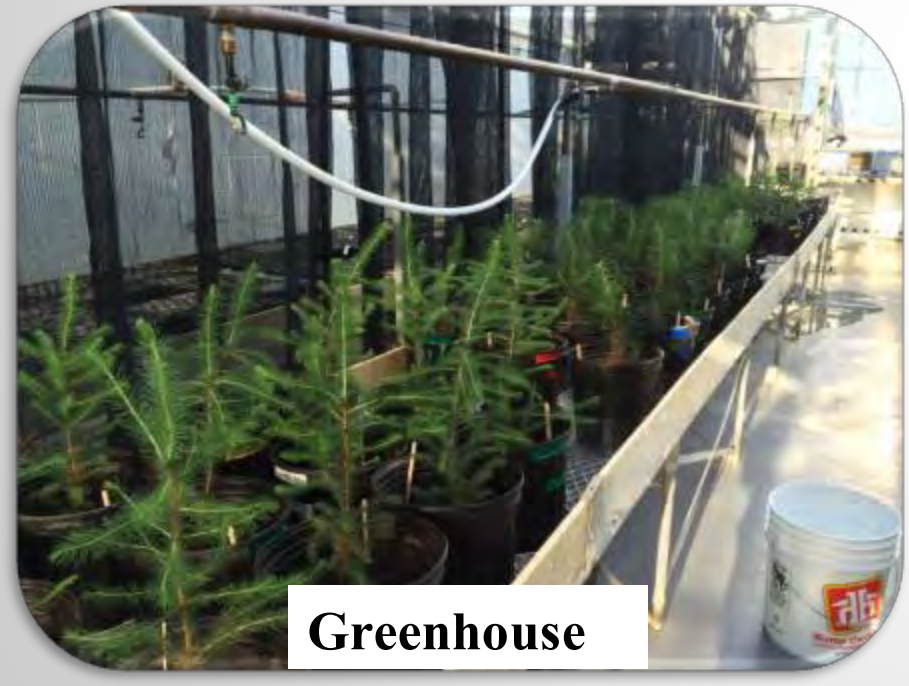
- In this context, we proposed to use this concentrate (ammonium sulfate) locally as a fertilizer in the boreal forest
  - Help enhance the nitrogen-limited boreal forest – can increase the wood volume
- The use of biochar with nitrogenous fertilizer increase nitrogen uptake and plant productivity
- Can MINING and FORESTRY companies share benefits together?



(Taghizadeh-Toosi et al. 2012; Spokas et al. 2012; Lévesque et al. 2021)

OBJECTIVE

- To evaluate the impact of biochar, nitrogen fertilization, and nitrogen fertilization combined with biochar on the growth of black spruce and jack pine seedlings [**Greenhouse**]
- To quantify the influence of nitrogen fertilization on the growth of black spruce plants [**Plantation**]



Greenhouse

Plantation

METHODOLOGY AND EXPERIMENTAL DESIGN

Greenhouse

Black spruce seedling

Jack pine seedling

N0B0:

- No fertilizer

N0B4:

- Biochar only (4090 kg/ha)

N2B0:

- Medium-dose nitrogen (200 kg N/ha)

N2B4:

- Medium-dose nitrogen + Biochar

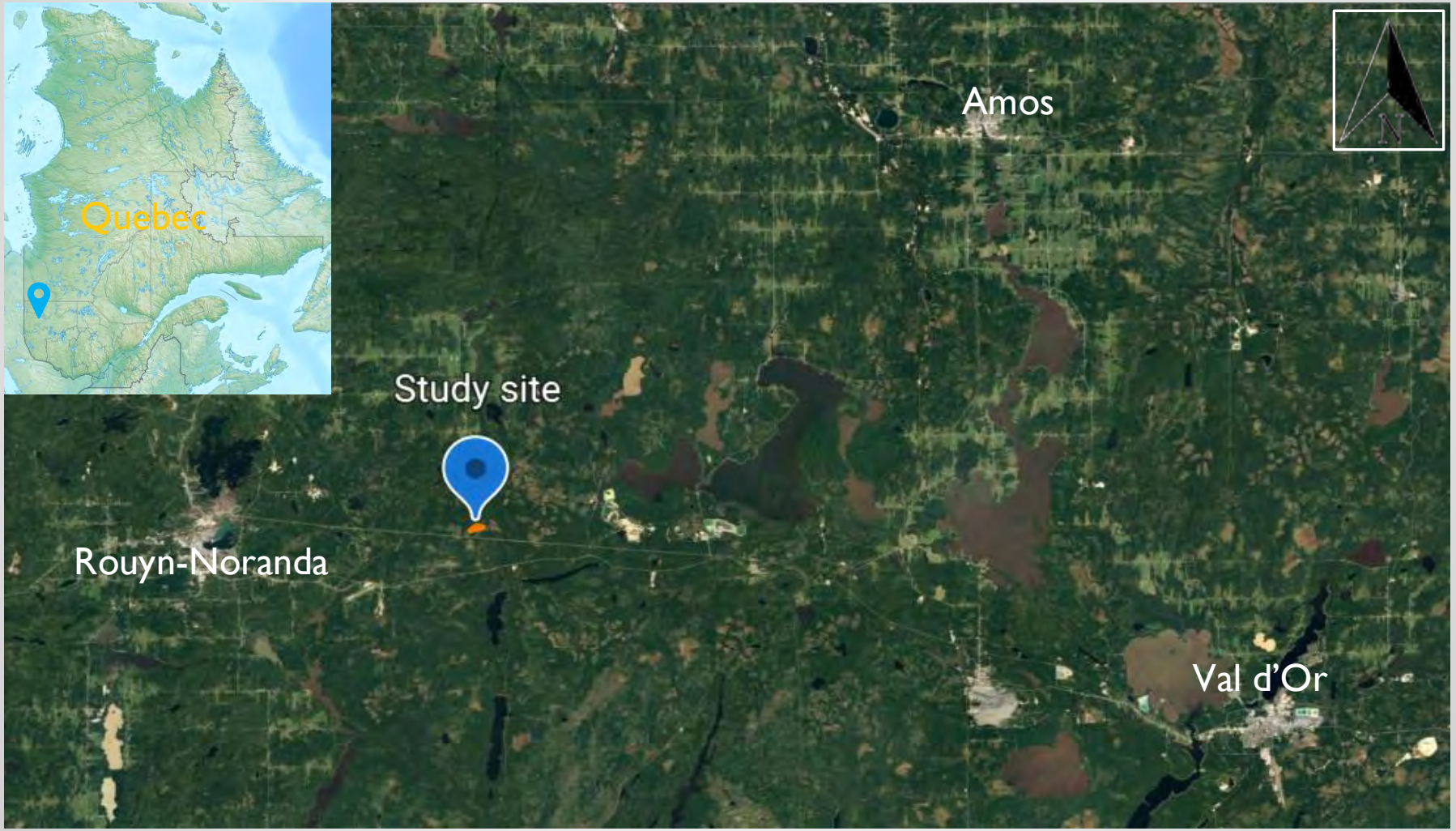
N4B0:

- High-dose nitrogen (400 kg N/ha)

(Hart & Luckai, 2014)

METHODOLOGY AND EXPERIMENTAL DESIGN

Field-plantation site



Study location

METHODOLOGY AND EXPERIMENTAL DESIGN

Field-plantation site

- Designed 3 forest blocks
- Sub-divided into 3 experimental plots
- 3 treatments assigned randomly

N0:

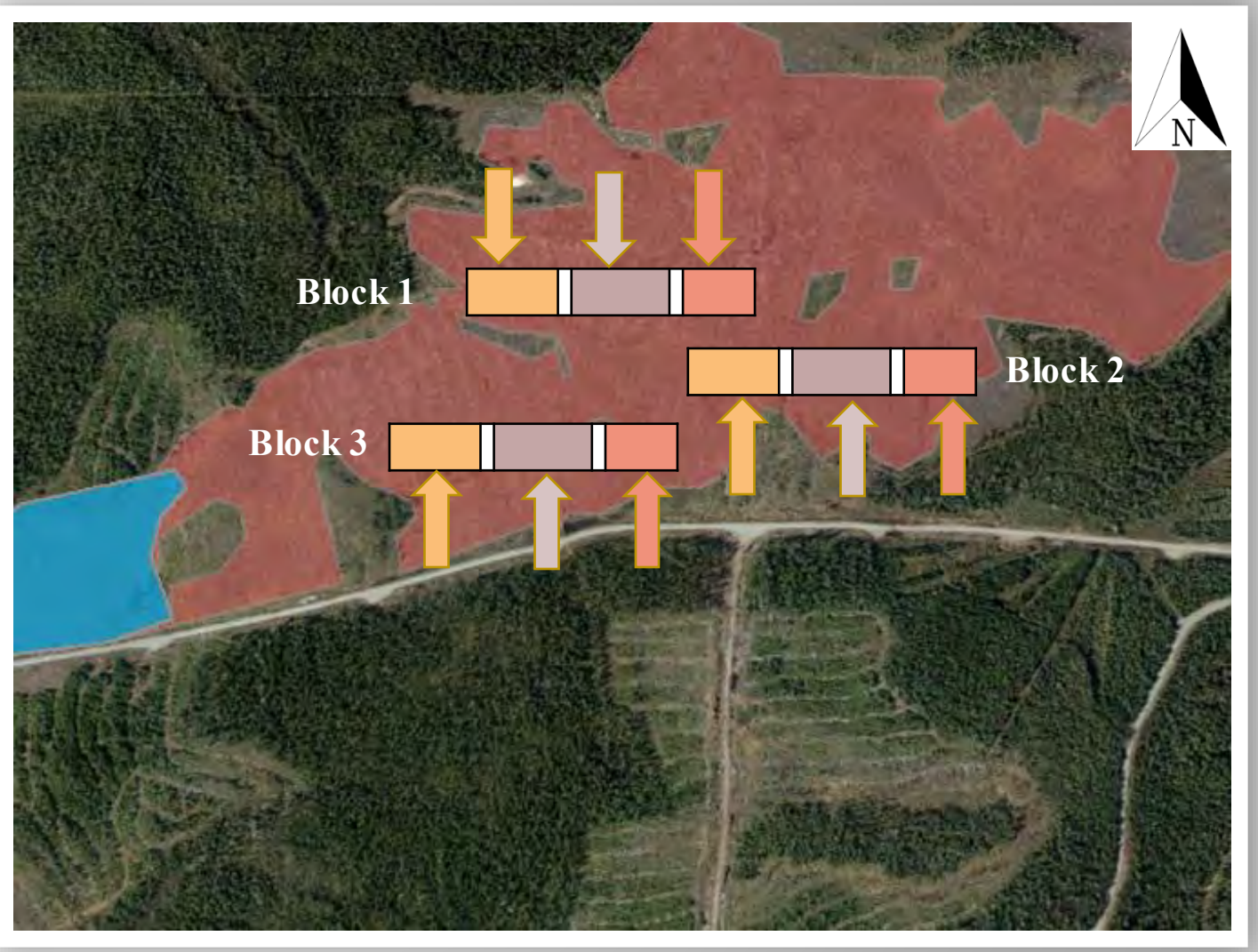
- No fertilizer

N1.5:

- Medium-dose nitrogen (150 kg N/ha)

N3:

- High-dose nitrogen (300 kg N/ha)



METHODOLOGY AND EXPERIMENTAL DESIGN

Measurements

- Height and diameter measurement:
  - Greenhouse: All seedlings at the interval of 0, 10, 20, and 30th week in 2015
  - Plantation: For 25 plants each year from 2015-2020 and in the plantation
- Biomass (weight) in greenhouse

METHODOLOGY AND EXPERIMENTAL DESIGN

Statistical analysis

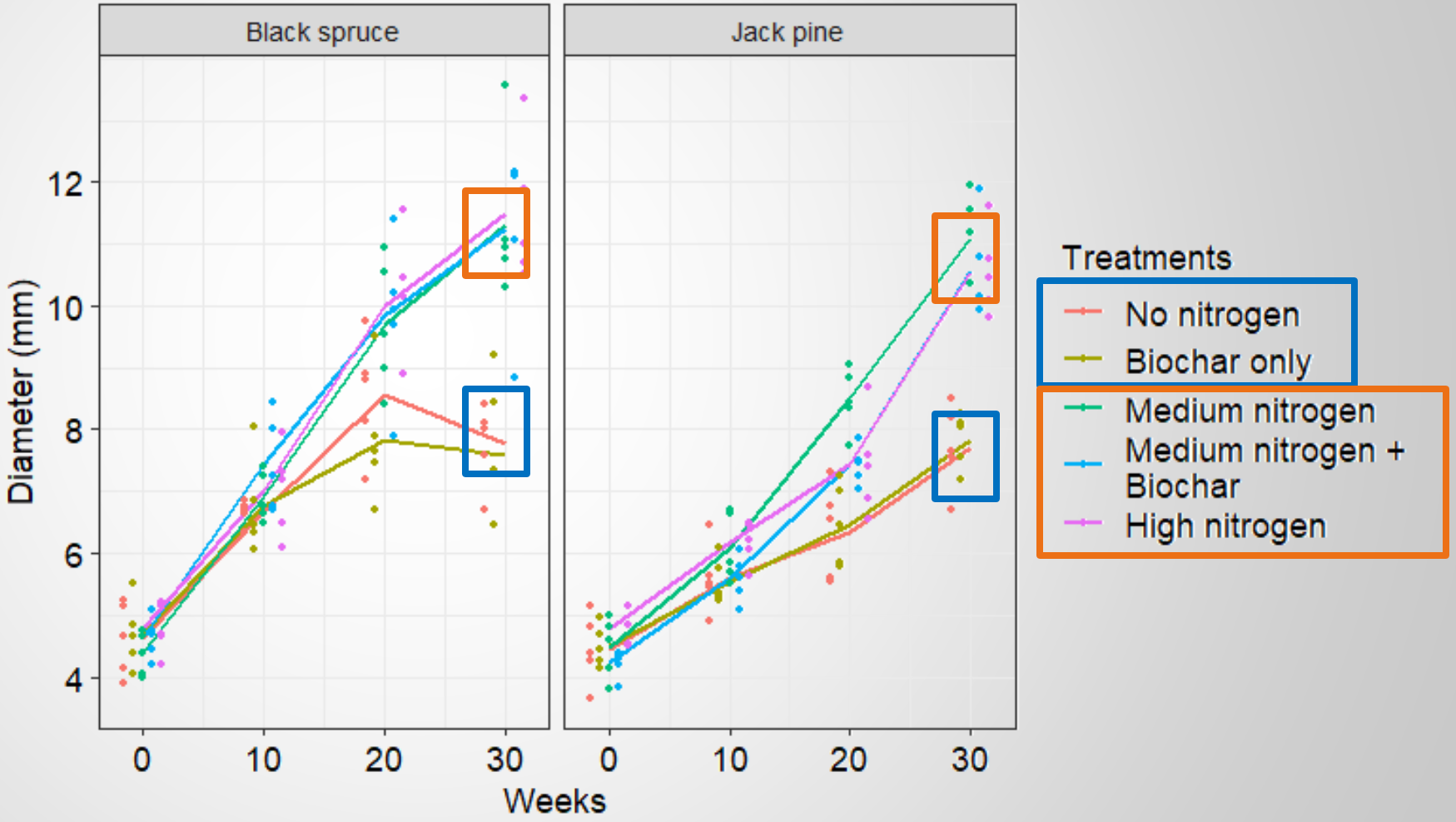
One-way analysis of variance (ANOVA)

Tukey's honest significant difference (HSD)

RESULTS

Greenhouse

- Black spruce – increased seedling size with a high dose of nitrogen
- Jack pine – the larger size of seedlings with medium nitrogen doses

