Forest Science and Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tfst20

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To cite this article: Gyeongwon Baek , Eun Ji Bae & Choonsig Kim (2020): Nutrient stocks of Japanese blue oak (*Quercus glauca* Thunb.) stands on different soil parent materials, Forest Science and Technology, DOI: 10.1080/21580103.2020.1822924

To link to this article: https://doi.org/10.1080/21580103.2020.1822924

FOREST SCIENCE AND TECHNOLOGY
https://doi.org/10.1080/21580103.2020.1822924

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Nutrient stocks of Japanese blue oak (*Quercus glauca* Thunb.) stands on different soil parent materials

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ABSTRACT

Soil parent materials originating from different geologic settings represented broad differences in the forest nutrient environment, but few studies have been conducted on the relationships between soil parent materials and nutrient stocks in forest stands. This study was performed to compare the nutrient stocks of Japanese blue oak (*Quercus glauca* Thunb.) stands grown on forest soils inherited from two different parent materials, basalt and sandstone, in southern Korea. A total of 29 Japanese blue oak trees were destructively sampled (15 trees on basalt and 14 trees on sandstone) to compare the nutrient content of the tree components (stem wood, stem bark, branches, and leaves). Samples of the forest floor and a soil depth of 0–30 cm were collected to measure the nutrient stocks of the two parent materials. The mean nutrient concentrations of the tree components varied significantly between the basalt and sandstone parent materials. The mean carbon and potassium concentrations of stem wood were significantly higher in sandstone than in basalt, whereas the nitrogen concentration of stem wood and stem bark were lower in sandstone than in basalt ($p < .05$). A significantly higher carbon, nitrogen, potassium, and magnesium stocks of the forest floor were found in sandstone than in basalt. However, the soil carbon, nitrogen, calcium, and magnesium stocks at a depth of 0–30 cm were significantly higher in basalt than in sandstone. The results demonstrate that the aboveground nutrient concentration and belowground nutrient stocks of Japanese blue oak stands can be altered greatly by different parent materials.

ARTICLE HISTORY
Received 5 July 2020
Accepted 8 September 2020

KEYWORDS
Evergreen broadleaved forests; forest soils; nutrient cycling; nutrient concentration; nutrient storage; subtropical forests

Introduction

Soil parent materials originating from different geologic settings represent broad differences in the forest nutrient environment in forest ecosystems (Hahm et al. 2014; Kumbasli et al. 2017; Marek and Richardson 2020). The growth rates of individual trees and forest productivity can be attributed to parent materials inherited from different rocks because the mineral compositions of rocks strongly influence soil physical and chemical properties (Neff et al. 2006; Abella and Springer 2008; Leonard et al. 2015). Thus, tree growth and forest productivity in forest ecosystems appear to be directly or indirectly related to soil parent materials, which constitute the primary sources of plant nutrients (White et al. 2012; Augusto et al. 2017; Christophe et al. 2017; Marek and Richardson 2020). For example, the growth and mortality rates of the Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, have been affected by different parent materials originating from different rocks (Shen et al. 2001). Furthermore, the mortality of western white pine (*Pinus monticola* Dougl. Ex D. Don) and Douglas-fir was higher in forests at sites over parent materials originating from meta-sedimentary rocks than on in those over parent materials originating from igneous rocks inland of Northwest, USA (Moore et al. 2004).

The nutrient stocks of forest stands play a key role in assessing the potential impacts of sustainable forest management and biogeochemical cycles in forest ecosystems (Leuschner et al. 2006; Neff et al. 2006; Augusto et al. 2008; Kim, Baek, et al. 2019). Thus, soils derived from different parent materials may influence tree growth and nutrient stocks differently due to difference in reservoirs of inorganic nutrients and the release rates of soil nutrients (Vestin et al. 2013; Christophe et al. 2017). However, few studies have explored the relationships between parent materials inherited from different rocks and nutrient stocks in forest stands (White et al. 2012; Vestin et al. 2013).

The Japanese blue oak (*Quercus glauca* Thunb.) is distributed in a broad range of sites in the subtropical forests of Korea (Han et al. 2018; Kim, Kim, et al. 2019). Thus, this tree species was used to determine whether parent materials originating from different rock types could explain variations in the nutrient

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stocks of tree biomass, forest floor, and mineral soils. The aims of this study were to determine differences in the nutrient stocks of Japanese blue oak stands grown on parent materials inherited from different rock types. We hypothesized that the parent material types may affect the nutrient stocks of the Japanese blue oak stands.

