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Article

The impacts of rock pulverization on soil quality and functional soil nematode and respiration properties of boreal lands converted from forest to agricultural use

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Abstract

Rock pulverization is recommended when converting boreal forests to agricultural land use to facilitate tillage operations. Resulting rock dust incorporation might alter physical, chemical, and biological properties of soils. We assessed soil nematode trophic group abundances and indices, basal and burst respiration, and phosphorus extractability after land use conversion (LUC) and recent pulverization (<1 year) on three soil types in eastern Newfoundland, Canada. Nine treatments representing varied pulverization statuses (managed pulverized, managed unpulverized, natural) were nested in soil type (Podzol, Luvisol, and Organic). Conversion to agriculture impacted soil quality more than the recent rock pulverization. Nonetheless, nematode indices (fungivore/bacterivore, fungivore/fungivore+bacterivore, fungivore + bacterivore/herbivore) suggested no significant functional differences with either LUC or pulverization. Soil organic matter (SOM) and pH were substantial direct and indirect drivers of nematode community composition and soil respiration, mainly by altering availability of aluminium and iron. The functional parameters diverged between Organic and mineral soils. For all soils, most respiration parameters were significantly related to SOM, pH, available iron and aluminium. For nematodes, significant relationships were identified in the Organic soil: bacterivores and fungivores abundances were inversely related to SOM, and bacterivore abundance was positively related to pH. While for the mineral soils, citric acid extracted more phosphorus than the Mehlich-3 or water methods, Mehlich-3 was most effective for the Organic soil. Pulverization did not affect phosphorus extractability. The distinct relationships between soil quality properties and functional parameters between mineral and Organic soils are of interest for further investigations into the concepts of soil quality and soil health.

Key words: land use change, rock pulverization, rock dust, free-living nematodes, soil respiration, soil phosphorus

Résumé

Quand on souhaite adapter la forêt boréale à l'agriculture, on préconise de pulvériser le roc pour faciliter les labours. L'incorporation de la poussière rocheuse au sol peut cependant en altérer les propriétés physiques, chimiques et biologiques. Les auteurs ont évalué l'abondance des groupes trophiques de nématodes dans le sol et leurs indices, ainsi que le taux de respiration de base, l'explosion oxydative et l'extractabilité du phosphore après conversion de la vocation des terres (CVT) et pulvérisation récente du roc (moins d'un an) pour trois types de sol de l'est de Terre-Neuve, au Canada. Ils ont combiné différents degrés de pulvérisation (gestion de la pierre pulvérisée, gestion de la pierre non pulvérisée, état naturel) et types de sols (podzols, luvisols et sols organiques) en neuf traitements. La conversion en terre agricole a plus d'impact sur la qualité du sol que la pulvérisation récente du roc. Malgré cela, les indices des nématodes (fongivore/bactérivore, fongivore/fongivore+bactérivore, fongivore+bactérivore/herbivore) laissent croire qu'il n'existe aucune différence sensible entre la CVT et la pulvérisation, sur le plan fonctionnel. La matière organique du sol (MOSL) et le pH sont d'importants paramètres qui affectent directement et indirectement la composition de la population de nématodes et la respiration du sol, essentiellement parce qu'ils modifient la disponibilité de l'aluminium et du fer. Les paramètres fonctionnels ne sont pas les mêmes pour les sols organiques et les sols minéraux. Dans tous les sols, la majorité des paramètres de la respiration présentent une relation significative avec la MOS, le pH ainsi que la quantité de fer et d'aluminium disponible. Les auteurs ont établi des liens significatifs entre les nématodes et le sol organique : l'abondance de nématodes bactérivores et fongivores est inversement reliée à la quantité de MOS, alors que la population de bactérivores est positivement corrélée au pH. En revanche, dans les sols minéraux, l'acide citrique extrait plus de phosphore que la méthode Mehlich-3 ou l'extraction à l'eau, tandis que la technique Mehlich-3 s'avère plus efficace pour le sol organique. La pulvérisation ne modifie pas l'extractibilité du phosphore. Les liens évidents entre les propriétés qualitatives et les paramètres fonctionnels des sols minéraux et organiques mériteraient qu'on entreprenne des recherches plus poussées sur les concepts que sont la qualité et la vitalité du sol. [Traduit par la Rédaction]

Mots-clés : modification de la vocation des terres, pulvérisation du roc, poussière de roche, nématodes naturels, respiration du sol, phosphore du sol

Introduction

Boreal region lands are notoriously challenging for agricultural production, but agriculture is expanding and intensifying at an unprecedented rate as boreal and Arctic communities advocate for economic development, food security, and food sovereignty. However, soil quality degradation in terms of carbon and nitrogen (N) losses, a consequence of boreal and arctic land use and land use change, is linked to alterations in the below-ground food web (Grunzweig et al. 2004; Duarte-Guardia et al. 2020). The removal and replacement of boreal forest, its understory, and organic soil horizon (LFH) with traditional agricultural crops results in soil organic matter (SOM) which is rapidly respired as carbon dioxide (CO_2), degradation of organic matter quality, and accelerated N mineralization. Postconversion management including tillage and pH control have direct and indirect impacts on soil quality (Carter 1986; Fierer and Jackson 2006).

Boreal regions typically have high rock content derived from glacial till that can hinder cropping (FAO 2017). To reduce damage to farming equipment and facilitate planting and harvesting, rocks in the upper soil horizons may be eliminated through pulverization with an agricultural stone crusher during or after land conversion from forest to agricultural use. This process can improve soil quality by adding micro and macro nutrients from the resulting rock dust, accelerating the natural formation of soil, and sequestering atmospheric carbon through enhanced weathering (Haraldsen and Pedersen 2003; Beerling 2018). Rock dust composition, i.e., the type and abundance of micro and macro nutrients, varies based on the parent material. Further, rock dust minerals degrade at varying rates depending on parent material, dust particle size, physicochemical parameters of the soil in which dust is incorporated, and interactions with soil biota (Palandri and Kharaka 2004; Renforth et al. 2015; Potysz and Bartz 2022).

Rock dust has been reported to replenish soil nutrients as a substitute to synthetic fertilizer (Haraldsen and Pedersen 2003; Ramos et al. 2014), correct the pH of acidic soils (Barral Silva et al. 2005), and consequently increase crop yields (Manning and Theodoro 2018; Jones, Guinel and Antunes 2020; Kelland et al. 2020). In contrast, other studies reported that dust incorporation does not result in changes to soil quality, fertility (Bolland and Baker 2000), or crop yields (Ramezanian et al. 2013). Rock pulverization has additionally been reported to deteriorate the structure of soils which are thus more easily compacted and more susceptible to wind and water erosion (Chow et al. 1992). Pulverization of rock can also lead to unpredictable shifts in soil physicochemical parameters since rocks mitigate rapid soil temperature changes (Saini and Maclean 1967; Chow et al. 1992).

To determine the impact that rock pulverization might have on a boreal agricultural soil, there is a critical need to understand not only the initial rock chemistry but also the system in which the rock is being pulverized. Soil functional parameters including nematode trophic group abundances and soil respiration parameters that are sensitive to shifts in soil physical and chemical parameters could ideally inform on the impact of changes induced by pulverization of native rocks. Nematode community analysis can be used to inform sustainable management decisions (Bongers and Ferris 1999) and can provide thorough quality information for soils undergoing land use and land use change (LULUC) as proximate indicators for multiple ecologically relevant interactions in the soil (Yeates et al. 1993). Information detailing the influence of rock pulverization on nematodes is limited; one study by Atungwu et al. (2014) reported that rock dust can control root-knot (*Meloidogyne incognita*) infection of plants. However, the effects of rock pulverization on nematode community composition are unknown. Additionally, the cumulative release of CO_2–carbon (CO_2–C) by microbes and other biota (i.e., soil respiration) is a broad indicator of community-level biological activity relevant to carbon and nutrient mineralization and immobilization. Steady-state and maximum potential respiration may indicate soil quality and functional status (Brinton and Vallotton 2019). How soil pulverization affects soil respiration is yet unexplored but is likely a significant modifier as it affects the physical structure, hydrology, and chemistry of soil, all of which govern microbial activity (Ryan and Law 2005).