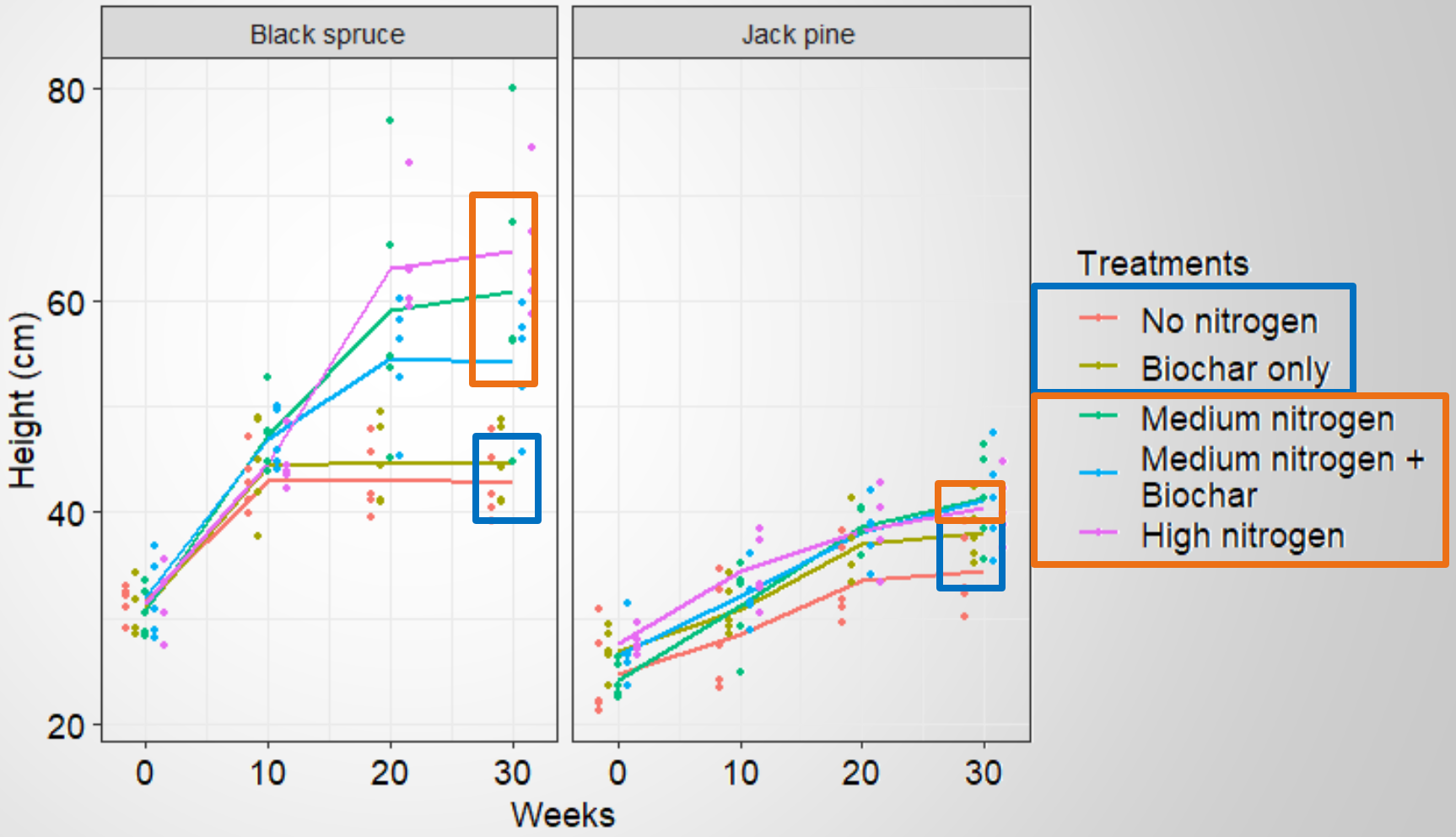


Diameter growth along weeks among different treatments

RESULTS

Greenhouse

- Height growth was doubled for black spruce compared to jack pine seedling

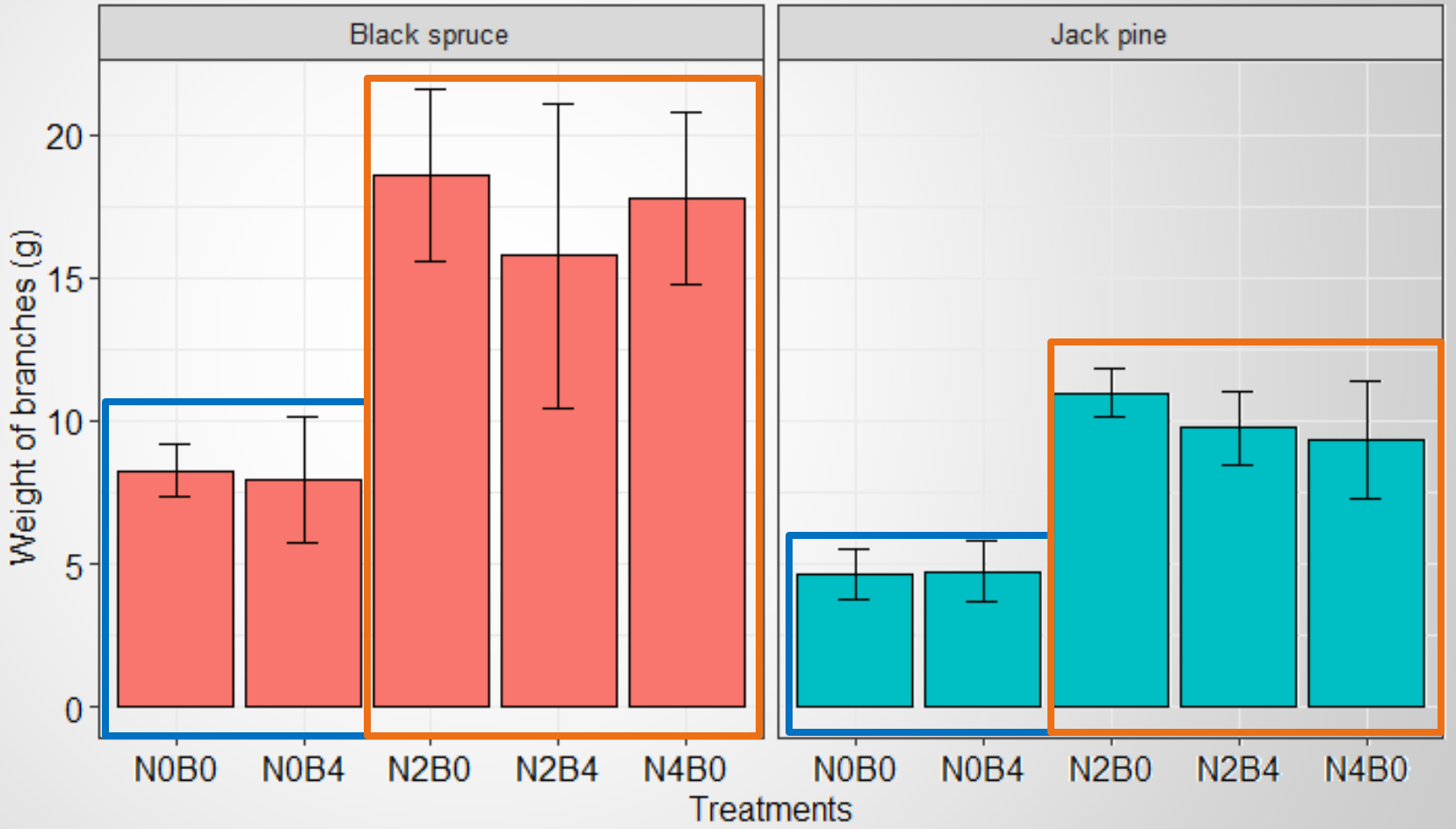


Height growth along weeks among different treatments

RESULTS

Greenhouse

- Seedlings that received nitrogen fertilization weighed approximately double the seedlings in the control pots



