Response of Soil Respiration and Litterfall in Phosphorus and Nitrogen Treatments in Northern Hardwood Forests

Final Report

MELNHE Internship

By

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**Abstract**

Ecosystems adjust to changes in resource availability. A limiting nutrient could affect parts of the same ecosystem in different ways. Soil nutrient availability in the Multiple Element Limitation in Northern Hard Wood Ecosystems (MELNHE) plots exhibit a synergistic response to N + P addition, but aboveground production is likely limited by P availability in northern hardwood forests. This study evaluated the effect of full factorial N x P fertilization in MELNHE plots on soil respiration in the 2019 field season and litter fall in the 2018 litter year. The data collected suggested P addition increased soil respiration and decreased litterfall (p<0.05). There are two major carbon influxes, belowground carbon allocation and litterfall, and one major efflux, soil respiration. The increase in respiration may be attributed to an increased need to grow fine roots to seek out N to accompany P and in turn, increased root turn over. Analyzing more years of data may help clarify the effects of P versus that of NP and N treatments. Assuming that the carbon in the soil is in steady state, it follows that the observed decrease in litterfall in response to P because the trees have to expend resources acquire N with fine roots. Further study on sources of carbon to leaf litter are necessary to support this explanation.

**Introduction**

Plant growth patterns can be likened to optimization theorems in economics. They acquire resources when nutrients are abundant, produce tissue until the benefit is no longer greater than the cost of resources, and adjust resource allocation such that growth limitation is equal for all resources (Bloom, 1985). In MELNHE project sites, pools of N in soil were found to increase more when N + P were added, suggesting N and P co-limitation in the ecosystem (Fisk, Ratliff, Goswami, & Yanai, 2014). This phenomenon has also been observed in tree leaves in MELNHE sites. Foliar resorption of nitrogen has been associated with the resorption of phosphorus (See et al., 2015).

Evidence of single element limitation was also present in northern hardwood forests. Nitrogen, phosphorus and potassium fertilization resulted in higher specific leaf area. The canopy and seed deposition increased in the species P. *pensylvanica* (Fahey, Battles, & Wilson, 1998). Furthermore, P fertilization has been found to be associated with increased aboveground production in the site associated with MELNHE. Basal area of trees increased with P addition (Goswami et al., 2017). Various elements within the forest ecosystem respond differently to element limitation. This study will consider full factorial N x P fertilization associated with Multiple Element Limitation in Northern Hardwood Ecosystems project to consider the impact of increased nitrogen and phosphorus availability on soil respiration and litterfall in northern hardwood forests

The major two major fluxes of carbon into the soil are litter fall and belowground carbon allocation while soil respiration is the major pathway of carbon out of soil. Litter fall and soil respiration can be measured and subtracted from one another to approximate belowground carbon allocation, under the assumption that soil carbon fluxes are in steady state (Raich & Nadelhoffer, 1989). It is notable that the carbon flux associated with soil respiration was found to be drastically greater in magnitude than that of litterfall (Bae, Fahey, Yanai, & Fisk, 2015). Thus, the treatment effect of soil respiration is likely dominant approximation of underground carbon allocation, and any treatments effects on soil respiration hint at treatment effects on belowground carbon allocation. Recent analysis of soil respiration in the sites under consideration suggest that N fertilization resulted in reduced soil respiration (Bae, Fahey, Yanai, & Fisk, 2015; Li, 2018).

Work by Shiyi Li et al. (2018) also suggests an overall suppression effect of N on belowground carbon allocation.

The objective of this research is to measure soil respiration and litter fall data for each of the stands in the 2019 field season and 2018 litter year in the context of analysis litter fall and soil respiration data analyzed by Bae et al. (2015) and Li et al. (2018). The litter fall data will be considered in tandem with soil respiration data to also infer changes in belowground carbon allocation related to availability of N and P in the soil. Because there is evidence that N and P pools in soil are co-limited and increase in response to N+P fertilization, fine root production, and in turn, soil respiration will likely decrease in response to N + P addition. Conversely, P fertilization will likely increase litter fall production because it increased aboveground growth.