To evaluate the impact of rock pulverization on soil functional parameters, we surveyed a farm in eastern Newfoundland, Canada that recently employed pulverization practices on soils classified as Orthic Humo-Ferric Podzol (Podzol), Orthic Gray Luvisol (Luvisol), and Typic Fibrosol (Organic) (Agriculture and Agri-Food Canada 1998). Twenty-one samples were Podzol, nine were Luvisol, and nine were Organic Nematode community abundances and indices, and basal and burst respiration measures were employed as primary functional parameters. The following research questions were addressed:

1. Both land use change from forest to agricultural use, and rock pulverization modify soil physicochemical properties at a soil-type-dependent magnitude. We anticipate a

general decrease in SOM and increase in pH with land use change. Rock pulverization is likely to increase pH and availability of minerals such as iron (Fe) and potassium (K).
2. The physical and chemical disturbances due to rock pulverization will directly and indirectly cause functional changes to the food web as reflected in the nematode trophic group abundances and respiration measurements. These changes will be dependent on soil type. More Mehlich-3 available (M3) cations, particularly Fe, may negatively impacts nematode's abundance. Soil respiration and microbial consuming nematodes (i.e., bacterivores and fungivores) will be stimulated due to pulverization making SOM more freely available and accessible to microbes.
3. Regardless of pulverization status, SOM and pH will directly and indirectly through interactions with metal ions (i.e., as indicated by M3 Fe and aluminium (Al)), affect soil nematode communities and respiration.
4. Extractability of phosphorus (P) will be modified due to rock pulverization facilitating the solubilization of rock minerals via increased surface area altering phosphorus–cation interactions.

Materials and methods

Study site

The study was located on a farm on the Avalon Peninsula of Newfoundland and Labrador, Canada (NL) (47.333070, –52.855397), a typical representation of the boreal ecosystem with dominant Podzolic and less abundant Luvisolic and Organic soils. The natural Organic soil has an organic layer, hemic (Om) in the top 20–30 cm over a fibric layer (Of), of at least 60 cm, with the water table within 30 cm from the surface. The site receives an average of 1534 mm of precipitation per year of which 328 mm is snow (Government of Canada 2021). Soil parent materials are silica-rich grey slate and granite with sandstone intrusions, rocks that have relatively slow dissolution (Palandri and Kharaka 2004). Adjacent to the managed land, natural vegetation consists of spruce (*Picea mariana*) and larch (*Larix laricina*) with sphagnum moss understory. Natural and pasture lands were converted to agricultural use between five and more than 60 years before sampling. Wet locations were drained, and soils were mechanically pulverized using a rock crusher tractor attachment. Rocks with equivalent diameters between 4 and 20 cm at a depth of up to 25 cm were crushed to <4 mm particle size using a Bugnot agricultural stone crusher (bugnot.com) (Fig. 1). Rocks larger than 20 cm and some rock fragments larger than 4 mm that escaped the rock crusher remained after pulverization treatment. The soil aggregates broke down into dust, noticeable during pulverization. As rock pulverization was completed at the test farm to facilitate ease of tillage and cropping, the exact quantity of rock dust that was incorporated at each pulverized site was not measured. However, a visual assessment indicated that all tested soils had similar size rocks and stoniness levels; for the Organic soil this suggested stones being brought to the soil surface from below the organic horizons when stumps were pulled at conversion. Pulverization on all tested cropland was completed between 2 weeks and 1 year before sampling (Table 1). Natural sites were forested. Managed sites were sown with oat and pea, garlic, cover crops (80% timothy hay, 15% red clover, 5% white clover) or were unmanaged pastures.

Experimental design and soil sampling

The study had two factors, soil type (Organic, Luvisol, or Podzol) and pulverization status (managed unpulverized, managed pulverized, or natural). Soil was collected across three sampling days in the first week of December of 2020, before any significant frost, from 13 sites, 10 managed and three natural. Of the managed sites, two were identified as Organic, two as Luvisol, and six as Podzol. For the natural sites, one was classified as Organic, one as Luvisol, and one as Podzol. For each soil type the managed pulverized, managed unpulverized, and natural test sites were adjacent to each other. Sites were irregular in shape and ranged in size from approximately 0.4 to 1 ha. Three replicate samples were collected from each site for a total of 39 samples for all analyses (Table 1).

Samples were collected using a soil knife from a depth of 0 to 15 cm. As nematode sampling requires unique sampling methods and more gentle handling, soil for nematode community analysis was collected separately. For nematode community analysis, three 10 $\times$ 10 m plots per site were randomly selected for sampling. From each plot, 50 soil knife cores (a total of 1950 cores across the 13 sites) were collected and composited to form one sample per plot. Soil samples for nematode analysis were placed undisturbed in 2 L plastic containers with air holes and stored at 4 °C until extraction 2 weeks later. For the physicochemical and respiration analyses, 10 additional soil cores were collected and composited per plot. The composite physicochemical/respiration samples were hand mixed, sieved through a 4 mm sieve in situ, and stored in bags at 4 °C until processed. Subsamples for the physicochemical and burst respiration tests were oven-dried at 40 °C for 2–3 days and further passed through a 2 mm sieve.

Analytical tests

The samples were analyzed for texture using the hydrometer method (Bouyoucos 1962), gravimetric soil water content (Topp et al. 2007), pH, and electrical conductivity (EC) using 1:2 soil to distilled water (Hendershot et al. 2007), and loss on ignition SOM using 10 g of oven-dried (105 °C) soil in a muffle furnace at 550 °C for 3 h (Ball 1964; Hoogsteen et al. 2015). Available soil cation concentrations were quantified in M3 extracts by inductively coupled plasma-optical emission spectrometry (ICP-OES). Given that available pools of P are dependent on land use and management in boreal soils (Kedir et al. 2021), we assessed the extractability of soil P using three extraction methods; citric acid (Dyer 1894), water extractable (Luscombe et al. 1979), and M3 (Mehlich 1984). The water extractable method measures readily available P, M3, and citric acid extracts mainly fixed P. The citric acid method closely mirrors P extraction from plant root environ-

Fig. 1. Examples of (A) unpulverized and (B) pulverized Podzols at the test farm at time of sampling; scale bar is approximate. [Colour online.]

