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Quantitative Characterization of Field-estimated Soil Nutrient Regimes in the Subalpine Interior Forest

Introduction

Site classification of the biogeoclimatic ecosystem classification system is based on climatic regime (expressed by biogeoclimatic subzone), soil moisture regime (SMR), and soil nutrient regime (SNR). A SNR represents a segment of a regional soil nutrient gradient, *i.e.*, a population of soils which provide similar levels of plant-available nutrients over a long period. SNR is identified in the field using a number of easily observable soil morphological properties and indicator plant species. However, we do not know the extent to which soil nutrient properties are supported by these indirect field-estimates. There have been several studies that quantitatively characterized regional soil nutrient gradients in different climatic regions (see *Sciencia Silvica* Number 21 for subalpine coastal forests), but this has not been done in the subalpine interior forest (Engelmann Spruce - Subalpine Fir (ESSF) zone) where soils are influenced by a continental subalpine boreal climate. In the study summarized here, relationships between soil chemical properties and field-estimated SNRs are examined and soil chemical properties and field-identified SNRs are related to the site index of subalpine fir (*Abies lasiocarpa* (Dougl. ex Loud.) Forbes) and Engelmann spruce (*Picea engelmannii* Parry ex Engelmann) - two major timber crop species in the ESSF zone.

Study Stands and Procedure

Study stands were selected across the ESSF zone of British Columbia. The study stands were deliberately selected across the widest range of climate, soil moisture, and soil nutrient conditions, and were all naturally regenerated, unmanaged, relatively even-aged, fully stocked, and in the stem exclusion stage of stand development (ranging from 40 to 200 years at breast height). The SNR of each stand was estimated using an heuristic procedure that integrates a number of easily observable soil morphological properties and indicator plants. Site index (m @ 50 yr bh) for each plot was obtained from stem analysis (see *Scientia Silvica* Number 23).

In each of the 155 study stands, a 0.04 ha plot was established and a composite sample was taken of the entire forest floor and the first 30 cm of the mineral soil from 15 randomly selected points. The samples were air-dried, prepared for chemical analysis, and analyzed for the following nutrient properties: pH, total C (tC), total N (tN), mineralizable-N (min-N), and extractable Ca (eCa), Mg (eMg), K (eK), P (eP), and S (eSO_4-S). All properties were expressed as concentration on a dry mass basis. To describe the quality of organic matter and N-availability, C:N and min-N:tN ratios were calculated.

Samples were stratified into five SNR classes by two methods: (1) a qualitative method, using the heuristically derived field-estimates, and (2) a quantitative method, using the soil chemical analysis. The agreement between the two methods was determined by discriminant analysis. Site index - SNR relationships were examined by multiple regression. Considering the wide geographical range and steep local climatic gradient, regressions included elevation, latitude, and longitude as independent variables.

Results and Discussion

The five field-estimated (qualitative) SNRs were similar to the five soil chemical derived SNRs (Table 1, Figure 1 and Figure 2). Soil nutrient properties varied along the regional soil nutrient gradient, but the differences were more pronounced in the mineral soil than in the forest floor. In forest floor, pH, total N, min-N, min-N:tN ratio, and sum of eCa, eMg, and eK increased, and the C:N ratio decreased from very poor to very rich sites; however, other properties did not show any consistent relationship with the field-identified SNR. In the mineral soil, total N, min-N, and min-N:tN ratio increased, and the C:N ratio decreased from very poor through very rich sites, indicating the presence of a steep, N-driven nutrient gradient. pH, tC, and sum of eCa, eMg, and eK also increased from poor through rich sites.

Table 1. Means and ± standard errors of the mean for measured forest floor and 0 - 30 cm mineral soil nutrient properties according to quantitatively classified groups. Values in the same row with same superscript are not significantly different ($p > 0.05$); variables without superscripts are not significantly different.