Material and methods

Study site

The study was conducted in Japanese blue oak stands grown on parent materials originating from two different rocks (basalt and sandstone) in the subtropical forest zone of southern Korea. The study sites were located in Jeju-do (basalt) and Goseong-gun (sandstone) (Figure 1). The mean annual precipitation and temperature are higher in Jeju-do (1923 mm and 16.6 °C, respectively) with basalt parent materials than in Goseong-gun (1450 mm and 14.7 °C, respectively) with sandstone parent materials. The soils in Jeju-do are well-drained, highly fertile volcanic ash forest soils (Andisols, USDA Soil Taxonomy) originating from basalt with a loamy texture, whereas the soils in Goseong-gun are a dark reddish-brown forest soil of medium fertility (mostly Inceptisols, USDA Soil Taxonomy) originating from sandstone with a silty loam texture. Both study sites were composed of residual parent materials.

Nutrient content of tree components

The experimental design consisted of three 20 m × 20 m plots within each site. Five diameter classes based on DBH ranges were established for each site, and sample trees were randomly selected from each DBH class. To measure the nutrient concentrations of the tree components, 14 trees from sandstone and 15 trees from basalt (total, 29 trees), representing the DBH range of the stands were destructively sampled in late April and early July 2015, respectively. The trees were separated into tree components (i.e. leaves, branches, stem bark, and stem wood). The fresh weight of all the tree components was determined in the field by using portable electronic balances. All the investigations were performed in accordance with the technical standards of biomass measurement formulated by the Korea Forest Research Institute (2010). Subsamples to determine the fresh-to-oven-dried biomass ratio were obtained from each tree component and oven-dried at 85 °C for one week. The dried samples were ground in a Wiley mill and passed through a 40-mesh stainless steel sieve. Carbon (C) and nitrogen (N) concentrations from the ground materials were determined using an elemental analyzer (Thermo Scientific Flash 2000, Milan, Italy). Phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) concentrations were determined through dry ashing 0.5 g of the ground material at 470 °C for 4 h, digesting the ash with 3 mL of concentrated 5 M HCl, diluting the digest with 0.25 mL of concentrated HNO_3 and 3 mL of concentrated 5 M HCl (Kalra and Maynard