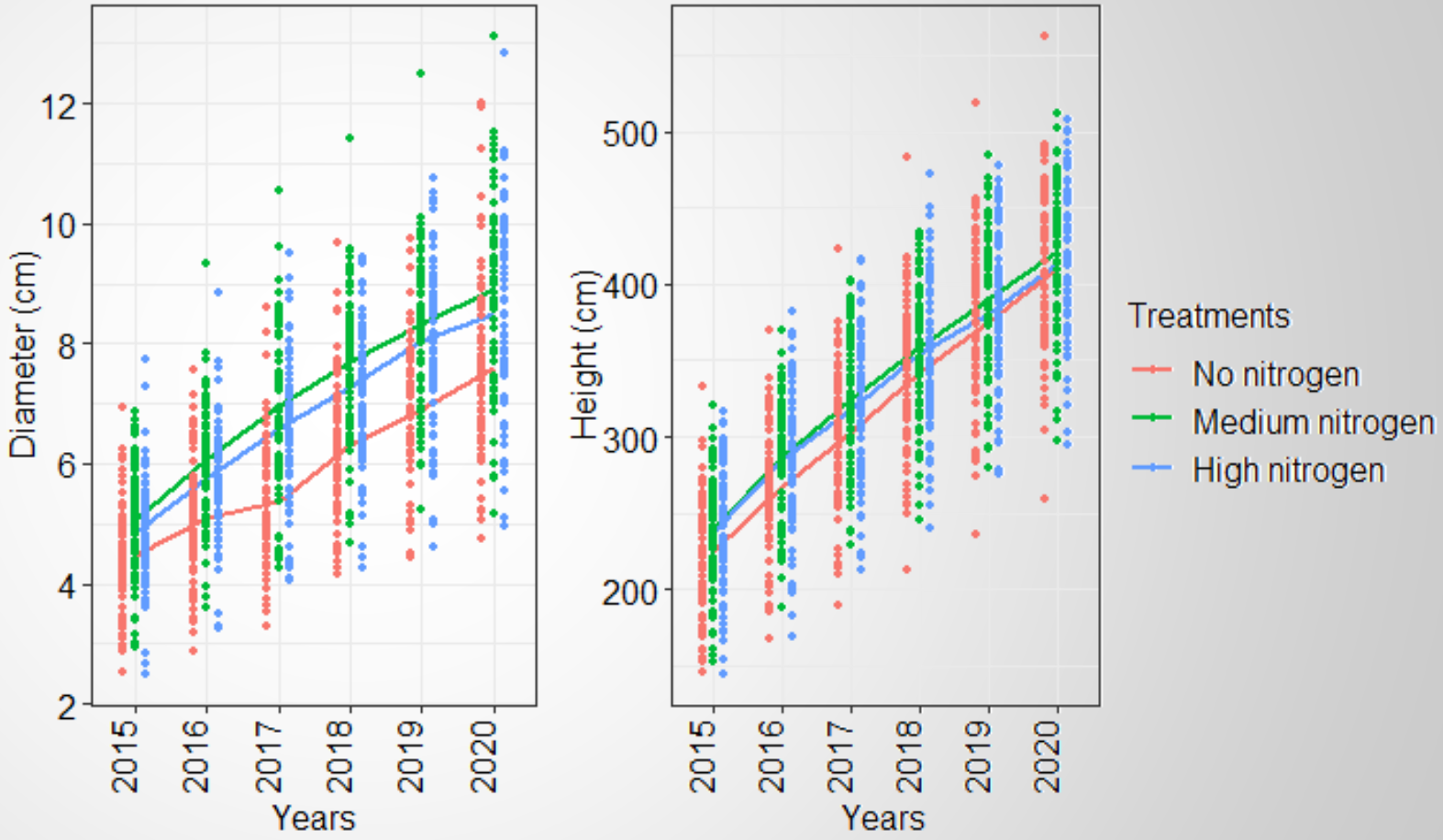
Biomass of the branches and needles for seedlings according to the treatment

RESULTS

Field experiment

- Medium and high dose fertilization increased the diameter growth by 0.96 cm and 0.7 cm

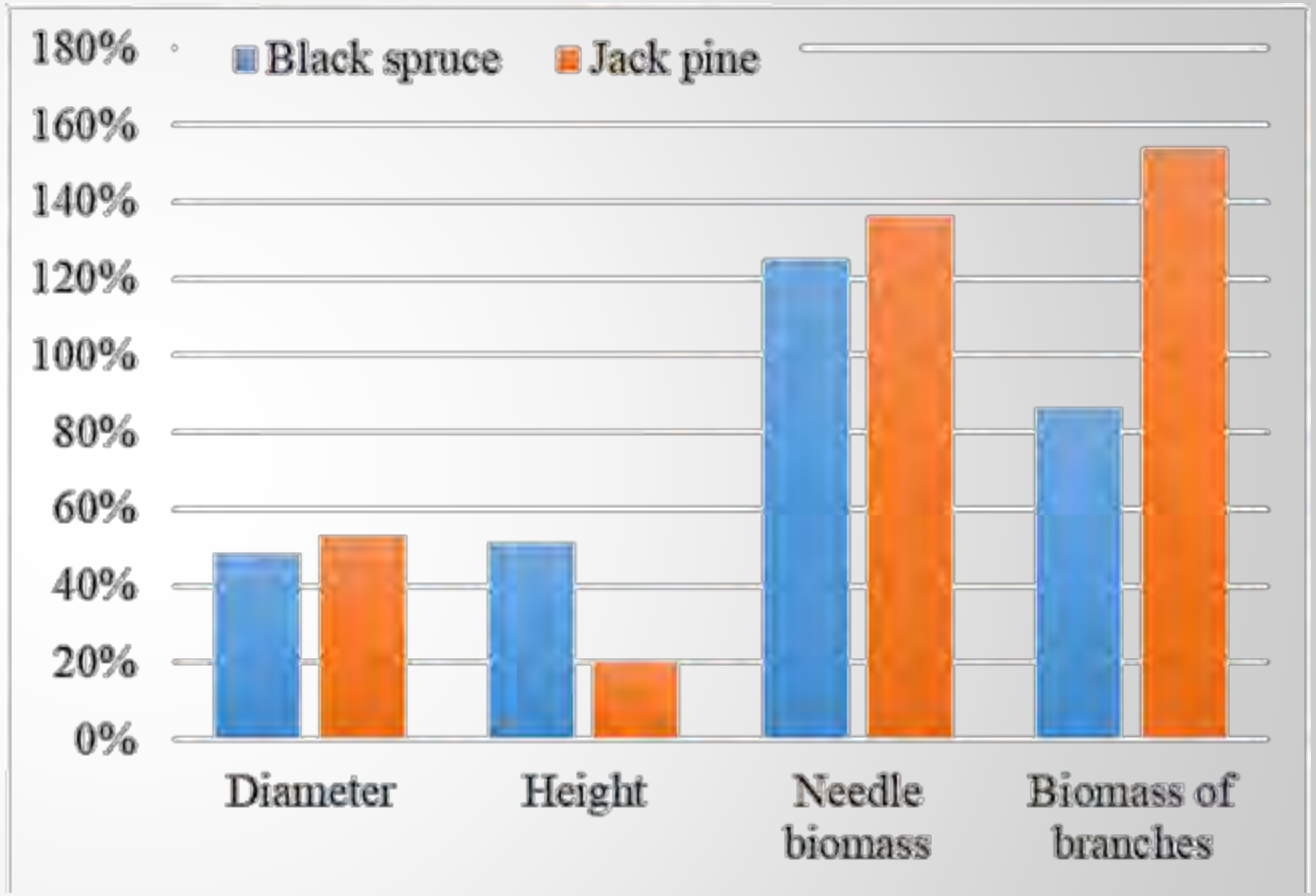
- The height growth was almost similar between the three treatments



The trend of the diameter and height growth of the black spruce seedlings

DISCUSSION

- Added fertilization - higher nutrition loading in the seedlings
- Increased in biomass is attributed to the increased nutrient uptake
- Biochar combined with fertilization – slightly lower growth than nitrogen
  - More water retention – sometimes limiting growth