Class	A	B	C	D	E
Number of stands	18	47	48	36	6
Forest floor					
pH	4.2±0.1^{c}	4.4±0.1^{bc}	4.5±0.1^{b}	4.9±0.1^{a}	5.1±0.3^{a}
Total C (g kg^{-1})	47.3±2.0	44.1±1.2	45.7±0.9	42.9±1.1	43.1±2.5
Total N (g kg^{-1})	1.08±0.05^{c}	1.28±0.04^{b}	1.47±0.05^{ab}	1.47±0.06^{ab}	1.57±0.09^{a}
C:N ratio	44.4±1.7^{a}	34.5±0.5^{b}	31.9±0.8^{c}	30.2±1.0^{cd}	28.1±3.2^{d}
Mineralizable-N (mg kg^{-1})	289±54^{c}	448±43^{b}	603±43^{a}	512±40^{ab}	553±49^{ab}
Min-N:total N ratio	0.26±0.03^{c}	0.33±0.03^{b}	0.39±0.02^{a}	0.34±0.02^{ab}	0.35±0.03^{ab}
Extractable P (mg kg^{-1})	158±17^{ab}	210±15^{a}	121±12^{b}	88±9^{c}	92±33^{bc}
Extractable SO_4-S (mg kg^{-1})	36.1±7.4	32.6±2.1	42.0±4.2	38.7±2.8	44.2±4.0
Sum of extractable Ca, Mg, and K (g kg^{-1})	4.1±0.8^{c}	4.5±0.3^{c}	5.7±0.4^{b}	8.6±0.8^{a}	9.3±1.8^{a}
Mineral soil					
pH	4.9±0.1^{b}	4.9±0.1^{b}	5.2±0.1^{ab}	5.7±0.1^{a}	5.5±0.1^{a}
Total C (g kg^{-1})	3.0±0.5^{c}	3.0±0.2^{c}	3.3±0.2^{c}	4.5±0.5^{b}	6.5±0.7^{a}
Total N (g kg^{-1})	0.08±0.01	0.12±0.01	0.17±0.01	0.29±0.02	0.41±0.04
C:N ratio	27.0±1.2	22.8±0.6	20.2±0.5	18.3±0.9	16.2±1.2
Mineralizable-N (mg kg^{-1})	3.8±1.2^{d}	9.5±0.9^{d}	18.9±1.4^{c}	54.1±3.2^{b}	115.4±15.3^{a}
Min-N:total N ratio	0.05±0.01^{e}	0.08±0.01^{d}	0.12±0.01^{c}	0.20±0.01^{b}	0.29±0.04^{a}
Extractable P (mg kg^{-1})	45.4±5.9^{a}	47.4±5.4^{a}	18.3±3.4^{b}	8.4±2.2^{c}	4.8±1.1^{c}
Extractable SO_4-S (mg kg^{-1})	8.5±1.6	7.4±0.9	14.0±2.0	8.4±1.3	7.2±1.4
Sum of extractable Ca, Mg, and K (g kg^{-1})	0.3±0.1^{c}	0.4±0.1^{c}	0.9±0.2^{b}	4.4±1.4^{a}	3.1±0.7^{a}