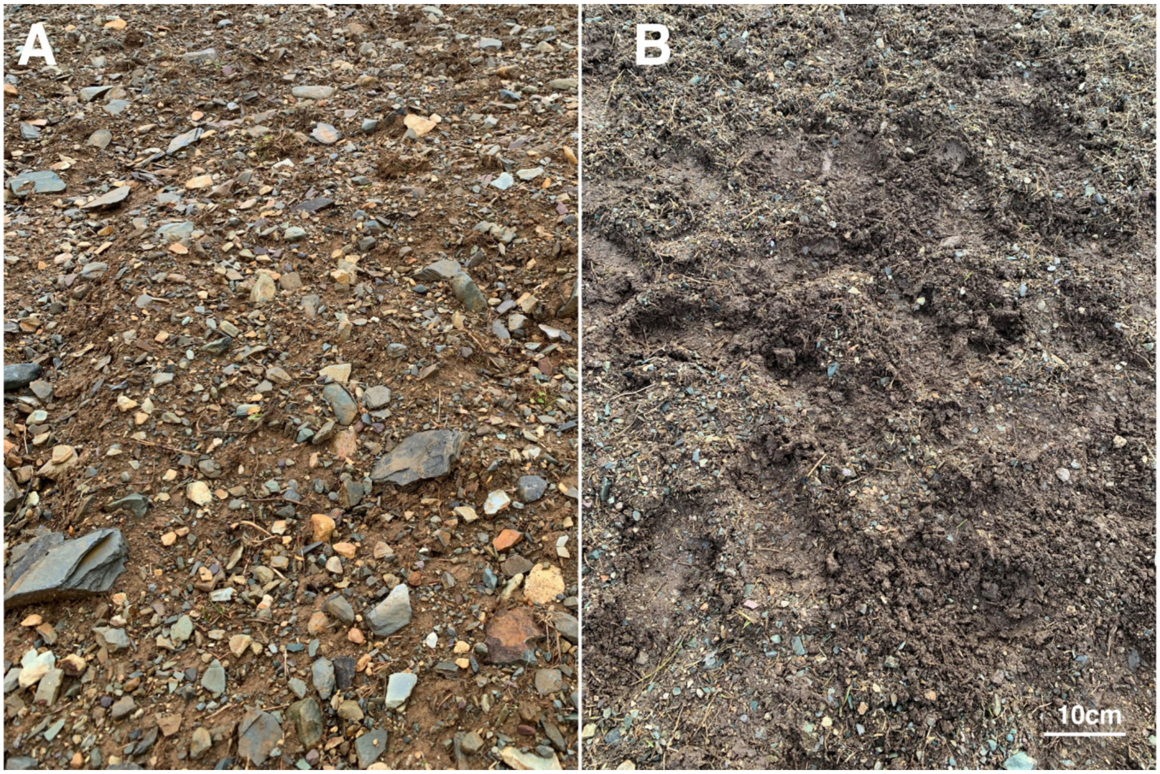


Table 1. Soil types and treatments at the study location

Soil type	No. of sites per soil type	Pulverization status (time between pulverization and sampling)	No. of samples collected (3 samples from each site)
Podzol	7	Unpulverized—managed	9
		Pulverized (1 month to 1 year)—managed	9
		Natural	3
Luvisol	3	Unpulverized—managed	3
		Pulverized (3 months)—managed	3
		Natural	3
Organic	3	Unpulverized—managed	3
		Pulverized (2 weeks)—managed	3
		Natural	3

Note: A total of 39 samples were collected for all analyses.

ments. Extracted P was analyzed using a standard colorimetric technique (Murphy and Riley 1962).

Nematode extraction and identification

Free-living nematodes were extracted from 175 g fresh soil aliquot using the Cobb method (Cobb 1918; Van Bezooijen 2006) followed by centrifugal floatation (Gooris and D'Herde 1972). Extracted nematode communities were preserved in 4% v/v formalin until counting and identification. Two to three 10% aliquots of the total extraction solution were used to count nematodes under 100× magnification. The first 150 individual nematodes in a subsample of the remaining solution were identified to trophic group using esophagus morphology under 400× magnification. For each sample, we measured total, bacterivore, fungivore, herbivore, omnivore, and predator abundances. Nematodes counts were expressed as absolute number of individuals per 100 g dry soil. The fungivore abundance:bacterivore abundance (FF/BF), fungivore abundance:fungivore+bacterivore abundance (FF/FF+BF), and fungivore abundance + bacterivore abundance/herbivore abundance ratios (FF+BF/PF) were calculated. FF/BF and FF/FF+BF identify the dominant decomposition pathway in terrestrial systems (slow, stable fungal vs. fast, ephemeral bacterial metabolism). These ratios can inform on qualitative changes in system functions caused by succession, physical disturbance, or nutrient enrichment, with higher ratios indicating more efficient functioning (Ruess and Ferris 2004). The FF+BF/PF indicates plant parasite feedback on the system with ratios greater than one indicating positive effects on productivity (Wasilewska 1997).

Respiration measurements

All sites are exposed to the same rainfall regime (as also observed during the sampling trips) and at sampling they were all at their soil texture-dependent field capacity for water (Saxton 1986). Solvita infrared CO_2 gas respirometers were used to measure both basal and burst respiration ex-situ (Brinton and Vallotton 2019). Basal respiration (CO_2–C) was measured on field-moist soil, burst respiration (CO_2–C) was analysed on air-dried soil rewetted to 50% water filled pore space (Brinton and Vallotton 2019). For both basal and burst respiration, independent 0–24, 24–48, and 48–72 h fractions were measured. Mean cumulative basal and burst respiration over 72 h were calculated (i.e., slope of 0–24, 0–48, and 0–72 fractions). Mean basal and burst CO_2–C rates of change were calculated as the slope of the linear fit for the three independent fractions (i.e., slope of 0–24, 24–48, and 48–72 fractions). Mean burst respiration represents the mean maximum potential respiration, while mean basal respiration represents the mean steady-state respiration. The rate of change of basal and burst respiration indicates the maximum potential or steady-state rate at which the 24 h respiration rates accelerated or decelerated over the 72 h of the tests providing information on rate of C loss. A negative value of respiration rate change indicates that the respiration rate decelerated over time. Basal respiration may best inform on average in situ conditions while burst respiration may inform on potential respiration if soils undergo a significant dry period followed by a rewetting event. Low respiration is indicative of a lack of accessible carbon to microbes and (or) an inactive microbial community while high respiration may indicate an abundance of accessible carbon (Janzen 2006).

Statistical analyses

Descriptive analyses were conducted for clay %, sand %, soil water content (SWC), SOM, pH, EC, citric acid P, water extractable P, M3-P, and M3-K, Fe, Al, calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn), zinc (Zn), boron (B), sodium (Na), sulfur (S); total bacterivore (BF), fungivore (FF), herbivore (PF), omnivore, predator nematode abundances; FF/BF, FF/FF+BF, FF+BF/PF, mean burst respiration, mean burst rate change, mean basal respiration, and mean basal rate change. As each pulverization factor level was present in each soil type, analyses of variance (ANOVAs) were performed for each parameter using pulverization status nested in soil type as a fixed factor for a total of nine treatments; post hoc Tukey's tests were used to compare means when residuals were Gaussian; $\alpha = 0.10$ was used for all analyses as a smaller alpha was not essential to make interpretations of the pulverization factor on our highly variable environmental data. When residuals were not normally distributed the parameters were log-transformed. If log transformation did not result in Gaussian ANOVA residuals, Kruskal–Wallis tests were performed followed by Dunn's tests for means comparison. Pairwise Pearson correlation matrices ($\alpha = 0.10$) were calculated (*i*) among soil properties, (*ii*) between functional parameters (nematode counts and respiration measures) and soil properties, and (*iii*) among functional parameters for all soils, for managed soils, and for natural soils. Only significant correlations with coefficients greater than 0.25 were considered. The trends between functional parameters (nematode counts and respiration measures), soil properties, soil type, and pulverization status were explored using canonical correspondence analysis (CCA) (Fig. 2). A path analysis based on hypothesized primary (SOM and pH) and secondary (Al, Fe, EC, and SWC) controls of the functional response parameters (nematode counts and respiration measures) regardless of soil type and pulverization status was generated using linear regression analyses on z-score transformed data. Only functional parameters that were significantly different between soil type and pulverization status treatments and linear regressions with R^2 greater than 0.25 (i.e., $r > 0.5$) were used in the path analysis. As soil conditions for the Organic and mineral soils (Luvisol and Podzol) were expected to vary, two sets of linear regressions, one for the Organic, one for mineral, were completed for the path analysis. First or second-degree polynomials curves were fitted for the path relationships. Linear regression analysis was employed to determine the relationships between nematode abundances and respiration parameters.