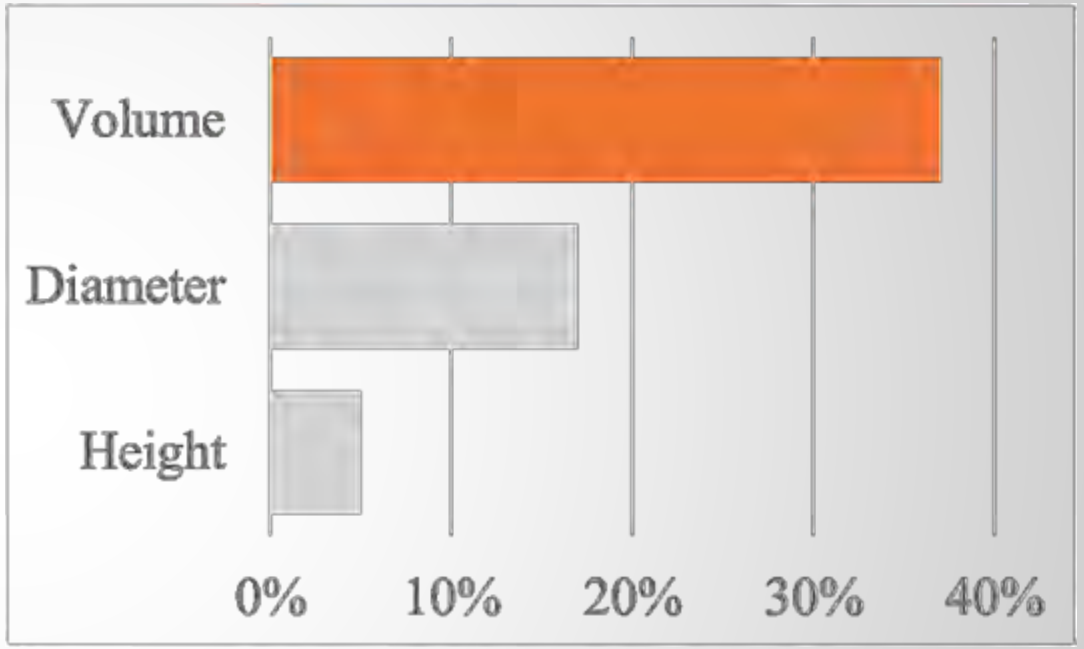


Growth gain after fertilization in greenhouse (compared to controlled seedlings)

(Schulte-Uebbing & de Vries, 2018; Salifu & Timmer, 2003; Houle et al., 2014; Saarsalmi & Mälkönen, 2001; Templer et al., 2012)

DISCUSSION

- The increment in the growth with the treatment shows boreal forest is nitrogen limited
- A volumetric increment of 37% even with the medium dose of nitrogen
- High-dose nitrogen causes acidification of the soil



Growth gain in black spruce after medium-dose of fertilization (compared to controlled plots)

(Schulte-Uebbing & de Vries, 2018; Salifu & Timmer, 2003; Houle et al., 2014; Saarsalmi & Mälkönen, 2001; Templer et al., 2012)

CONCLUSION

- The growth and biomass of plants increase with the addition of nitrogen fertilization with or without biochar
- Even a medium dose of nitrogen fertilization is sufficient to acquire a higher wood volume
- Ammoniacal effluent as a fertilizer: a promising avenue, both from the industrial effluent management and forest management perspective
- **WIN-WIN situation** for mining and forest companies

CONCLUSION

- The growth and biomass of plants increase with the addition of nitrogen fertilization with or without biochar
- Even a medium dose of nitrogen fertilization is sufficient to acquire a higher wood volume
- **Ammoniacal effluent as a fertilizer:** a promising avenue, both from the industrial effluent management and forest management perspective
- **WIN-WIN situation** for mining and forest companies

ACKNOWLEDGEMENTS

UQAT Université du Québec en Abitibi-Témiscamingue
GREMA
CTRI Centre technologique des résidus industriels
Fonds de recherche Nature et technologies Québec
GOLDCORP ÉLÉONORE
CRSNG NSERC
MISA Réseau d'expertise en innovation minière
Mine Canadian Malartic
Hecla Québec
Valorix Cultivez l'efficacité
IAMGOLD
RICHMONT
SANEXEN Services environnementaux inc.

Merci beaucoup!

REFERENCES

Doucet, R., & Côté, M. (2009). *Manuel de foresterie* (Éditions M).

Hart, S. A., & Luckai, N. J. (2014). Charcoal carbon pool in North American boreal forests. *Ecosphere*, *5*(8), 1–14. https://doi.org/10.1890/ES13-00086.1

Högberg, P., Fan, H., Quist, M., Binkley, D., & Tamm, C. O. (2006). Tree growth and soil acidification in response to 30 years of experimental nitrogen loading on boreal forest. *Global Change Biology*, *12*(3), 489–499. https://doi.org/10.1111/j.1365-2486.2006.01102.x

Houle, D., Moore, J. D., Ouimet, R., & Marty, C. (2014). Tree species partition N uptake by soil depth in boreal forests. *Ecology*, *95*(5), 1127–1133. https://doi.org/10.1890/14-0191.1

Robert, É., & Braghiroli, F. L. (2022). Development of a Biochar-Based Substrate Added with Nitrogen from a Mining Effluent for the Production of Picea mariana Seedlings. *Clean Technologies*, *4*(3), 770–784. https://doi.org/10.3390/cleantechnol4030047

Saarsalmi, A., & Mälkönen, E. (2001). Forest fertilization research in Finland: A literature review. *Scandinavian Journal of Forest Research*, *16*(6), 514–535. https://doi.org/10.1080/02827580152699358

Salifu, K. F., & Timmer, V. R. (2003). Nitrogen Retranslocation Response of Young Picea mariana to Nitrogen-15 Supply . *Soil Science Society of America Journal*, *67*(1), 309–317. https://doi.org/10.2136/sssaj2003.3090

Schulte-Uebbing, L., & de Vries, W. (2018). Global-scale impacts of nitrogen deposition on tree carbon sequestration in tropical, temperate, and boreal forests: A meta-analysis. *Global Change Biology*, *24*(2), e416–e431. https://doi.org/10.1111/gcb.13862

Spokas, K.A.; Novak, J.M.; Venterea, R.T. Biochar's Role as an Alternative N-Fertilizer: Ammonia Capture. Plant Soil 2012, 350, 35–42

Taghizadeh-Toosi, A., Clough, T. J., Sherlock, R. R., & Condron, L. M. (2012). Biochar adsorbed ammonia is bioavailable. *Plant and Soil*, *350*(1–2), 57–69. https://doi.org/10.1007/s11104-011-0870-3

Tamm, C. O., Aronsson, A., Popovic, B., & Flower-Ellis, J. (1999). Optimum nutrition and nitrogen saturation in Scots pine stands. In *Studia Forestalia Suecica* (Issue 206).