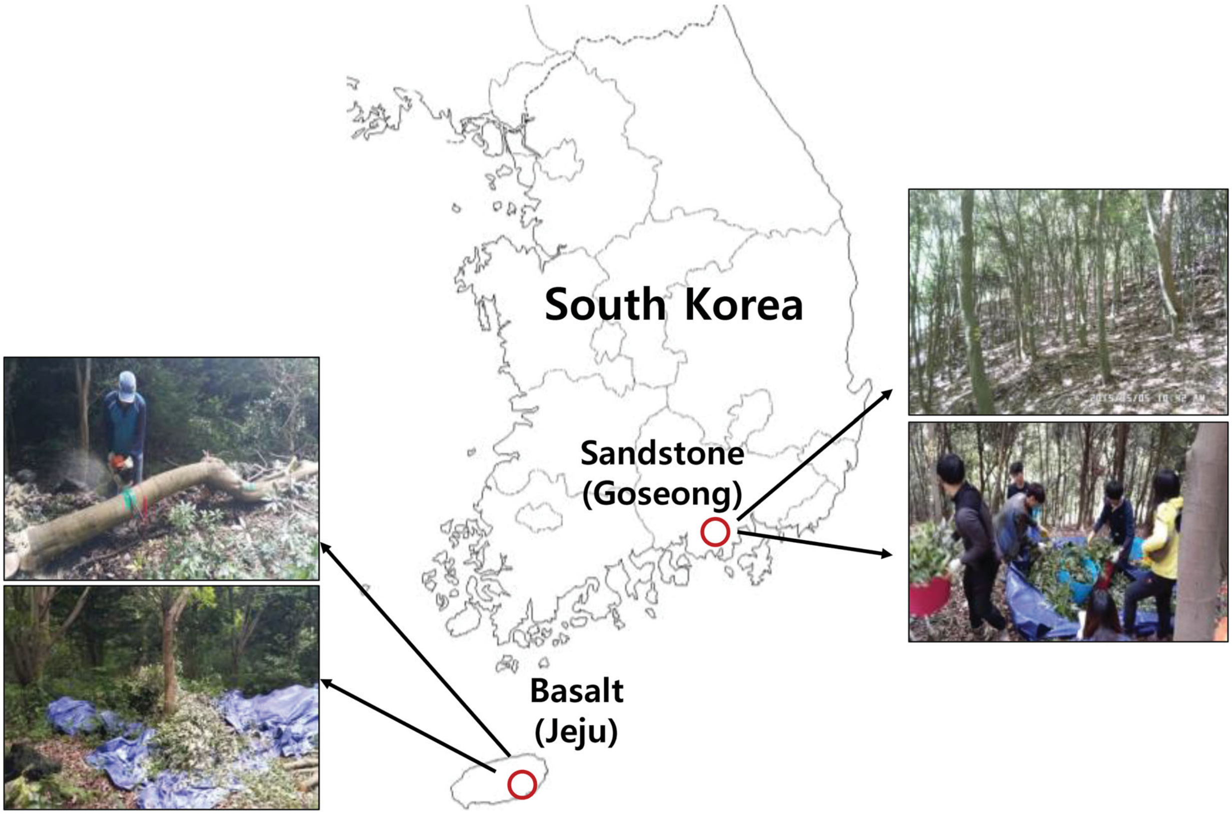

Figure 1. Location of the study site in *Quercus glauca* stands on different parent materials.

Table 1. General site and stand characteristics in *Quercus glauca* stands on different parent materials.

Parent material	Stand age (yrs)	Location	Aspect	Elevation (m)	Slope (°)	Stand density (tree ha^{-1})	DBH (cm)	Height (m)	Basal area (m^2 ha^{-1})
Basalt	31	33°20′4.2″N 126°39′31.1″E	S	363	8–10	967 (176)*	20.2 (0.7)	10.2 (0.5)	32.00 (10.9)
Sandstone	27	34°57′52.3″N 128°10′33.4″E	SE	264	15–20	1610 (350)	13.65 (1.0)	10.2 (0.6)	22.57 (3.6)

*Values in parenthesis are standard error.

1991), and measuring the concentrations via ICP-OES (Perkin Elmer Optima 5300DV, Shelton CT, USA). The nutrient content of each tree component was determined by multiplying the dry weight and nutrient concentration of each tree component.

The simple linear regression equation to estimate the nutrient content (C, N, P, K, Ca, and Mg) of each tree component was as follows;

$$Y = a + b \times (\mathrm{DBH})$$

where, Y is the nutrient content (g) of the respective tree component, DBH is the diameter at breast height (cm), and a and b are regression coefficients.

Nutrient content of forest floor and mineral soils

In April 2015, forest floor samples were collected from three random points of each plot by using a 900 cm^2 steel template (30 cm × 30 cm). The forest floor samples were oven-dried at 85 °C, ground with a Wiley mill, and passed through a 40-mesh stainless sieve. Nutrient analysis of the forest floor was according to the same procedure for tree nutrient analysis.

Soil samples were collected from three randomly selected points in each plot. At each point, two soil samples were collected from three depths (0–10 cm, 10–20 cm, and 20–30 cm) by using 400 cm^3 stainless core cans. The collected soil samples were oven-dried at 105 °C to measure bulk density, and air-dried to analyze the soil nutrients, respectively. The soil C and N concentrations were determined using an elemental analyzer (Vario Macro cube, Langenselbold, Germany). The soil P extracted with NH_4F and HCl solutions (Kalra and Maynard 1991) was determined using a UV spectrophotometer (Jenway 6505, Staordshire, UK). Exchangeable K, Ca, and Mg concentrations extracted with NH_4Cl solution (Kalra and Maynard 1991) and a mechanical vacuum extractor (Model 24VE, SampleTek, Science Hill, KY, USA) were determined with ICP-OES (Perkin Elmer Optima 5300DV, Shelton, CT, USA).

Soil nutrient stocks at each soil depth were calculated using the following formula:

$$\mathrm{NS} = \sum \mathrm{NC}_i \times \mathrm{BD}_i \times \mathrm{D_i} \times (1\text{–}\mathrm{VF}_i/100)$$

where NS is the nutrient stocks at soil depth, NC_i is the concentration of soil nutrients at each soil depth ($_i$), BD_i is soil bulk density at each soil depth, D_i is each soil depth (cm), and VF_i is volumetric coarse fragments content (%) at each soil depth.