**Methods**

*Site Description*

Soil respiration and litter fall data from three sites within the White Mountains National Forest, NH, USA will be considered: Bartlett Experimental Forest (BEF; 44°2-4’N,71°9-19’W; elevation 250-500 m), Hubbard Brook Experimental Forest (HBEF; 43°56’N, 71V44’W; elevation 500 m), and Jeffers Brook Forest (JBF; 44°02’N, 71°53’W; elevation 730 m) (Bae et al., 2015). The climate at all three stands is cool-temperate humid continental. The mean annual precipitation is 140 cm per year. Each site contains stands of different ages. The age of each stand is determined by time since the last logging event, younger forests being those clear-cut between 1966 and 1990. The older stands contain predominantly sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.) and yellow birch (*Betula allegheniensis* Britt.) trees whereas younger stands contain a mixture of paper birch (*Betula papyifera* Marsh.), pin cherry (*Prunus pennsylvanica* L.f.), red maple (*Acer rubrum* L.), and aspen (*Populus grandidentata* Michaux.) in addition to a mixture of the species present in older forests (Kang et al., 2016).

The White Mountains have a glacial history, which gave rise to spodosols, which vary in composition based on the parent material (Allen et al.; Bae et al., 2015). The White Mountains contain igneous bodies of rock and major zones of metamorphosed rock which are major contributors to the soil till (Allen et al., 2001). The bedrock present at BEF consists of granite and gneiss, whereas schist and quartz monzonite are the dominant bedrock types at HBEF, and amphibolite is the most common bedrock type at JBF (Bae et al., 2015).



**Figure 1.** Map of the stand sites included in this study.

*Experimental Design*

Starting in 2011, 13 stands of varying age in Bartlett Experimental Forest (BEF), Hubbard Brook Experimental Forest (HBEF), and Jeffers Brook Forest (JBF) have been fertilized with a full-factorial combination of nitrogen and phosphorus treatment. Low level nutrient fertilizers are added annually. Nitrogen is applied in 30 kg N/ha/yr to the nitrogen-treated and the nitrogen and phosphorus treated plots. Phosphorus is applied in 10 kg P/ha/yr to the phosphorus and nitrogen and phosphorus plots.

Each of 13 stands considered in this study has four treatment plots. Plots within each stand are 50 x 50 m. A 10 m buffer zone surrounds a 30 x 30 m measurement area Plots in stand HBM and JBM are unique in that a 5 m buffer zone surround a 20 x 20 m measurement area, but the nutrient addition in those plots is equivalent. Each plot contains five litter baskets and seven respiration collars distributed throughout the measurement area.

*Field Methods*

Soil respiration data were collected twice from each of the thirteen stands during the summer of 2019 using a Li-Cor Soil Flux System. The flux was measured over a 1.5 minutes period. Data collection from each plot within a stand occurred on the same day between 9 am and 4 pm so as to produce comparable data. When the coefficient of variation (CV) for any soil respiration data point was greater than 2, it was rejected and retested. Data from one round of collection were recorded within a two-week period as to minimize environmental variation in the data set (table 1).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Round | Stand | Site | Date of Measurement |  | Round | Stand | Site | Date of Measurement |
| 1 | C1 | BEF | 6/28/19 |  | 2 | C1 | BEF | 7/26/19 |
| 1 | C2 | BEF | 6/20/19 |  | 2 | C2 | BEF | 7/14/19 |
| 1 | C3 | BEF | 6/26/19 |  | 3 | C3 | BEF | 7/18/19 |
| 1 | C4 | BEF | 6/20/19 |  | 2 | C4 | BEF | 7/14/19 |
| 1 | C5 | BEF | 6/28/19 |  | 2 | C5 | BEF | 7/26/19 |
| 1 | C6 | BEF | 6/27/19 |  | 2 | C6 | BEF | 7/27/19 |
| 1 | C7 | BEF | 6/24/19 |  | 2 | C7 | BEF | 7/15/19 |
| 1 | C8 | BEF | 6/25/19 |  | 2 | C8 | BEF | 7/15/19 |
| 1 | C9 | BEF | 7/3/19 |  | 2 | C9 | BEF | 7/27/19 |
| 1 | HBM | HBEF | 7/1/19 |  | 2 | HBM | HBEF | 7/19/19 |
| 1 | HBO | HBEF | 7/1/19 |  | 2 | HBO | HBEF | 7/19/19 |
| 1 | JBM | JBF | 7/2/19 |  | 2 | JBM | JBF | 7/25/19 |
| 1 | JBO | JBF | 7/2/19 |  | 2 | JBO | JBF | 7/25/19 |