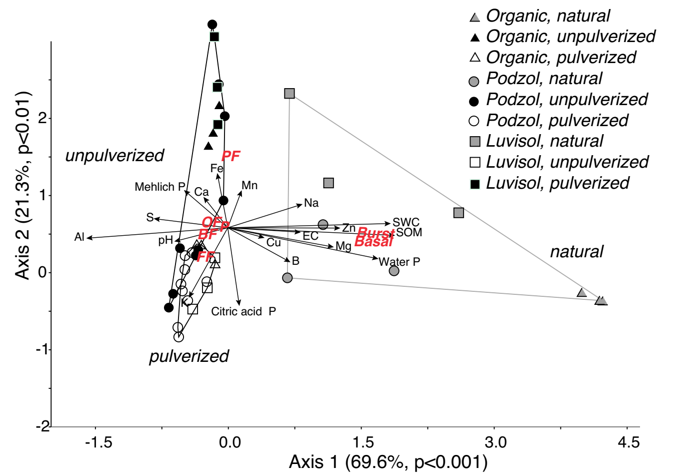


Fig. 2. Canonical correspondence analysis of the counts of bacterivore, fungivore, herbivore, omnivore, predator nematodes (per 100 g dry soil) and the mean basal and burst respiration (mg per kg dry soil) in relation to soil environmental variables plotted as vectors. 95% Convex hulls were calculated for pulverization status. Triangles, organic; squares, Luvisol; circles, Podzol. Gray, natural; black, unpulverized; white, pulverized. BF, bacterivore; FF, fungivore; PF, herbivore; OF, omnivore; P, predator; burst, burst respiration; basal, basal respiration. [Colour online.]

Results

Soil properties

Based on their texture, the mineral soils had clay, clay loam, sandy clay loam, or loam textures while the Organic soil was clay loam (Table 2). Pulverized Podzol was significantly sandier than unpulverized Podzol. For the Luvisol and Organic soil, soil particle size i.e., clay and sand did not differ significantly between pulverized and unpulverized treatments (Table 2). The pH ranged from acid to near neutral (4.0–6.9), which is typical for natural and managed boreal soils. Although there was no difference in pH between natural and managed Organic soil, pH was significantly higher for the managed Luvisol and Podzol than the natural equivalents, a result of limestone application. The pH was not statistically different between pulverized and unpulverized soils of any type (Table 2). SOM ranged from 5.4% to 72.9% (Table 2). SWC ranged from 17.6% to 89.3% directly related to the SOM values (Table S1). Thus, while SWC was significantly higher in natural Podzol than in pulverized Podzol, SWC did not significantly vary between natural and managed Organic soil or Luvisol. There was however a general trend of higher SOM and SWC in natural soils of all types than in the managed (Table 2). There were significant linear regressions between SOM and SWC, pH and M3 Fe, pH and M3 Al for both mineral and organic soil, SOM and EC for organic soil: pH mediates metal availability (M3 Fe and Al), EC mediates SOM, and SOM mediates SWC (Fig. 3 and Table S4). Though not measured here, EC alters plant growth and thus decomposition or organic matter accumulation in soils.

Citric acid P ranged from 0.1 to 144.4 mg kg^{-1} dry soil. Pulverization did not have a significant effect on citric acid P concentration for any soil type (Table 2). Water extractable P ranged from 0.2 to 34.7 mg kg^{-1} dry soil. Natural Organic soil and Luvisol had significantly more water extractable P than the managed equivalents (Table 2). Water extractable P was significantly lower in pulverized Podzol than unpulverized Podzol. There were no significant differences between unpulverized and pulverized water extractable P concentration in Organic soil and Luvisol (Table 2). M3-P concentrations ranged from 2.4 to 285.0 mg kg^{-1} dry soil. Natural Organic soil and Podzol had significantly less M3-P than the managed equivalents. There were no significant differences among pulverized and unpulverized Organic soil and Luvisol. The pulverized Podzol had significantly less M3-P concentration than the unpulverized Podzol (Table 2). For the Podzol and Luvisol, extractability of soil P was generally greatest with the citric acid method followed by M3 and then the water method. For the Organic soil, P extractability was generally greatest with M3 followed by citric acid and then the water method (Table 2).

The cation concentrations in natural Luvisol and natural Podzol were largely similar. Notably, M3-Fe was greatest in the natural Podzol (Table 2). Conversely, M3-cation concentrations were statistically different between the natural Organic soil and natural Luvisol apart from M3-K, MP3-Mn, MP3-Zn, MP3-Na, and MP3-S. Natural Organic soil and natural Podzol had comparable concentrations for M3-K, MP3-Mn, MP3-Zn, MP3-B, MP3-Na, and MP3-S (Table 2). Elemental differences with pulverization were greatest for the Podzol which had more M3-Ca and MP3-K than the unpulverized Podzol. Unpulverized Podzol had more M3-Cu and M3-Zn than the pulverized Podzol. The only measured elemental difference between unpulverized and pulverized Luvisol was for M3-Cu that was significantly higher in the pulverized soils. There were no statistical differences in the M3 cation concentrations between pulverized and unpulverized Organic soil (Table 2).

Functional parameters

Nematode counts and indices

Total nematode counts ranged from 39 to 4814 individuals per 100 g dry soil for all samples and did not vary significantly among natural soils (Table 3 and Fig. 4). Bacterivores dominated in all soil samples (Fig. 4) indicating dominant bacterial decomposition pathways. For the Organic soil and Luvisol, pulverization status did not lead to significant differences in total nematode or trophic group abundances. While there were significantly more total nematodes and herbivores in the unpulverized Podzol than in the pulverized Podzol, the bacterivore, fungivore, omnivore, and predator nematode abundances were not affected by the Podzol's pulverization status. The nematode indices, FF/BF, FF/(FF+BF), (FF+BF)/PF, did not vary significantly between pulverized and unpulverized status for any soil type (Table 3 and Fig. 4).

There were no statistically significant linear regressions between the soil properties and nematode trophic group abundances for the mineral soils (Fig. 3). For the Organic soil, there were significant negative linear regressions between SOM and bacterivore abundance and SOM and fungivore abundance. There were significant positive linear relationships between pH and bacterivore abundance, M3-Fe and bacterivore abundance, M3-Fe and fungivore abundance, M3-Fe and herbivore abundance, M3-Al and bacterivore abundance, M3-Al and fungivore abundance, and M3-Al and herbivore abundance (Fig. 3).

Respiration

Mean basal respiration ranged from 0.9 to 158.5 mg CO_2–C per kg dry soil per day while mean burst respiration ranged from 12.2 to 595.0 mg CO_2–C per kg dry soil per day (Table 3, Fig. 5). The natural soils did not differ significantly from the managed soils in terms of basal rate change for any soil type. Unpulverized Luvisol had larger negative burst respiration rate change and lower mean burst respiration than the natural Luvisol. While pulverized Luvisol respired less, most respiration occurred immediately after the start of the incubation suggesting less mineralizable but more labile organic matter. Mean burst respiration was greatest of all treatments in the natural Organic soil, albeit not significantly. Aside from mean burst respiration, the respiration parameters did not vary between pulverized and unpulverized treatments; Pulverized Podzol had significantly lower mean burst respiration than the unpulverized Podzol (Table 3 and Fig. 5).