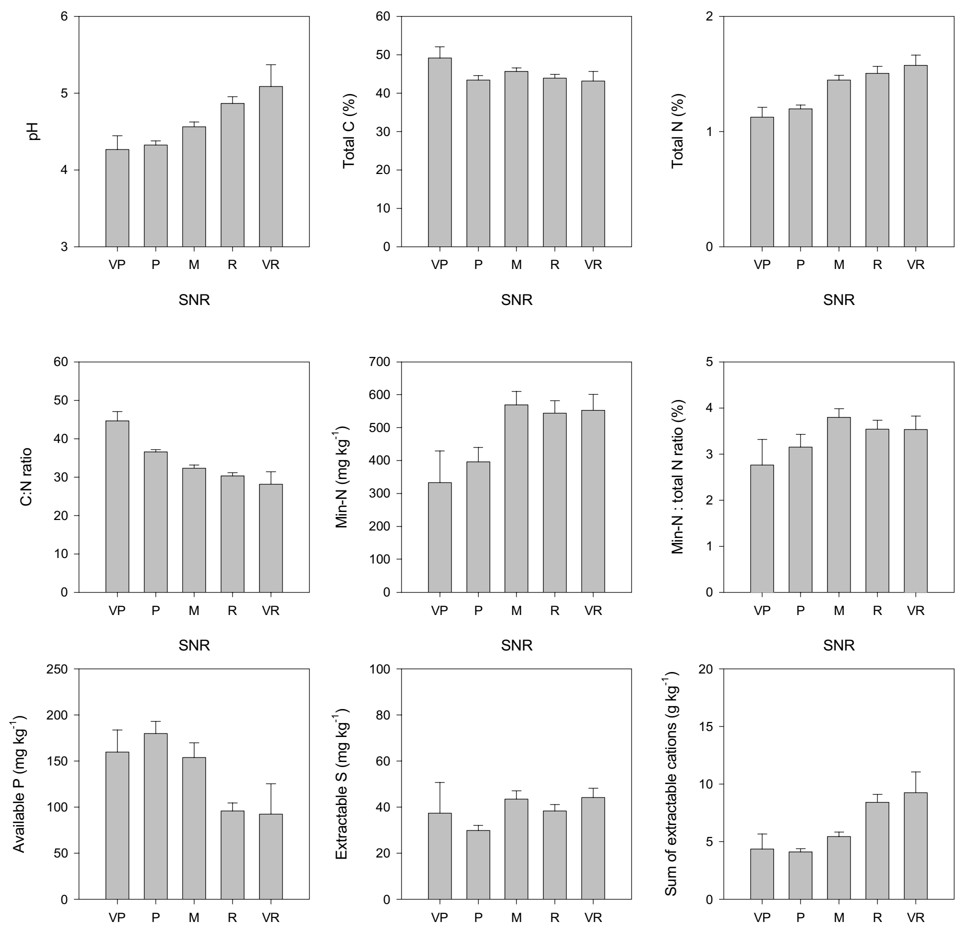

Figure 1. Direct measures of forest floor nutrient properties stratified according to field-estimated SNRs. Error bar is one standard error of the mean. VP, P, M., R, and VR are very poor, poor, medium, rich , and very rich, respectively.

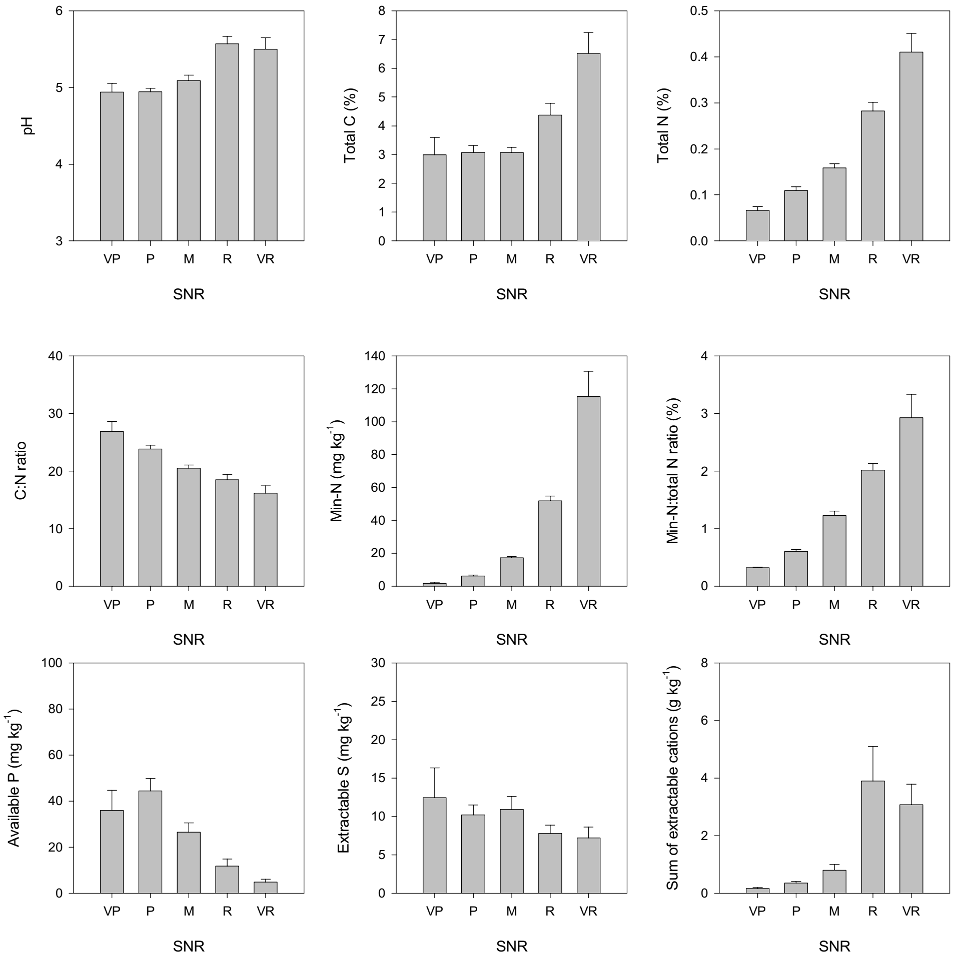

Figure 2. Direct measures of mineral soil nutrient properties stratified according to field-estimated SNRs. Error bar is one standard error of the mean. VP, P, M, R, and VR are very poor, poor, medium, rich , and very rich, respectively.