Data analysis

The linear relationships between nutrient content and DBH were examined at $p < .05$ (SAS Institute Inc., 2003). The nutrient concentrations and stocks of aboveground and belowground for both parent materials were compared at $p < .05$ by using the PROC *t*-test procedure of SAS (SAS Institute Inc., 2003).

Results

Stand characteristics

The mean stand densities were higher for the sandstone (1610 trees ha^{-1}) than for the basalt (967 trees ha^{-1}) parent material, whereas the mean tree age for the sandstone parent material was slightly lower than that for the basalt parent materials (Table 1). The mean DBH and basal area were higher for the basalt (20.2 cm and 31.00 m^2 ha^{-1}) than for the sandstone (13.65 cm and 22.57 m^2 ha^{-1}) parent material. The mean tree height (10.2 m) was the same for both parent materials.

Nutrient concentration of tree components

The mean concentrations of C and K in the stem wood were significantly higher for sandstone than for basalt, whereas the N concentration in the stem wood was significantly lower for sandstone than for basalt (Table 2). The P, Ca, and Mg concentrations of the stem wood were not significantly different between the parent materials. The stem bark showed a trend similar to that of stem wood. In contrast to stem wood and stem bark, mean concentrations of P, K, and Mg in the branches were significantly higher for sandstone than for basalt. The nutrient content of all tree components and DBH was linearly related. The regression equations for the tree components were significant ($p < .05$), with DBH accounting for 32–88% of the variation in nutrient content (Table 3).

Nutrient concentration of forest floor and mineral soils

The N, P, and Ca concentrations of the forest floor were significantly higher for basalt than for sandstone, whereas the K concentration was significantly lower for basalt than for sandstone parent material (Table 4). The C and Mg concentrations of the forest floor were not affected by the parent materials. The organic C, total N, and exchangeable Ca^{2+} and Mg^{2+} at each soil

Table 2. Mean nutrient concentration of tree components in *Quercus glauca* on different parent materials type.

		C	N	P	K	Mg	Ca
Tree component	Parent material	(%)					
Stem wood	Basalt	45.3 (0.06)b	0.17 (0.01)a	0.006 (0.00)a	0.09 (0.01)b	0.03 (0.00)a	0.29 (0.03)a
	Sandstone	45.7 (0.12)a	0.12 (0.01)b	0.005 (0.00)a	0.18 (0.02)a	0.03 (0.00)a	0.22 (0.03)a
Stem bark	Basalt	43.7 (0.29)b	0.62 (0.03)a	0.033 (0.00)a	0.22 (0.02)a	0.11 (0.01)a	2.70 (0.17)a
	Sandstone	44.6 (0.22)a	0.53 (0.03)b	0.025 (0.00)b	0.23 (0.01)a	0.10 (0.01)a	2.27 (0.13)a
Branches	Basalt	46.4 (0.29)a	0.46 (0.03)a	0.034 (0.01)b	0.20 (0.02)b	0.07 (0.01)b	1.18 (0.15)a
	Sandstone	46.5 (0.12)a	0.41 (0.03)a	0.109 (0.01)a	0.82 (0.07)a	0.17 (0.01)a	0.60 (0.06)b
New leaves	Basalt	48.3 (0.19)a	1.53 (0.03)a	0.098 (0.00)a	0.64 (0.00)b	0.18 (0.01)a	0.67 (0.06)a
	Sandstone	47.8 (0.23)a	1.59 (0.06)a	0.129 (0.01)a	0.87 (0.06)a	0.18 (0.01)a	0.51 (0.05)b
Old leaves	Basalt	48.1 (0.15)a	1.27 (0.03)a	0.072 (0.00)a	0.41 (0.03)a	0.15 (0.01)a	1.00 (0.07)a
	Sandstone	48.3 (0.20)a	1.18 (0.04)a	0.061 (0.00)b	0.43 (0.01)a	0.14 (0.01)a	0.66 (0.04)b

Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at $p < .05$.

depth were significantly higher for basalt than for sandstone parent material (Table 5).