Templer, P. H., Mack, M. C., Chapin, F. S., Christenson, L. M., Compton, J. E., Crook, H. D., Currie, W. S., Curtis, C. J., Dail, D. B., D'Antonio, C. M., Emmett, B. A., Epstein, H. E., Goodale, C. L., Gundersen, P., Hobbie, S. E., Holland, K., Hooper, D. U., Hungate, B. A., Lamontagne, S., … Zak, D. R. (2012). Sinks for nitrogen inputs in terrestrial ecosystems: A meta-analysis of 15N tracer field studies. *Ecology*, *93*(8), 1816–1829. https://doi.org/10.1890/11-1146.1

VickyLévesque, MarenOelbermann, and NouraZiadi (2021). Biochar in temperate soils: opportunities and challenges. Canadian Journal of Soil Science. 102(1): 1-26. https://doi.org/10.1139/cjss-2021-0047

ACKNOWLEDGEMENTS

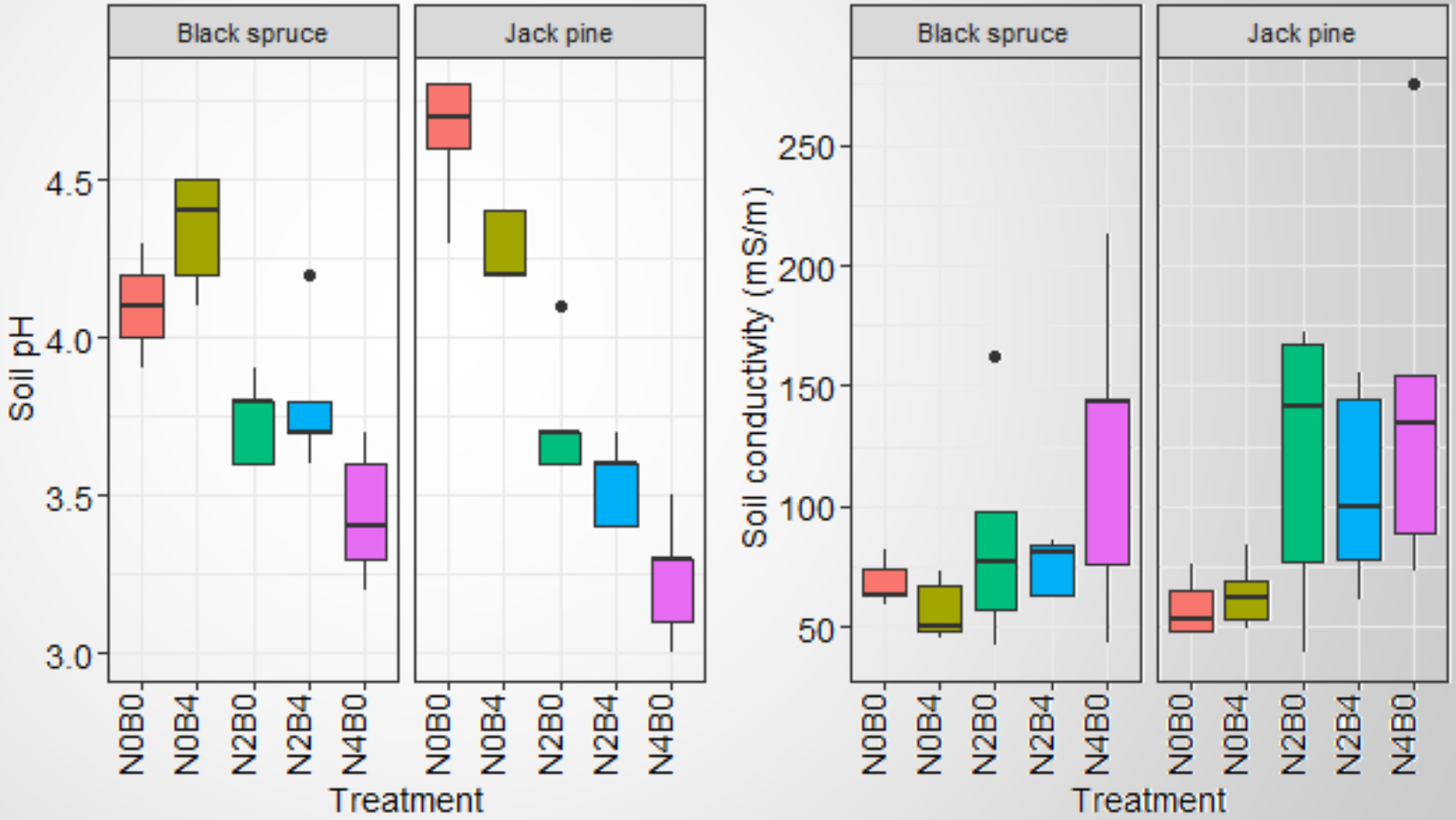
UQAT Université du Québec en Abitibi-Témiscamingue
GREMA
CTRI Centre technologique des résidus industriels
Fonds de recherche Nature et technologies Québec
GOLDCORP ÉLÉONORE
CRSNG NSERC
MISA Réseau d'expertise en innovation minière
Mine Canadian Malartic
Hecla Québec
Valorix Cultivez l'efficacité
IAMGOLD
RICHMONT
SANEXEN Services environnementaux inc.

Thank you!