For mineral soils, significant negative linear regressions were found between SOM and mean basal respiration, mean basal respiration rate change, mean burst respiration rate change (Fig. 3); pH and mean basal respiration, mean basal respiration rate change, and mean burst respiration; M3-Fe and mean basal respiration rate change; M3-Al and mean basal respiration rate change. Significant positive linear re-

Table 2. Mean soil properties among soil types and pulverization treatments.

Soil type	Management status	Clay (%)	Sand[a] (%)	SWC[a] (%)	SOM[a] (%)	pH	EC (μS/cm)[a]	Citric acid P[a] (mg kg^{-1} dry soil)	Water P[b] (mg kg^{-1} dry soil)	Mehlich-3 P[b] (mg kg^{-1} dry soil)
Organic	Natural	—	—	87.6a	71.7a	6.4abc	242.2a	83.9ab	33.2a	7.6cd
	Unpulverized	33.3ab	29.3a	35.2ab	13.4ab	6.8a	166.5ab	1.8a	4.1b	172.8a
	Pulverized	32.0ab	33ab	35.6ab	15.6ab	6.8a	165.7ab	3.8ab	3.8b	230.0a
Luvisol	Natural	—	—	65.7a	51.8a	4.1d	111.8ab	31.6ab	3.8bc	12.1cd
	Unpulverized	31.3ab	41.3ab	28.1ab	9.4ab	6.5abc	84.8ab	53.8ab	0.3de	5.5cd
	Pulverized	36.3a	34.7a	28.2ab	11.1ab	6.7ab	217.6a	89.8b	0.4de	26.3bc
Podzol	Natural	—	—	64.7a	26.9ab	4.3d	115.2ab	10.0ab	0.4de	3.5d
	Unpulverized	35.8a	27.2a	36.5ab	17.4ab	6.2bc	160.1ab	29.3ab	1.0cd	89.0ab
	Pulverized	28.2b	45.2b	21.8b	7.6b	6.1c	89.5b	82.9b	0.4e	16.7c

Soil type	Management status	Ca	Mg[b]	K[a]	Fe	Cu	Mn[a]	Zn[a]	B	Na	Al[a]	S
		mg kg^{-1} dry soil										
Organic	Natural	1119abc	858a	34.6abc	64.3d	2.0b	10.5a	22.2a	0.7a	24.0ab	0.7e	11.0cde
	Unpulverized	1778ab	463ab	26.0a	178.5bc	1.7bc	5.3a	5.1abc	0.4ab	18.1b	714ab	17.5ab
	Pulverized	1822a	424abc	33.9abc	186.9bc	1.7bc	6.9a	2.8abc	0.5ab	16.8b	862abc	17.7a
Luvisol	Natural	106e	104ef	44.1abc	176.4bc	0.8cd	3.4a	0.8abc	0.2b	35.9a	635abc	7.3e
	Unpulverized	800cd	185cdef	42.9abc	141.7bcd	0.9cd	7.8a	0.2bc	0.3b	18.3b	1306bc	11.8bcde
	Pulverized	1105bcd	326bcd	122.4bc	134.4bcd	3.1a	10.9a	3.5abc	0.5ab	23.7ab	1052abc	15.5abcd
Podzol	Natural	78e	77.4f	34.9abc	297.4a	0.9cd	5.7a	0.6abc	0.5ab	26.5ab	807abc	9.7de
	Unpulverized	1226bc	180.0de	34.2ac	143.7bc	1.4bc	13.1a	8.0ac	0.4b	24.1b	997abc	14.9abc
	Pulverized	569de	130.0ef	96.3b	113.0cd	0.8d	5.1a	0.3b	0.4b	16.3b	1312c	14.1abcd

Note: Soil cations are Mehlich-3 available concentrations. Letters represent post hoc Tukey's or Dunn's tests ($\alpha = 0.1$) for all treatments. See Table S6 for variances. SWC, soil water content; SOM, soil organic matter; EC, electrical conductivity; P, phosphorus; Ca, calcium; Mg, magnesium; K, potassium; Fe, iron; Cu, copper; Mn, manganese; Zn, zinc; B, boron; Na, sodium; Al, aluminium; S, sulfur.
[a]Kruskal–Wallis and Dunn's tests performed on unstandardized data.
[b]One-way analyses of variance (ANOVA) and Tukey's tests performed on log-transformed data.

Fig. 3. Path analysis for z-score standardized data: (A) main effects of the soil properties on the functional response variables; (B) indirect effects of pH on the functional response variables. The numbers on the arrows are linear regression slope coefficients: above the arrow (black) numbers are for mineral soils (Podzol and Luvisol) and under the arrow (red) numbers are for the Organic soil. Only response variables that were significantly different between soil type and pulverization factors as indicated by one-way analyses of variance (ANOVAs) or Kruskal–Wallis tests were used in path analysis (Table 3). Regressions slope coefficients with R^2 less than 0.25 were not included in diagram. $P \leq 0.10$, $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, and $^{***}P \leq 0.001$. Linear regressions between nematodes and respiration parameters not shown here, see Table S5. [Colour online.]