Nutrient stocks of tree components, forest floor, and mineral soils

The aboveground C, N, P, Ca, and Mg stocks of the tree components were not significantly different ($p > .05$) between the parent materials, whereas the K stock of the branches was significantly higher for sandstone than for basalt (Table 6). The nutrient stocks of the forest floor were significantly different between the parent materials, except for Ca stock (Table 7). However, the total nutrient stocks at mineral soil depth (0–30 cm) were significantly higher in the basalt parent material than in the sandstone parent material, except for the P and K stocks (Table 7). The soil K stocks at two soil depths (10–20 cm and 20–30 cm) were significantly different between the parent materials. However, P, K, and Ca stocks at the surface soil depth (0–10 cm) were not affected by the parent materials.

Discussion

Nutrient concentrations of tree components, forest floor, and mineral soils

The study supports our hypothesis that forest soils derived from different parent materials have significantly different nutrient concentrations of tree components, forest floor, and mineral soils. The trees grown on basalt had a generally high nutrient uptake, except for leaf K concentration in the sandstone parent material. The higher mean nutrient concentrations of the stem wood and stem bark on basalt are likely due to the difference in soil nutrients between the parent materials. For example, soils derived from basalt tend to be richer in organic C and total N with high exchangeable cations (Table 5). In contrast, sandstone parent materials provide a poor nutrient and moisture environment for tree growth, with low nutrient concentration when compared with basalt parent material. Previous studies have found that trees growing on different rock types have different foliar nutrient concentrations, particularly P, K, and Ca (Shen et al. 2001; Moore et al. 2004; Christophe et al. 2017; Marek and Richardson 2020).

The high concentrations of N, P, and Ca in the forest floor of basalt when compared with sandstone parent material could be associated with the high nutrient concentration of the tree leaves, which are major litterfall components of the forest floor. Thus, high soil organic C concentration of the basalt parent material could be due to the increased inputs of organic matter obtained from litterfall decomposition with good soil properties. However, the difference in exchangeable cation concentrations in both parent materials may be attributable to the inherent mineralogical character and nutrient uptake throughout stand development (Binkley and Giardina 1998; Christophe et al. 2017; An et al. 2020; Marek and Richardson 2020). In addition, the accumulation of nutrients in the tree biomass of sandstone may be the main mechanism responsible for this low exchangeable cation concentration.

Nutrient stocks of tree components, forest floor, and mineral soils

The nutrient stocks of the tree components could be associated with the differences in tree density (Węgiel et al. 2018; Verma and Garkoti 2019), stand basal area, and nutrient concentrations of the tree components (Rodríguez-Soalleiro et al. 2018; Yang et al. 2018). In this study, the aboveground nutrient stocks of the tree components were not affected by the different parent materials, except for P and K stocks of the branches. The P and K stocks of the branches in sandstone parent material could be affected by high P (sandstone: 0.109%, basalt: 0.034%) and K concentrations

Table 3. Linear regression equations to estimate nutrient content (g) of tree components in a *Quercus glauca* on different parent materials type.