**Table 1**. Dates of 2019 soil respiration data collection.

Litter was collected from each of the 13 stands once at the time of stand fertilization, in August, and will again be collected in the fall. This study considered the fall and spring data for the 2018 ‘litter year’, which began in the fall of 2018 and ends in the summer of 2019. Baskets with minor breaks in the walls were repaired with duct tape. Any disturbed baskets were repositioned. Baskets with damage to the base were replaced.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Season | Stand | Site | Date of Measurement |  | Season | Stand | Site | Dates of Measurement |
| Spring | C1 | BEF | 6/5/19 |  | Fall | C1 | BEF | 10/7/18, 10/12/18, and April 2019 |
| Spring | C2 | BEF | 6/6/19 |  | Fall | C2 | BEF | 10/7/18, 10/12/18, and 10/31/18 |
| Spring | C3 | BEF | 6/10/19 |  | Fall | C3 | BEF | 10/12/18 and 10/31/18 |
| Spring | C4 | BEF | 6/6/19 |  | Fall | C4 | BEF | 10/7/18, 10/12/18, and 10/31/18 |
| Spring | C5 | BEF | 6/10/19 |  | Fall | C5 | BEF | 10/7/18, 10/12/18, and April 2019 |
| Spring | C6 | BEF | 6/4/19 |  | Fall | C6 | BEF | 10/7/18, 10/12/18, and 10/31/18 |
| Spring | C7 | BEF | 6/1/19 |  | Fall | C7 | BEF | 10/7/18, 10/12/18, and April 2019 |
| Spring | C8 | BEF | 5/30/19 |  | Fall | C8 | BEF | 10/7/18, 10/12/18, and 10/31/18 |
| Spring | C9 | BEF | 6/4/19 |  | Fall | C9 | BEF | 10/7/18, 10/12/18, and 10/31/18 |
| Spring | HBM | HBEF | 7/11/19 |  | Fall | HBM | HBEF | 10/7/18, 10/12/18, 10/21/19and 10/31/18 |
| Spring | HBO | HBEF | 7/11/19 |  | Fall | HBO | HBEF | 10/7/18, 10/12/18, 10/21/19and 10/31/18 |
| Spring | JBM | JBF | 6/12/19 |  | Fall | JBM | JBF | 10/12/18 and 10/31/18 |
| Spring | JBO | JBF | 6/12/19 |  | Fall | JBO | JBF | 10/12/18 and 10/31/18 |

**Table 2.** Dates of 2018 leaf litter collection.

*Data Analysis*

The treatment effect of a full factorial treatment of N and P on litter fall and soil respiration in the MELNHE stands was tested using a two-way ANOVA. The treatment effect was modeled as a fixed variable whereas the spatial effects of the stands, litter fall baskets, and the soil respiration collars within those stands were treated as random effects. The mean of the soil respiration collars within a given plot was considered the sample unit for the soil respiration data. Likewise, the mean of the litter baskets in a given plot was considered the sample unit of litter fall. These sample units were considered replicates across stands. We acknowledge that this analysis does not consider stand age. It is also worth noting that seeds were removed from some spring litter by mistake. Values of p< 0.05 were considered statistically significant.

**Results**

In plots treated with P, mean soil respiration is increased and the mean litterfall is decreased (figure 2, p=0.0056; figure 3, p= ). The data suggested that there is no interaction between NP in the soil respiration or litterfall data (F=1.19, p=0.34; F= 1.47, p=0.20; Fcrit=2.15). In both cases the mean NP is shifted in the same direction as N and the mean C is shifted with P.

A screenshot of a cell phone

Description automatically generated

**Figure 2.** The mean soil respiration from the 13 MELNHE stands in 2019. The response to P treatment is significantly difference (appendix 1; p<0.0056).

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Description automatically generated**

**Figure 2.** The mean litterfall from the 13 MELNHE stands in the fall and spring of the 2018 litter year. The response to P treatment is significantly different (appendix 2; p= ).

**Discussion**

The soil respiration data from 2010 does not support my hypothesis, soil respiration data only exhibits a statistically significant difference in P treated plots. However, the graphs suggest that while P increases soil respiration, N fertilization and NP fertilization may decrease soil respiration (figure 2). Although there was not a detectable difference between treatments using a two-way ANOVA, the graphs generally agree with the observations of Li et al. (2018) on soil respiration data from 2013, 2014, 2016, and 2017 that NP decrease soil respiration. Meanwhile, the response of litter fall to P addition was in the opposite direction from the aboveground biomass response to P addition potentially indicating a change in aboveground patterns of carbon allocation. In fact, P fertilization may decrease litter production. Again, the mean litterfall for N and NP were increased when considering figure 3.