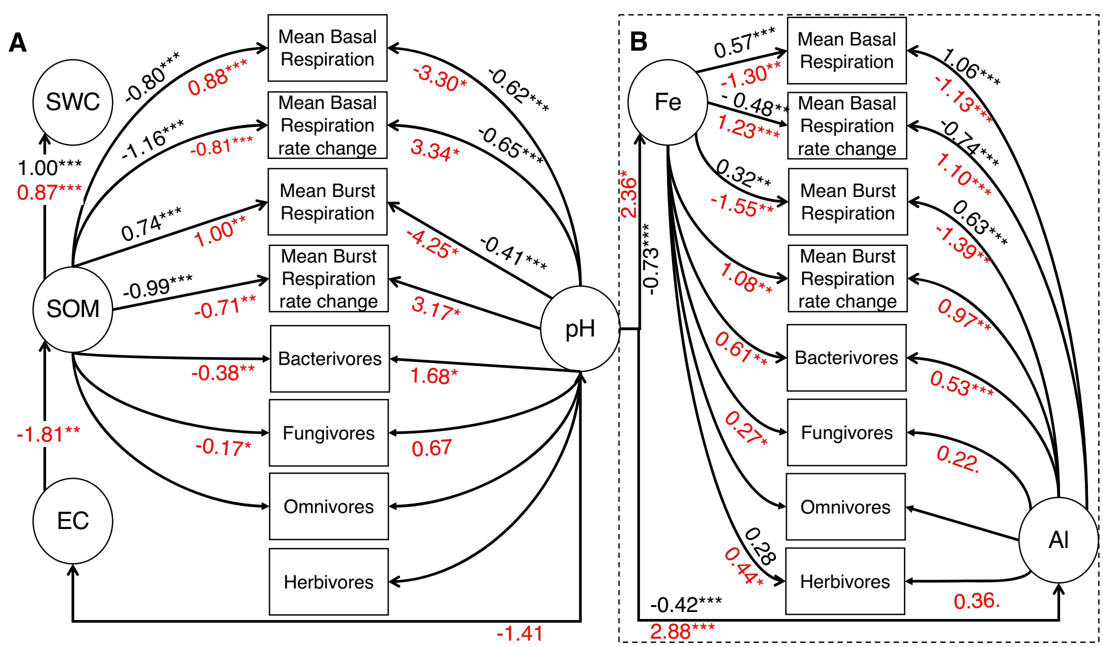


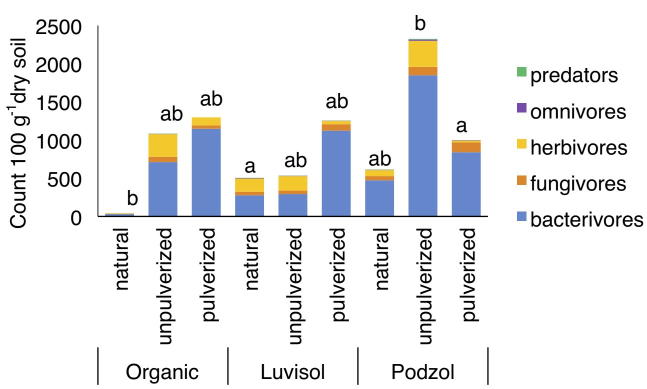
Table 3. Mean nematode counts and respiration parameters among soil types and pulverization treatments.

Soil type	Management status	Nematodes abundances (count 100 g dry soil^{-1})						Nematode indices		
		Total[a]	Bacterivores[a]	Fungivores[b]	Herbivores[b]	Omnivores[b]	Predators[a]	FF/BF[b]	FF/(FF+BF)[b]	(FF+BF)/PF[a]
Organic	Natural	42a	31a	1b	10cd	0b	1a	0.03a	0.03a	3.5ab
	Unpulverized	1085ab	712ab	68a	299a	2ab	5a	0.10a	0.09a	2.6ab
	Pulverized	1297ab	1148ab	44a	105abcd	0ab	0a	0.04a	0.04a	11.7ab
Luvisol	Natural	506a	277a	46a	173abc	6ab	3a	0.16a	0.14a	1.9a
	Unpulverized	536ab	293a	45a	190ab	4ab	4a	0.15a	0.13a	1.9a
	Pulverized	1256ab	1123ab	85a	41bcd	3ab	3a	0.07a	0.07a	20.8ab
Podzol	Natural	614ab	473ab	55a	78abcd	2ab	6a	0.12a	0.11a	8.0ab
	Unpulverized	2326b	1848b	110a	341a	16a	10a	0.05a	0.05a	29.9b
	Pulverized	999a	841ab	128a	25d	5ab	1a	0.11a	0.09a	46.0ab

Soil type	Management status	Soil respiration (mg CO_2–C kg dry soil^{-1} day^{-1})			
		Basal rate change[a]	Burst rate change[b]	mean Masal[a]	Mean burst[b]
Organic	Natural	−43.7a	−251.7a	141.2a	491.5a
	Unpulverized	−10.1ab	−66.3abc	12.2ab	71.4bcde
	Pulverized	−10.2ab	−70.0ab	44.2ab	61.5cde
Luvisol	Natural	−44.9a	−281.5a	71a	315.3ab
	Unpulverized	−7.1ab	−25.8bc	7.3ab	31.2de
	Pulverized	−17.0ab	−70.4ab	24.3ab	87.2bcd
Podzol	Natural	−25.1ab	−66.2abc	106.1a	223.8abc
	Unpulverized	−16.9ab	−57.3bc	20.8ab	102.2cd
	Pulverized	−6.7b	−19.8c	7.2b	29.3e

Note: Respiration rate change values are negative as they indicate the rate at which the 24 h respiration rates decelerated over the 72 h testing period. FF/BF, fungivore abundance:bacterivore abundance; FF/(FF+BF), fungivore abundance:fungivore + bacterivore abundance; (FF+BF)/PF, fungivore abundance + bacterivore abundance/herbivore abundance ratios. Letters represent post hoc Tukey's or Dunn's tests ($\alpha = 0.1$) for all treatments. See Table S6 for variances.
[a]Kruskal and Dunn's tests performed on unstandardized data.
[b]One-way ANOVA and Tukey's tests performed on log-transformed data.

Fig. 4. Nematode community composition for all soils ($n = 39$). Letters are post hoc Dunn's test results for total nematode abundances for combined soil type and pulverization status. Means that do not share a letter are significantly different at $\alpha = 0.10$. See Table S6 for variances. [Colour online.]

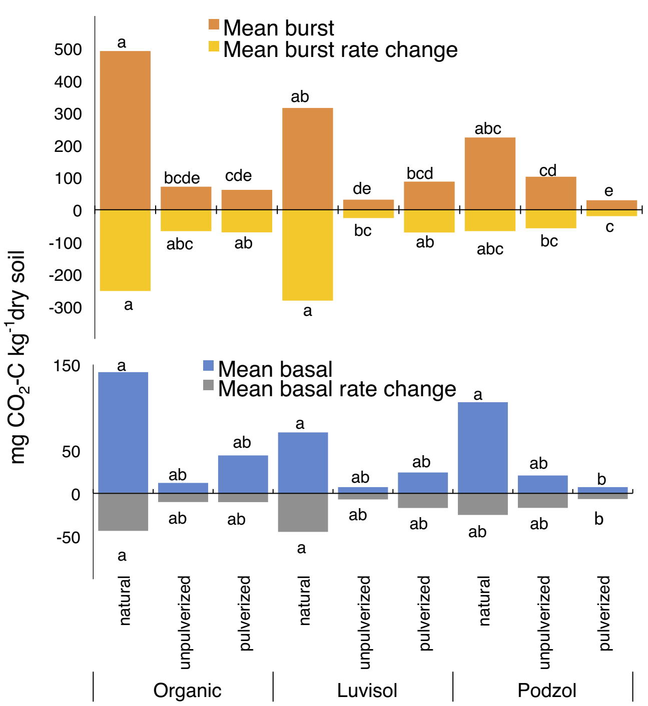


gressions were found between SOM and mean burst respiration, M3-Fe and mean basal respiration, M3-Fe and mean burst respiration, M3-Al and mean basal respiration, and mean burst respiration. For the organic soil, there were significant negative linear relationships between SOM and mean basal respiration rate change, mean burst respiration rate change; pH and mean basal respiration, mean burst respiration; M3-Fe and mean basal respiration, mean burst respiration; M3-Al and mean basal respiration, mean burst respiration. Significant positive linear relationships were noted between SOM and mean basal respiration, mean burst respiration; pH and mean basal respiration rate change, mean burst rate change; M3-Fe and mean basal respiration rate change, mean burst respiration rate change; M3-Al and mean basal respiration rate change, mean burst respiration rate change.

Relationship between the nematodes and respiration parameters

There were significant linear regressions between the following nematode abundances (predictor) and respiration parameters (response) in Organic soil only (Table S5): bacterivore abundance and mean basal respiration (slope coefficient: −1.71, $R^2 = 63.8\%$), fungivore abundance and mean basal respiration (−2.64, 49.3%), herbivore abundance and mean basal respiration (−1.91, 76.2%), bacterivore abundance and mean basal respiration rate change (1.76, 82.9%), fungivore abundance and mean basal respiration rate change (2.25, 44.3%), herbivore abundance and mean basal respiration rate change (1.48, 49.8%), bacterivore abundance and mean burst respiration (−2.18, 72.2%), fungivores and mean burst respiration (−2.82, 39.5%), herbivore abundance and mean burst respiration (−1.79, 46.4%), bacterivore abundance and mean basal respiration rate change (1.52, 61.1%), fungivore abundance and mean basal respiration rate change

Fig. 5. Mean respiration rate and average daily change in respiration rate over the three test days. Letters are post hoc Tukey's on log-transformed data (mean burst respiration and mean burst rate change) or Dunn (mean basal respiration and mean basal rate change) test results for combined soil type and pulverization status for basal and burst methods respectively. Means for each soil type that do not share a letter are significantly different at $\alpha = 0.10$. See Table S6 for variances. [Colour online.]