Comparison of the quantitative and qualitative methods showed that 111 (71.6%) of the sampled sites fell into the same SNR, 40 (25.8%) samples fell to the adjacent SNR, and 4 (2.6%) samples were apart by two or more SNR classes. There was no discrepancy between very rich SNR, however, there were discrepancies between the other SNR classes. For example, of the 52 sites that were field-estimated as having medium SNR, approximately 40% were placed by multivariate analysis into poorer (A or B) or richer (D) classes, indicating a disagreement between the qualitative and quantitative methods. Further, of the 48 sites classified by multivariate analysis into class C (medium SNR), approximately 30% were estimated in the field as having very poor, poor, or rich SNRs.

Three types of linear regression models were developed for each study species: (1) the SNR model using field-identified SNRs as dummy variables (Equations [1] and [4]), (2) the model using classes derived from multivariate analysis as dummy variables (Equations [2] and [5]), and (3) the analytical model using direct measures of soil nutrient properties as continuous variables (Equations [3] and [6]) (Table 2). All models were significant ($p < 0.001$) and indicated the presence of strong relationships between site index and climatic and soil nutrient variables. As expected, site index decreased with increasing elevation, latitude, and longitude, and increased with increasing levels of plant-available soil nutrients.

Regardless of study species, the correlation between site index and independent variables determined by each model was quite similar. The SNR models had somewhat stronger relationships with site index than the class models (adjusted R^2 ranged from 0.41 to 0.52 for the SNR models compared to 0.41 to 0.47 for the class models); however, the analytical models had the strongest relationships compared to the SNR and class models (adjusted R^2 ranged from 0.47 to 0.65) (Table 2).

Table 2. Models for the regression of subalpine fir and Engelmann spruce site index (SI) on categorical continuous soil nutrient variables. Abbreviations used are: ELE - elevation (m); LAT - N latitude (degrees and minutes in metric); LONG - W longitude (degrees and minutes in metric); P - poor, M - medium, R - rich, and VR - very rich are qualitative SNRs (based on field observable soil morphological properties); A - class A, B - class B, C - class C, D - class D, and E - class E are quantitative SNRs (based on direct soil nutrient measures and multivariate analysis); ff - forest floor property, ms - mineral soil property; tN - total N (g/kg); eSO_4-S - extractable SO_4-S (mg/kg); pH - acidity; C:N - C:N ratio; SEB = sum of extractable Ca, Mg, and K (mg/kg).

Regression model	Adjusted R^2	SEE	p	n
Subalpine fir				
[1] SI = 145.9 – 0.013(ELE) – 0.858(LAT) – 0.705(LONG) + 1.643(P) + 3.7(M) + 2.577(R) + 5.13(VR)	0.41	3.44	<0.001	101
[2] SI = 145.9 – 0.013(ELE) – 0.858(LAT) – 0.705(LONG) + 1.643(B) + 3.7(C) + 2.577(D) + 5.13(E)	0.41	3.44	<0.001	101
[3] SI = 125.2 – 0.011(ELE) – 0.927(LONG) + 4.877(tNff) – 0.057(eSO_4-Sms) + 2.192(pHms) – 0.206(SEB)	0.47	3.26	<0.001	101
Engelmann Spruce				
[4] SI = 183. 8 – 0.019(ELE) – 1.147(LAT) – 0.705(LONG) + 3.26(M) + 0.71(R) + 1.94(VR)	0.52	3.04	<0.001	52
[5] SI = 174.0 – 0.018(ELE) – 1.205(LAT) – 0.629(LONG) + 4.261(B) + 4.565(C) + 2.52(D) + 3.947(E)	0.47	3.19	<0.001	52
[6] SI = 249.9 – 0.021(ELE) – 1.063(LAT) – 1.182(LONG) – 0.368(C/Nff) + 0.213(C/Nms) 0.078(eSO_4-Sms) – 0.495(SEBms)	0.65	2.58	<0.001	52

Conclusions

Nitrogen related variables (C:N, total N, mineralizable -N, and mineralizable-N:total N) in the mineral soil were the nutrient properties that segregated best among soil nutrient regimes of both qualitative and quantitative methods for subalpine boreal soils. However, assignment of the study sites into one of the five soil nutrient regimes varied between the methods. Regardless of these differences, both qualitatively and quantitatively derived soil nutrient regimes had a similar accountability for the variation of site index of subalpine fir and Engelmann spruce. This similarity justifies the use of the quantitative methods in estimating the ecological quality of forest sites in the subalpine interior forest.

References

Chen, H.Y.H., Klinka, K., J. Fons, and P.V. Krestov. 1998. Characterization of nutrient regimes in some continental subalpine boreal soils. Can. J. Soil Sci. 78: 467-475.

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