RESULTS

Greenhouse

- The soil pH seems to become more acidic with the addition of the fertilizer

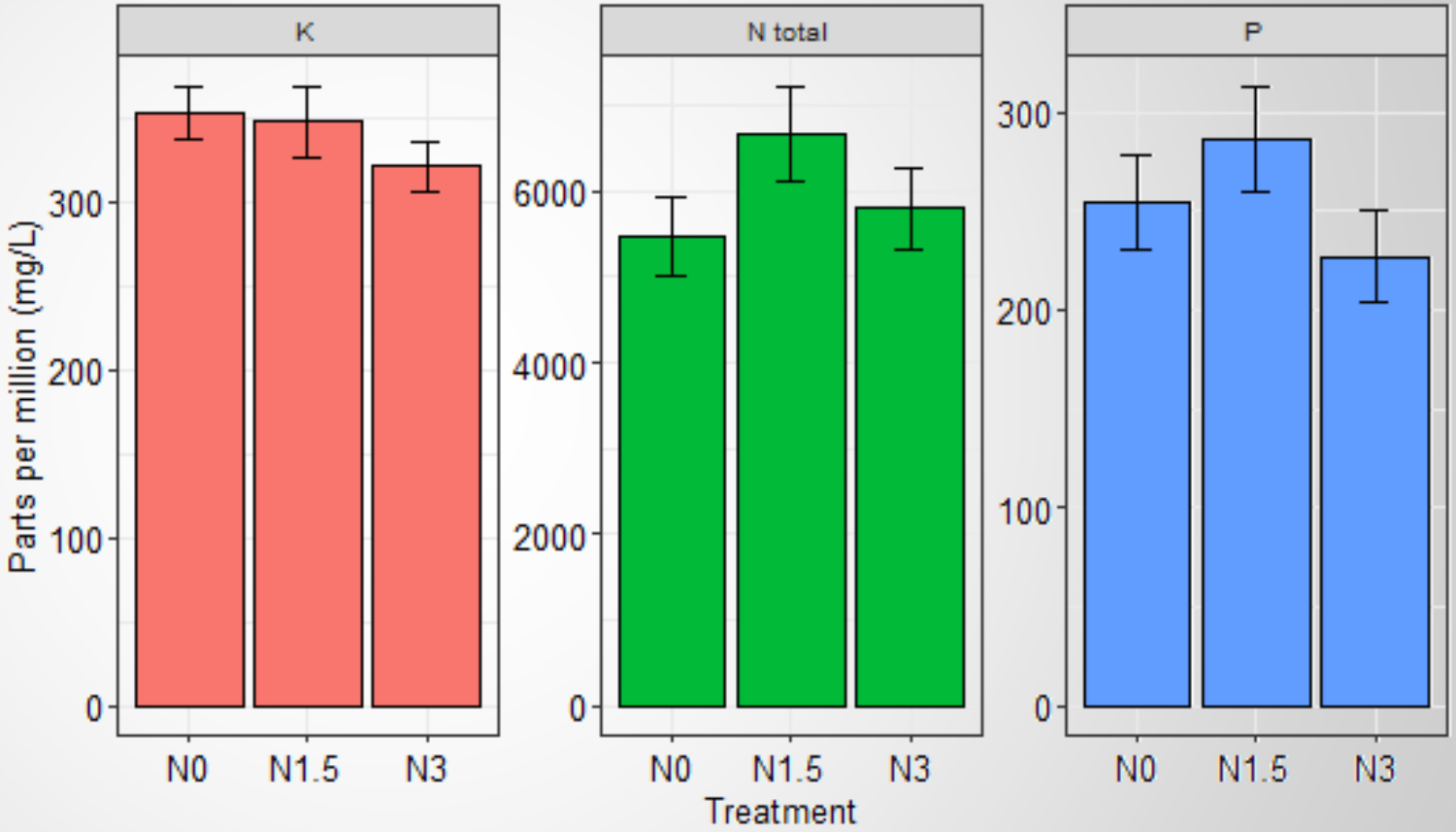


Soil properties variation among the different treatments

RESULTS

Field experiment

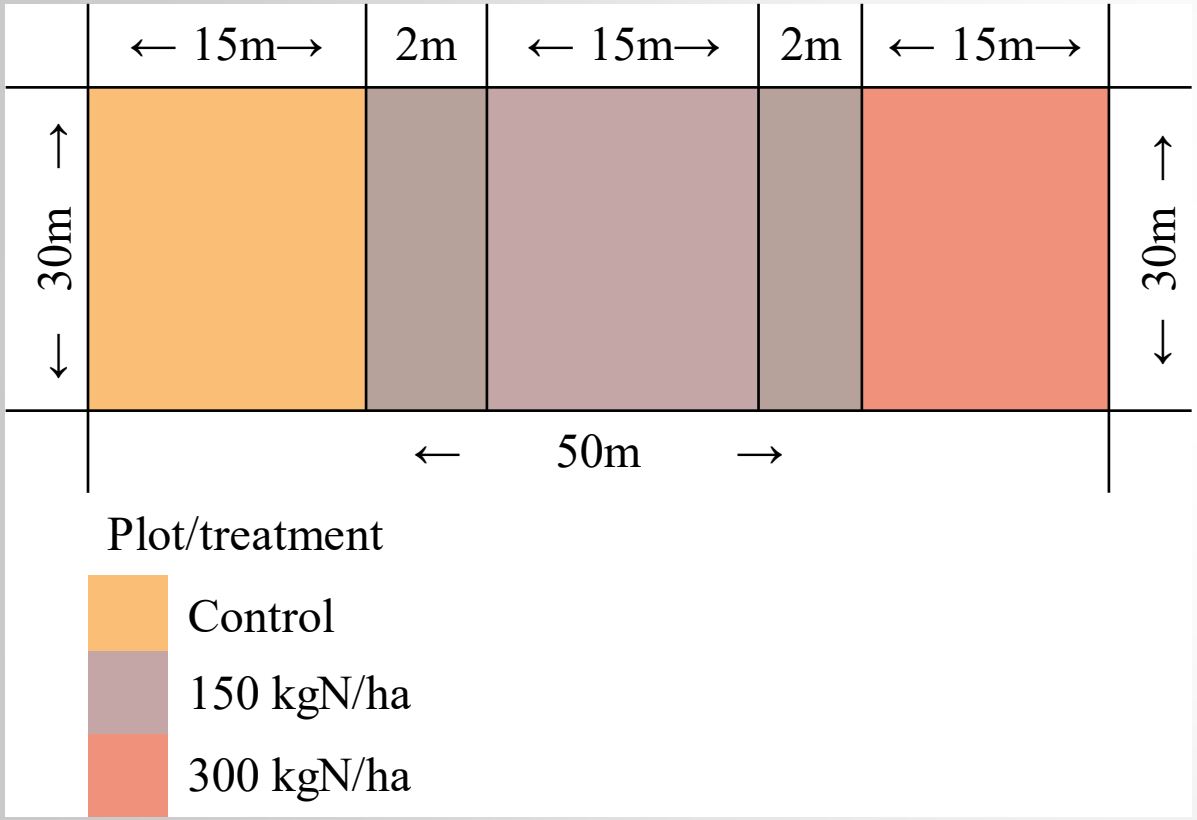
- Analysis of the foliar composition didn't show a significant difference specifically between treatments for N, P, and K