(1.97, 36.3%), and herbivores abundance and mean basal respiration rate change (1.31, 46.8%) (Table S5). No significant linear relationships between nematode abundances and respiration parameters were found for the mineral soil. The coefficients are in units of standard deviation, i.e., z-scores.

Soil properties, functional parameters, and pulverization status

The first two axes of a canonical correspondence analysis using all soil properties as environmental data and functional parameters (bacterivore, fungivore, herbivore, omnivore, and predator nematodes, average basal, and burst measurements) as response variables explained 90.9% of the variability of the data set (Fig. 2). There were clear distinctions between natural and managed soils with some overlap between the pulverized and unpulverized. Soil properties such as SOM, SWC, and water extractable P were closely clustered with, and thus larger for, the natural soils. M3-P, M3-Al, M3-S, M3-Ca, M3-Fe, M3-Mn, citric acid P, and pH were clustered with the managed soil. Notably, citric acid P was most closely associated with the pulverized managed treatment while M3-P, M3-Ca, M3-Fe, and M3-Mn were more associated with the unpulverized managed treatment. Mean basal and burst respiration measurements were strongly associated with the natural soils while the nematode trophic groups were associated with the managed soils (Fig. 2). Herbivores grouped closer to the unpulverized managed treatment and fungal feeders more with the pulverized managed. There were further distinctions between soils of different types within pulverization status, a trend most notable for the natural soil and less so for managed (Fig. 2).

Correlation analyses suggested that the relationships among soil properties and between the soil properties and functional parameters were distinct between natural and managed soil. For example, for natural soil, pH, and EC were strongly correlated, a trend surprisingly not seen in the managed soils. Similarly, the bacterivores were significantly negatively correlated to all soil properties aside from M3-P, M3-K, M3-B, M3-Na, and M3-S for managed soils but were not significantly related to any soil properties for the natural soils. Further, respiration measures were more correlated to each other in the managed than in the natural soil (Tables S2 and S3).

Discussion

Effect of pulverization status on soil properties

Palviainen et al. (2012) found that crushing and adding rock substrate to forest soils had only minor effects on soil properties and those effects were overcome by acidity in less than 10 years after application when the soils were analysed. In our survey the putative impact of pulverization on soil parameters, while slight, was still dependent on soil type with the greatest impact shown in the Podzol. Though time between pulverization and sampling was not consistent among soil types (2 weeks to 1 year) the varying impact of rock pulverization/dust incorporation with soil type is likely the result of different initial physicochemical parameters of the soils rather than the very short time since pulverization in our study. It may be presumed, considering that the rocks at our study site, slate and granite, have relatively slow dissolution rates (White and Brantley 2003) and that all soil samples were collected less than 1 year after pulverization, that the full effects of rock pulverization and subsequent dust incorporation were not yet fully quantifiable for any soil type. For example, in a column flow reactor study, Panola mountain granite ground to <2 mm had a reported dissolution rate of 7×10^{-18} mol cm^{-2} s^{-1} (White and Brantley 2003), a weathering rate that is surely several orders of magnitude faster than in situ (White and Brantley 2003; Renforth et al. 2015). Even fast weathering minerals such as olivine ($(Mg^{2+}, Fe^{2+})_2SiO_4$) have been estimated to take 1–5 years ($10^{-16.4}$ to $10^{-15.5}$ mol cm^{-2} s^{-1}) to ripen in soil when ground to 1 mm particle size and added to soil in columns (Renforth et al. 2015). Moreover, although a visual inspection of the sampling locations indicated that all test soils had similar stoniness, the sandier texture of the pulverized Podzol compared to unpulverized Podzol, a finding not found in the Luvisol or Organic soil, indicated that the Podzol likely received more incorporated rock dust than the soils of the other two types.

Our hypothesis that the impact of pulverization on soil properties would vary with soil type is supported. Nevertheless, we did not see the expected pH and M3-Fe increase with pulverization for any soil type, highlighting the need for longer-term studies that allow time for the minerals to weather in soil. M3-K did increase with pulverization only in the Podzol, indicating that the pulverized rock at the Podzol sites had greater M3-K than the rocks in the Organic soil and Luvisol sites or that the Podzol sites did receive more rock dust than the soils of other types. Regardless, this indicates that rock pulverization could be a source of K in managed boreal soils with similar parent materials; however, potassium plant uptake and use efficiency was not assessed here. Further, the significant positive correlation between sand% and M3-K and citric acid P (Table S1*b*) along with the general association of citric acid P and pulverization, while not statistically significant, might be a preliminary indication that pulverization makes K and P more freely available to plants.

Effect of pulverization on soil functional parameters

Rock pulverization had limited functional effects, altered carbon and nutrient dynamics as identified by the functional nematode and respiration parameters, but like the physicochemical parameters did show soil-type-dependent trends. The findings of lower nematode abundances and mean burst respiration in the pulverized Podzol do not support our hypothesis that physical disturbance of pulverization would stimulate microbial and nematode community growth. Instead, it seems that the alteration to physicochemical parameters caused by rock pulverization had a negative impact, at least over the short-term, on those soil functional parameters in the Podzol. Our prevailing theory is that the sandier texture induced by pulverization of the Podzol at our test location had a negative impact on total nematode abundance, herbivore abundance, and mean burst respiration evidenced by the significant negative correlations ($P < 0.01$) to sand% for all three parameters (Table S1*b*). Due to the few changes induced to the soil parameters for the Organic soil and Luvisol, rock pulverization did not have significant effects on the soil functional parameters. Additionally, since all three nematode indices were not significantly different among pulverization treatments for any soil type, soil pulverization less than 1 year prior to sampling did not substantially change the dominant decomposition pathways or productivity of our system, a novel finding in terms of boreal land use.

Effect of land use change on soil properties

Land use change produced greater and more consistent measurable shifts in soil properties than subsequent management, the impact of which varied with soil type. The clear distinction between natural and managed soil but less obvious dissimilarity between pulverized and unpulverized soil indicate that for all three soils long-term management and associated practices, such as tillage, cropping, fertilizer, and limestone incorporation, likely rendered the managed soils more physiochemically homogeneous than under natural conditions at our test location.

Like reported alterations to soil hydrology and carbon dynamics in lands that have been converted from forest to agricultural use (Kurz et al. 2013; Altdorff et al. 2017), there was a tendency for more SOM and associated SWC in the natural soils of our study than the managed for all soil types, though not statistically significant. The clear cutting and removal of organic soil horizons during conversion along with draining of wet fields as seen here reduce soil carbon stocks and alter soil water dynamics. Additionally, the pH of managed soils was greater than the natural equivalents for the acidic Luvisol and Podzol as boreal and Arctic soils must be amended with limestone to sustain crops.

Water extractable P was greater in the natural soils than managed while M3-P was greater at the managed sites than natural, likely an effect of the removal of the organic layer of soil (Hilli et al. 2008; Hensgens et al. 2020) suggesting that P was more soluble in the natural soils and less so in the managed. Supporting this, M3-P was significantly positively correlated with pH and water extractable P was significantly positively correlated with SOM and SWC (Table S1*b*).