			Regression coefficient			
Nutrient	Parent material	Tree component	*a*	*b*	r^2	*p* value
C	Basalt	Stem wood	−33,917	4012.76	0.8335	.0001
		Stem bark	−2903.6	303.62	0.8209	.0001
		Branches	−55,553	5395.53	0.5339	.0020
		Leaves	−3823.0	638.14	0.6517	.0003
		Total	−96,197	10350	0.7495	.0001
	Sandstone	Stem wood	−25,500	3885.12	0.8373	.0001
		Stem bark	−1994.4	312.33	0.8191	.0001
		Branches	−35,395	3834.40	0.8610	.0001
		Leaves	−3235.9	415.64	0.7894	.0001
		Total	−66,126	8447.51	0.8843	.0001
N	Basalt	Stem wood	−140.554	15.942	0.6186	.0005
		Stem bark	−42.987	4.386	0.8386	.0001
		Branches	−577.772	53.395	0.5642	.0012
		Leaves	−113.311	18.647	0.6602	.0002
		Total	−874.621	92.372	0.7760	.0001
	Sandstone	Stem wood	−64.802	9.560	0.8330	.0001
		Stem bark	−34.019	4.604	0.7842	.0001
		Branches	−358.204	37.758	0.8392	.0001
		Leaves	−84.654	11.072	0.7923	.0001
		Total	−541.677	62.995	0.8610	.0001
P	Basalt	Stem wood	−4.475	0.502	0.3230	.0271
		Stem bark	−1.708	0.201	0.7771	.0001
		Branches	−39.664	3.812	0.4933	.0035
		Leaves	−6.740	1.126	0.6474	.0003
		Total	−52.586	5.642	0.6754	.0002
	Sandstone	Stem wood	−1.775	0.361	0.3458	.0443
		Stem bark	−1.602	0.213	0.8104	.0001
		Branches	−82.343	8.772	0.6886	.0008
		Leaves	−5.298	0.707	0.8056	.0001
		Total	−91.006	10.054	0.7073	.0006
K	Basalt	Stem wood	−62.421	7.733	0.5208	.0024
		Stem bark	−15.475	1.560	0.6945	.0001
		Branches	−154.494	18.236	0.5484	.0016
		Leaves	−44.964	7.108	0.7534	.0001
		Total	−277.361	34.639	0.8200	.0001
	Sandstone	Stem wood	−53.680	11.250	0.5792	.0040
		Stem bark	−8.728	1.491	0.7735	.0002
		Branches	−636.594	66.997	0.6590	.0013
		Leaves	−39.099	5.070	0.7824	.0001
		Total	−738.101	84.808	0.7065	.0006
Ca	Basalt	Stem wood	−164.285	22.899	0.5925	.0008
		Stem bark	−142.079	16.742	0.7333	.0001
		Branches	−1650.149	146.456	0.7003	.0001
		Leaves	−66.732	11.122	0.6450	.0003
		Total	−2023.253	197.221	0.7988	.0001
	Sandstone	Stem wood	−181.323	22.747	0.5886	.0036
		Stem bark	−114.821	17.042	0.8642	.0001
		Branches	−565.729	59.837	0.7912	.0001
		Leaves	−51.255	6.177	0.7349	.0004
		Total	−913.134	105.805	0.8371	.0001
Mg	Basalt	Stem wood	−16.449	2.234	0.3745	.0153
		Stem bark	−8.941	0.839	0.6835	.0001
		Branches	−75.892	7.167	0.6203	.0005
		Leaves	−11.380	2.066	0.6149	.0005
		Total	−112.669	12.308	0.8770	.0001
	Sandstone	Stem wood	−21.724	2.815	0.8529	.0001
		Stem bark	−6.372	0.844	0.6609	.0013
		Branches	−125.286	13.501	0.7446	.0003
		Leaves	−8.721	1.188	0.7571	.0002
		Total	−162.102	18.349	0.7863	.0001

Linear regression equation form is $y = a + b \times$ (DBH). The r^2 is the coefficient of determination. *p* values represent the significance of the equations.

Table 4. Nutrient concentration of the forest floor in *Quercus glauca* stands on different parent materials.

	Nutrient (%)					
Parent material	C	N	P	K	Ca	Mg
Basalt	45.4	1.28	0.61	0.94	1.26	0.14
	(0.37)a*	(0.06)a	(0.05)a	(0.01)b	(0.07)a	(0.01)a
Sandstone	46.2	1.07	0.35	1.65	0.78	0.14
	(0.80)a	(0.04)b	(0.02)b	(0.14)a	(0.06)b	(0.01)a

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at $p < .05$.

(sandstone: 0.82%, basalt: 0.20%), but not the differences in stand basal area (sandstone: 22.57 m^2 ha^{-1}, basalt: 32.00 m^2 ha^{-1}) and stand density (sandstone: 1610 tree ha^{-1}, basalt: 967 tree ha^{-1}). In contrast to this result, Barron-Gafford et al. (2003) have reported that the nutrient stocks of the tree biomass were significantly higher in more dense stands than in less dense stands as a result of greater acquisition of resources and biomass growth of the loblolly pine in the USA.

Table 5. Soil physical and chemical properties in *Quercus glauca* stands on different parent materials.