One explanation for the increase in soil respiration with P addition is an increase in fine root turnover. Adding N was found to increase the N pool, but adding NP was associated with even greater increase the N availability in soil (Fisk, Ratliff, Goswami, & Yanai, 2014). A similar pattern was observed in soil respiration. P treatment increased soil respiration while the mean soil respiration of NP and N fertilization was decreased. Perhaps when P alone is available, more roots are necessary to procure N to accompany it. This is supported by the work of Bae, Fahey, Yanai, & Fisk, (2015). N and NP fertilization may have decreased belowground carbon allocation. Under the assumption that carbon flux of respiration continues to be drastically larger than that of litter fall in the MELNHE plots, the treatment effect on soil repiration suggests that a treatment effect on belowground carbon allocation may also exist. Thus, increased fine root turn over may be a factor in the observed increased soil respiration in the P treated plots. An assessment of belowground carbon allocation since 2011 may be a good way to further support this explanation or suggest a need for another explanation.

The a need for N or N + P, not P alone may also be responible for the decreased in litter fall (figure 3). The litter fall decreased while the soil respiration increased in P plots. The increase in soil respiration may be triggering a decrease in leaf production (Raich & Nadelhoffer, 1989). However, there may be a treatment effect on soil carbon fluxes, which would mean the realtionship between soil repiration, litterfall, and belowground carbon allocation is not upheld. This explanation may also tie leaf production to soil carbon too closely. Studies on photosynthesis in the different treatment plots are necessary. A study on soil carbon and belowground carbon allocation would likley offer more information about the decreased litter fall in reponse to P treatment.

These conclusions are drawn from data that suggests significant difference of P treatment from the other treatments, not a difference between P and N as well as NP plots. This may be because this study only includes data from the year 2019. Because there are various other related studies going on in the Multiple Element Limitation in Northern Hardwood Ecosystems project, the study contributes to the larger research goal of testing for co-limitation and mechanisms of maintaining co-limitation.

**Appendices**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | |  |  |  |  | |  |
| Source of Variation | | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| P vs. Not P | 78.5 | | 12 | 6.54 | 3.26 | 0.00564 | 2.15 |
| N vs. Not N | 0.400 | | 1 | 0.380 | 0.1200 | 0.659 | 4.23 |
| Interaction | 28.7 | | 12 | 2.39 | 1.19 | 0.338 | 2.154 |
| Within | 52.1 | | 26 | 2.01 |  |  |  |
|  |  | |  |  |  |  |  |
| Total | 160 | | 51 |  |  |  |  |

**Appendix 1**. ANOVA table for soil respiration data.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ANOVA |  |  | | |  |  |  |  |
| Source of Variation | *SS* | *df* | *MS* | *F* | | | *P-value* | *F crit* |
| P vs. Not P | 8680 | 12 | 723 | 13.4 | | | 3.22E-08 | 2.15 |
| N vs. Not N | 61.9 | 1 | 61.9 | 1.15 | | | 0.294 | 4.23 |
| Interaction | 953 | 12 | 79.4 | 1.47 | | | 0.199 | 2.154 |
| Within | 1410 | 26 | 54.1 |  | | |  |  |
|  |  |  |  |  | | |  |  |
| Total | 11100 | 51 |  |  | | |  |  |
|  |  |  |  |  | | |  |  |

**Appendix 2**. ANOVA table for leaf litter data.

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**Edits from Ruth That Have Not Been Fully Addressed**—

INTRO--

* ~~When I refer to our own work, make it clear~~
* Add outside work—if there were time
* ~~Consolidate objectives—don’t need whole section if its in the intro. Make sure it’s not repeated~~
* ~~Prediction is part of same paragraph as objectives within intro~~

METHODS

* ~~Remove unnecessary things that aren’t necessary—writing on paper, bag labeling etc~~
* ~~Don’t need to ref—things we know as part of study—amt fertilizer, plot area, stuff internal to project, still cite species comp~~
* ~~Add stands and dates—table of dates of collection~~
* ~~Melany has 2018 fall litter dates~~
* ~~Shiyi/ dan have spring dates~~
* ~~Remove other years info~~
* ~~Don’t mention air then oven dried~~
* ~~Email gif about seeded~~
* ~~Remove rest of paragraph about weighing—those details only important to proposal~~

RESULTS

* ~~Report exact p values~~ 
  + ~~How do I report that for everything properly?~~
  + Check anova table information—why is df wrong?
* Indicate use of avgs
  + ~~Color for treatment~~
  + Shape
* Remove mentions of correlation

DISCUSSION

* ~~Can definitively say leaf production depressed~~
* ~~Suggest that there could be a change in soil carbon, don’t say assuming. No basis for assuming steady state~~
* Ask *Alex* about leaves—what would control them