Effect of land use change on soil functional parameters

Free-living nematodes, especially the dominant opportunistic bacterivores, tend to increase in abundance with agricultural nutrient enrichment resulting from regular disturbance and fertilizer inputs (Ferris et al. 2001; Puissant et al. 2021), a similar outcome to the present study where the proportional abundance of all nematode trophic groups increased with management. Yet, it was unexpected that at our study location fungal feeders were not more closely clustered with natural soils; as they are often associated with complex SOM, fungal-dominated communities are often found in boreal coniferous forests (Matlack 2001). For instance, the managed Organic soil had significantly more fungivores than natural Organic soil (Table 2). While there was a trend of higher SWC in the natural than managed Organic soil (i.e., mean = 88% vs. 35% respectively), this had likely not affected the water activity status as, according to their textural mix (Saxton 1986), the managed Organic soil had water at or above the field capacity for water. Fungivores might have been inhibited in the natural Organic soil that have near surface water tables and are regularly waterlogged, albeit not at sampling. Alternatively, the significant positive regression between fungivores' abundance and M3-Al, a parameter associated with management, in the Organic soil, is a potential explanation for which the possible mechanisms behind the association are discussed below. Unlike nematodes, the respiration parameters were heavily driven by SOM, a parameter highly reduced with conversion from forest to agricultural use in boreal regions, and as such were closely associated with SOM and proportionally increased in the natural soils.

Still, fungivore abundance and mean burst respiration, the maximum potential respiration, were the only functional parameters that were significantly influenced by land use change (i.e., differed between natural and managed treatments) and only for the Organic soil. Even with land conversion from forest to agricultural use as recent as 5 years before sampling, there were no quantifiable differences in soil functions in terms of putative energy and matter flow between natural and managed soils as indicated by the stability of the nematode indices.

Relationship between the soil properties and functional parameters

Primary controls of the functional parameters were hypothesized and statistically supported to be pH and SOM, with lesser impacts of M3-Al and Fe. As soil pH is the key physicochemical microbial control at regional and local scales (Fierer and Jackson 2006), it was anticipated that the respiration parameters would be most affected by pH and less so by SOM. This trend was true in the organic soil with steeper slope coefficients between pH and respiration than between respiration and SOM but did not apply to the mineral soil. The respiration parameters were more strongly affected by SOM than pH in the mineral soil, a reflection of the generally lower quantity of SOM and associated limiting effects in the mineral soils than in the Organic. Nonetheless significant linear regressions were found between both SOM and pH for all measures of respiration for all soils, except for pH and mean burst rate change in the mineral soil. SOM and pH were less predictive of the nematode abundances than the respiration parameters with significant relationships only between the soil properties and microbivorous nematodes (bacterivores and fungivores) in Organic soil. As pH was a positive predictor of bacterivore abundance and a negative predictor of mean respiration (basal and burst) for the Organic soil, it may be hypothesised that increased pH indirectly reduces soil respiration but supports bacterivore abundance and accompanying grazing of the microbial biomass; this is a possible signal of increased C utilisation efficiency, i.e., C assimilated in the food web instead of respired. Supporting this is the negative relationship between the bacterivorous nematode abundance and respiration parameters. Like microbes, microbial feeding nematodes have been previously reported to be positively correlated to SOM due to increased carbon resource availability (Yeates et al. 1998; Ruess et al. 2002). However, in our study, bacterivores and fungivores had a negative relationship with SOM in the Organic soil. This may be the indirect result of high SOM in the natural Organic soil and the close link between SOM and SWC that was at field capacity (Fig. 3). More SOM implies higher SWC and possible negative effects of high SWC on the aerobic nematodes.

Al and Fe in soluble forms are known toxicants of free-living nematodes (Williams and Dusenbery 1990; Höss et al. 2015) so the positive relationships between M3-soil metals and nematode parameters in Organic soil are surprising. One may speculate that Mehlich-3 extraction of cations, as employed here and as commonly employed for agricultural soils in the region, is not a useful descriptor of the bioavailability of Al and Fe and that water soluble forms might be more informative (Shao et al. 2012). On the other hand, while many nematodes, particularly late successional groups such as omnivores and predators, are known to be sensitive to metal contaminants (Bongers and Bongers 1998), nematodes have been documented to develop tolerances to metal pollution (Ekschmitt and Korthals 2006). This however does not explain why nematode abundance and M3- metals are positively linked. It is possible that relationships between M3-Al, M3-Fe and soil properties not measured here, such as diverse functional carbon pools (Borůvka et al. 2009), indirectly stimulate certain nematode trophic group abundances. A field study in acidic forested soils also showed that water soluble and total Al were linked to negative impacts on soil nematode assemblages but those impacts were overshadowed by soil enrichment and the relationships between nematodes and overlying vegetation (Shao et al. 2012). Otherwise, Fe and Al oxide status in soil reflects degree of soil oxygenation and consequently water saturation of the Organic soil. The positive regression between nematode trophic abundances and soil metals may simply infer that less anoxic conditions (i.e., more oxygen available to oxidize Fe and Al) support nematodes.

Relationship between free-living nematode abundances and microbial respiration

The strongest relationships between the nematodes and respiration measures were found in the Organic soil: (*i*) bacterivore abundance and mean basal respiration rate change, (*ii*) herbivore abundance and mean basal respiration, (*iii*) bacterivore abundance and mean burst respiration, (*iv*) bacterivore abundance and mean basal respiration, and (*v*) bacterivore abundance and mean burst respiration rate change. Bacterivore grazing likely stimulated the steady-state and maximum potential respiration rate change (mean basal respiration rate change and mean burst respiration rate change), reduced average maximum potential respiration (mean burst respiration), and reduced average steady-state respiration (mean basal respiration). While studies have reported that moderate levels of nematode grazing can promote microbial growth (Ingham et al. 1985; Fu et al. 2005; Jiang et al. 2017) our findings are in line with a meta-review that found the global impact of nematode and protist grazing reduced microbial biomass and bacterial abundance by 16% and 17%, respectively (Trap et al. 2016). These relationships support a top-down association between the bacterivores and their resources and attest that those physicochemical parameters that influence bacterivore abundance (e.g., pH) ultimately influence the microbes. Likewise, for the Organic soil only, nematode herbivory was linked to decreased average steady-state respiration (mean basal respiration), a possible result of herbivory diminishing resources for microbes in the food web. It is unknown why significant trends were not found in the mineral soils.

Conclusions

Our study did not find major alterations to soil properties or functional parameters that could be linked to rock pulverization. Soil differences between natural and managed were orders of magnitude greater than those between pulverized and unpulverized indicating that land use change had a greater impact on soil properties than recent rock pulverization. Even so, the influence of both rock pulverization and land use change on the functional parameters is relatively small. It is evident that the impacts of rock pulverization and land conversion from forest to agriculture are soil-type-dependent, and the full effects of dust amendment may not be quantifiable until many years after incorporation, a possibility that could not be determined within the scope of our study. Our current data suggests that rock pulverization in boreal and Arctic agriculture is most valuable in terms of soil workability rather than soil enrichment. Irrespective of soil type and management, the direct and indirect effects of pH and SOM were essential drivers of basal and burst respiration for all soils and for nematode community composition in the Organic soil. Future inquiries should examine the long-term impacts of pulverization and associated mineral dust application on functional parameters from a variety of parent materials in boreal and Arctic agricultural soils.

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Data availability

Data generated and analyzed during this study are available from the corresponding author upon request.

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Figure 1 images: JDV

Competing interests

The authors declare there are no competing interests.

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Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/cjss-2022-0007.

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