Soil depth (cm)	Parent material	Bulk density (g cm^{-3})	Coarse fragment (%)	pH	C (%)	N (%)	P (mg kg^{-1})	K^+	Ca^{2+}	Mg^{2+}
								(cmolc kg^{-1})		
0–10	Basalt	0.48 (0.03)b*	55 (5)a	4.55 (0.06)a	13.6 (0.94)a	0.96 (0.07)a	7.2 (0.55)a	0.31 (0.03)a	1.02 (0.22)a	0.57 (0.10)a
	Sandstone	0.73 (0.04)a	36 (3)b	4.52 (0.03)a	5.3 (0.45)b	0.40 (0.03)b	6.4 (0.91)a	0.23 (0.02)b	0.39 (0.04)b	0.24 (0.04)b
10–20	Basalt	0.44 (0.02)b	38 (2)a	4.61 (0.05)a	9.9 (0.58)a	0.70 (0.04)a	8.2 (0.34)a	0.18 (0.02)a	0.50 (0.06)a	0.26 (0.05)a
	Sandstone	0.90 (0.04)a	47 (4)a	4.50 (0.04)a	3.0 (0.18)b	0.24 (0.01)b	6.5 (0.96)a	0.15 (0.01)a	0.14 (0.03)b	0.11 (0.01)b
20–30	Basalt	0.44 (0.01)b	46 (2)a	4.70 (0.07)a	8.4 (0.32)a	0.57 (0.02)a	9.5 (1.00)a	0.12 (0.01)a	0.44 (0.07)a	0.18 (0.02)a
	Sandstone	0.96 (0.03)a	41 (3)a	4.47 (0.04)b	2.6 (0.25)b	0.21 (0.02)b	7.5 (1.09)a	0.12 (0.01)a	0.10 (0.01)b	0.11 (0.01)b

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at $p < .05$.

Table 6. Nutrient stocks of aboveground tree components in *Quercus glauca* stands on different parent materials.

		Nutrient (kg ha^{-1})					
Component	Parent material	C	N	P	K	Ca	Mg
Stem wood	Basalt	45,921 (9731)a*	177 (38)a	5.5 (1.2)a	91 (19.3)a	290 (61)a	28 (5.8)a
	Sandstone	41,058 (3191)a	106 (8)a	4.7(0.3)a	149 (10.7)a	192 (17)a	25 (2.1)a
Stem bark	Basalt	3155 (680)a	37 (8)a	2.3 (0.5)a	16 (3.4)a	191 (41)a	8 (1.7)a
	Sandstone	3379 (260)a	51 (4)a	2.0 (0.7)a	17 (1.3)a	176 (14)a	8 (0.6)a
Branches	Basalt	52,132 (11,389)a	480 (106)a	36.4 (8.0)a	208 (44.2)b	1277 (285)a	67 (14.8)a
	Sandstone	25,004 (2574)a	236 (25)a	55.4 (5.8)a	409 (44.2)a	370 (40)a	87 (9.0)a
Leaves	Basalt	8817 (1817)a	263 (54)a	15.6 (3.2)a	96 (19.8)a	153 (32)a	30 (6.1)a
	Sandstone	3630 (310)a	97 (8)a	6.5 (0.5)a	45 (3.8)a	49 (4)a	11 (0.9)a
Total aboveground	Basalt	110,027 (23,610)a	958 (206)a	59.8 (12.8)a	411 (86.6)a	1912 (417)a	132 (28.4)a
	Sandstone	73,071 (6267)a	491(45)a	68.3 (6.8)a	621 (59.0)a	787 (74)a	131 (12.7)a

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at $p < .05$.

Table 7. Nutrient stocks of the forest floor and at 30 cm of mineral soil depth in *Quercus glauca* stands on different parent materials.

		Nutrient (kg ha^{-1})					
Component	Parent material	C	N	P	K	Ca	Mg
Forest floor	Basalt	3391 (207)b*	94 (2)b	7.4 (1.0)a	6 (0.3)b	85 (4)a	10 (0.6)b
	Sandstone	5763 (537)a	133 (12)a	1.9 (0.3)b	20 (2.1)a	95 (9)a	18 (2.5)a
Soil (0–10 cm)	Basalt	57,301 (2708)a	3984 (189)a	3.0 (0.3)a	53 (3.6)a	89(19)a	28 (4.0)a
	Sandstone	33,318 (224)b	2521 (146)b	4.2 (0.7)a	57 (3.7)a	49 (5)a	18 (2.3)b
Soil (10–20 cm)	Basalt	42,830 (2853)a	3034 (241)a	3.6 (0.3)a	29 (2.8)b	44 (6)a	13 (2.0)a
	Sandstone	22,132 (1224)b	1761 (99)b	4.8 (0.7)a	43 (4.1)a	21 (5)b	10 (0.8)a
Soil (20–30 cm)	Basalt	34,050 (1152)a	2307 (81)a	3.9 (0.4)b	19 (1.4)b	36 (6)a	9 (1.1)a
	Sandstone	21,212 (2375)b	1724 (170)b	5.9 (0.9)a	37 (2.3)a	16 (2)b	9 (1.0)a
Total soil	Basalt	134,181 (3192)a	9323 (302)a	10.5 (0.6)a	101 (5.5)b	169 (24)a	52 (5.2)a
	Sandstone	74,895 (365)b	5864 (272)b	14.4 (2.1)a	134 (9.4)a	84 (9)b	35 (4.3)b

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at $p < .05$.