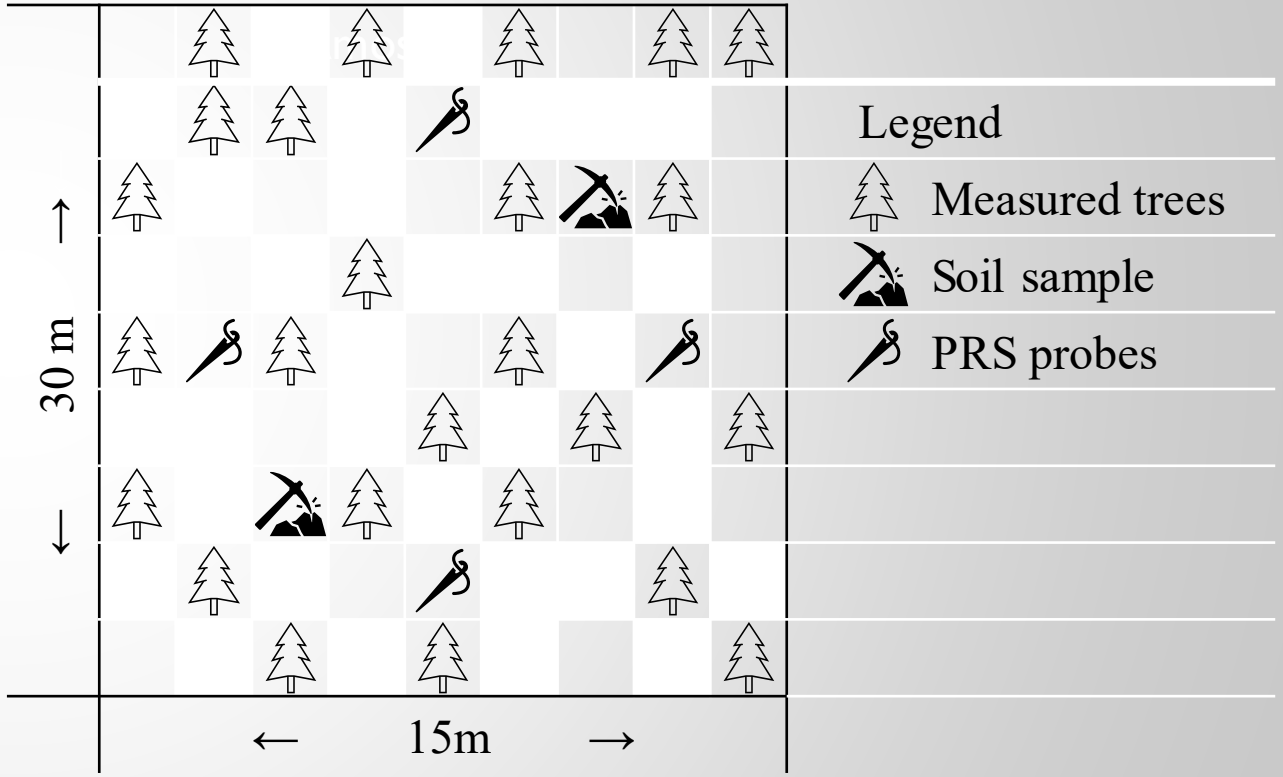


Foliar composition of the black spruce needles

METHODOLOGY AND EXPERIMENTAL DESIGN

Field-plantation site

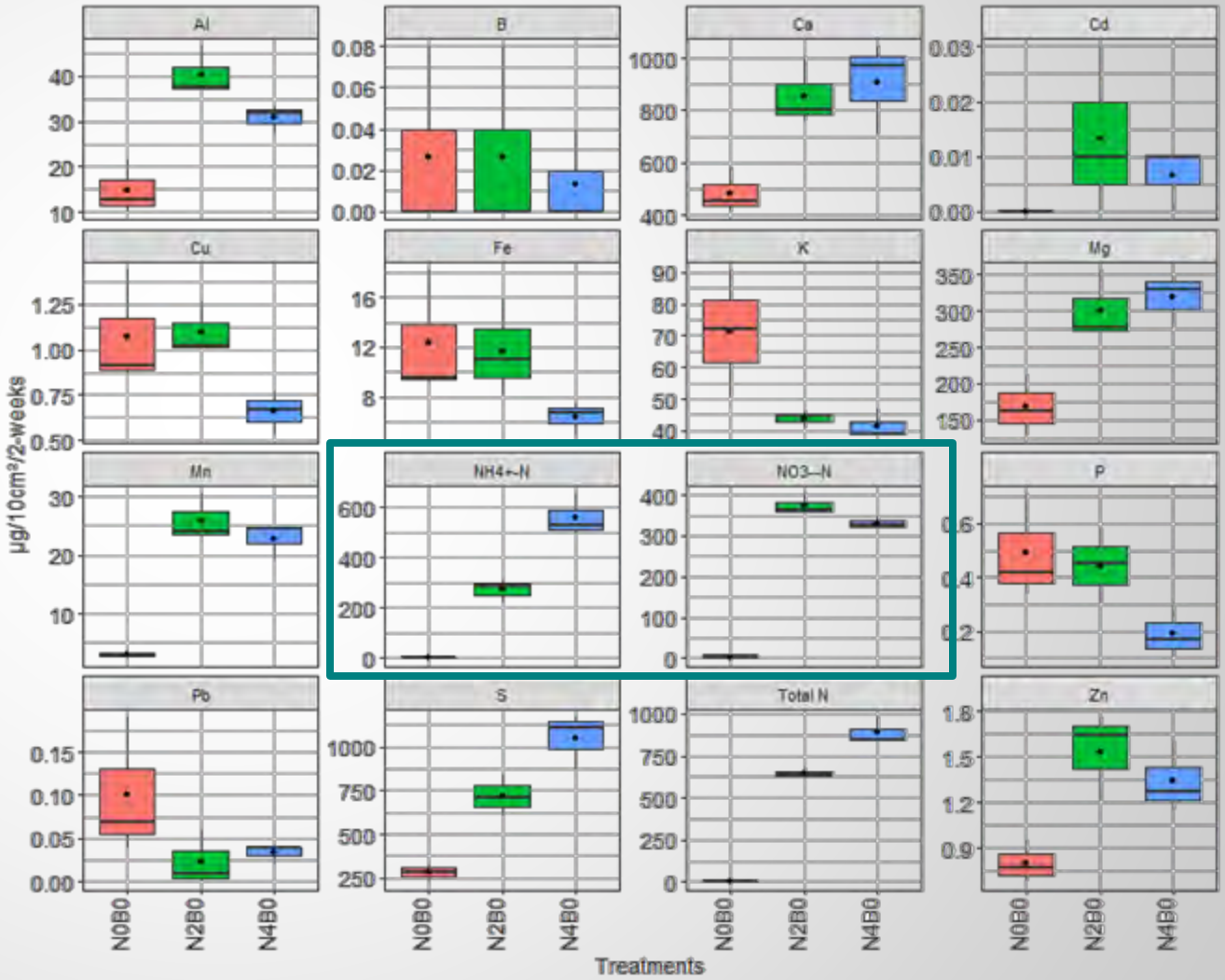




RESULTS

Greenhouse

- Most significant variability was seen in the nitrogen according to the treatment; a higher amount of nitrogen was obtained in highly concentrated nitrogen treatment.

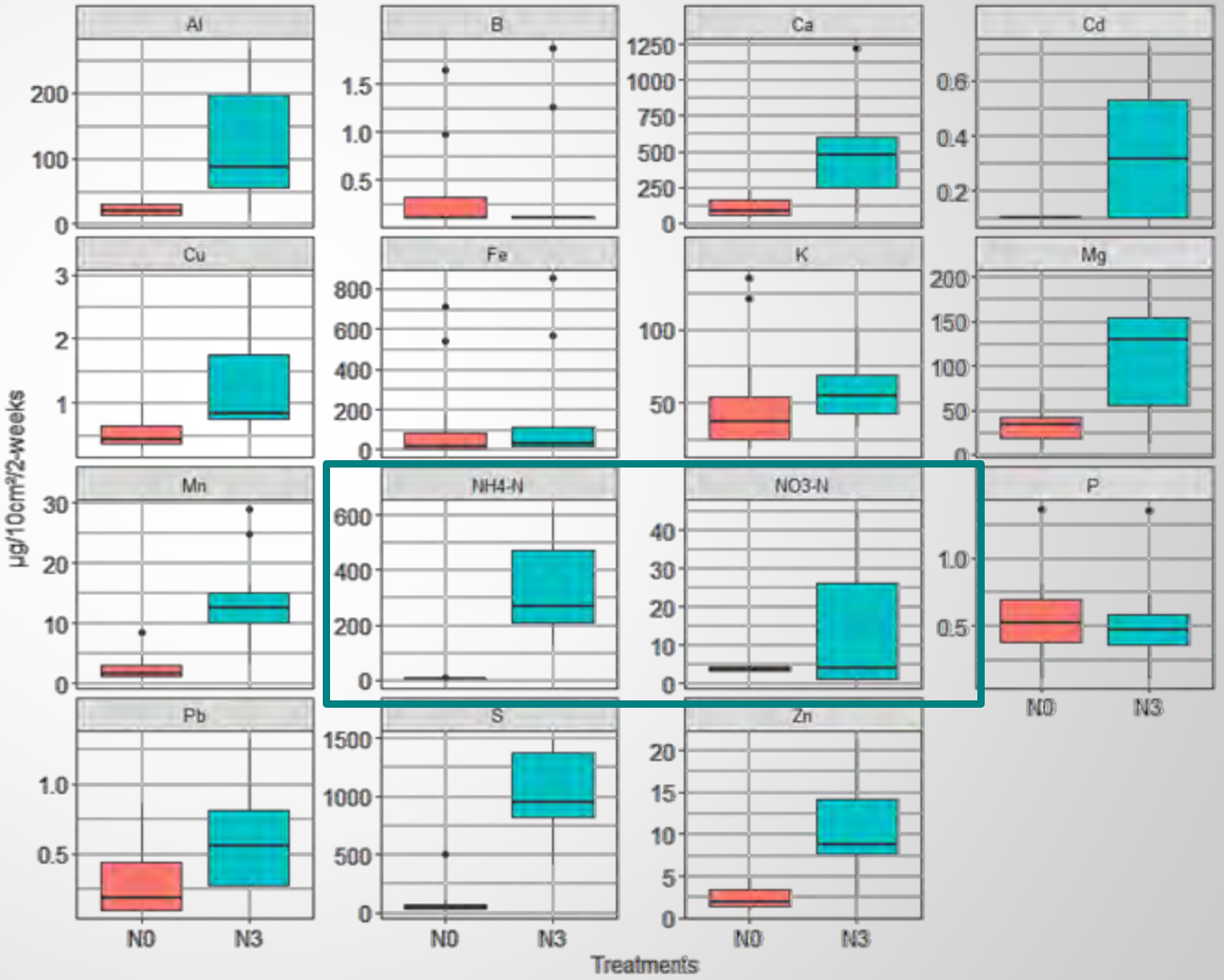


Variation in soil ion composition

RESULTS

Field experiment

- Nitrogen levels were higher in the soil solution for the plots with nitrogen treatment than in the controls



DISCUSSION

- The increment in the growth with the treatment (with or without biochar) shows boreal forest is nitrogen limited
- Increased in biomass is attributed to the increased nutrient uptake
- Added fertilization assisted in the higher nutrition loading in the seedlings

Growth gains; Control vs ammoniacal fertilization Greenhouse

	Black spruce	Jack pine
Diameter	48%	53%
Height	51%	20%
Needle biomass	125%	136%
Biomass of branches	86%	154%

Growth gains; Control vs ammoniacal fertilization Field experiment

	Black spruce
Diameter	17%
Height	5%
Volume	37%

(Schulte-Uebbing & de Vries, 2018; Salifu & Timmer, 2003; Houle et al., 2014; Saarsalmi & Mälkönen, 2001; Templer et al., 2012)

DISCUSSION

- As for the pH, it decreases with the addition of ammonium sulfate, because of the acidifying nature of the fertilizer

- Similar N, P, and K foliar composition in black spruce due to different mineralization rate

(Högberg et al., 2006; Tamm et al., 1999; Doucet & Côté, 2009; Saarsalmi & Mälkönen, 2001; Robert and Braghiroli, 2021)