The mean values of the aboveground C stocks were 110,027 kg C ha^{-1} for basalt and 73,071 kg C ha^{-1} for sandstone. Aboveground C stocks in basalt were slightly lower than the reported range (124,500–132,630 kg C ha^{-1}) for *Q. glauca* stands in basalt in Jeju-do, Korea (Han et al. 2018), whereas the values in sandstone were considerably lower than the range. However, the mean values (basalt: 958 kg N ha^{-1}, sandstone: 491 kg N ha^{-1}) of the N stocks of the tree components were considerably higher than 226 kg N ha^{-1} for other coniferous forests in Korea (Kim 1999). The results indicate that *Q. glauca* exhibits higher nutrient uptake than other coniferous tree species in Korea.

The differences in the nutrient stocks of the forest floor could be related to the amount of forest floor, and not nutrient concentration of the forest floor. For example, the low C stocks in basalt could be due to rapid C mineralization, whereas the high accumulation in the forest floor of sandstone may have been due to slow decomposition rates as a consequence of low precipitation and temperature, which are major abiotic factors that regulate decomposition processes (Berg and Laskowski 2006). Furthermore, the concentrations of N, P, and Ca in the forest floor were lower in sandstone than in basalt. However, high P stocks in basalt could be due to P inputs through leaf litterfall from high P concentrations in >1-year-old leaves in the basalt parent material. The C stocks of the forest floor in this study were within 3610–6390 kg C ha^{-1} of the *Q. glauca* stands on basalt reported by Han et al. (2018).

This study demonstrates that different parent materials have significant influences on the soil nutrient stocks at each soil depth. Significant effects of parent materials on soil nutrient stocks have been reported by Neff et al. (2006) and Li et al. (2017). Larger organic matter input in highly fertile soil would likely explain the higher soil C pool in basalt than in sandstone parent material. The influences of parent materials on soil N stocks may be due to their effects on soil organic C as soil nutrients because N is not a rock-derived element. However, similar P stocks in both parent materials could be due to similar soil acidity (basalt: pH 4.55–4.70; sandstone: pH 4.47–4.52) because plant-availability of P in forest soils depends on soil acidity (Augusto et al. 2017). In contrast to C, N, and P stocks, the higher soil K stocks in sandstone could be due to the differences in inherent mineral characteristics because K_2O concentration in basalt is generally lower than that in sedimentary rocks (Moore et al. 2004). In addition, this result may be attributable to the higher leaching losses in basalt regions because of the difference in annual precipitation (basalt: 1923 mm; sandstone: 1450 mm). Tripler et al. (2006) reported that exchangeable K^+ is soluble and easily leached from forest soils. Although, the Ca^{2+} and Mg^{2+} concentrations in both parent materials showed significant differences ($p < .05$) at the three soil depths, the nutrient stocks of these cations did not differ in the parent materials. The significantly low bulk density in the basalt parent material (Table 5) may be an additional factor that probably influences the differences in soil nutrient stocks. Therefore, the bulk density difference between basalt and sandstone parent materials could be an important controlling factor for nutrient stocks than the actual nutrient concentration in the soil.

Conclusions

This study quantitatively demonstrated broad differences in the nutrient environments represented by parent materials originating from different bedrocks in Japanese blue oak stands. The Japanese blue oak stands developed from basalt parent material exhibited greater nutrient accumulation than those developed from sandstone parent material. Although both parent materials may have different mechanisms for the nutrient cycle because of different stand characteristics, the parent materials accounted for the consequence of nutrient stocks due to the difference in inherent bedrocks. Thus, parent materials can be a useful variable for explaining forest nutrition responses throughout stand development processes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was supported by the Post-Doc development program of Gyeongnam National University of Science and Technology (2020), and National Institute of Forest Science, Korea.

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