Introduction

Soil parent materials originating from different geologic settings represent broad differences in the forest nutrient environment in forest ecosystems (Hahn 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 Doug. 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 differences 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
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 x 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 HNO₃ and 3 mL of concentrated 5 M HCl (Kalra and Maynard...
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 | S      | 363           | 8–10      | 967                             | 20.2     | 10.2      | 32.00                       |
|                 |                 | 126°39’31.1”E |        |               |           | (176)*                         | (0.7)   | (0.5)    | (10.9)                      |
| Sandstone       | 27              | 34°57’52.3”N | SE     | 264           | 15–20     | 1610                            | 13.65    | 10.2      | 22.57                       |
|                 |                 | 128°10’33.4”E |        |               |           | (350)                          | (1.0)   | (0.6)    | (3.6)                       |

*Values in parenthesis are standard error.

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 depth were calculated using the following formula:

\[
\text{NS} = \sum (\text{NC}_i \times \text{BD}_i \times \text{D}_i \times (1-\text{VF}_i/100))
\]

where NS is the nutrient stocks at soil depth, NC\(_i\) is the concentration of soil nutrients at each soil depth \((\%\)), 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.
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 \((p > 0.05)\) 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 \((0–30 \, \text{cm})\) 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 \((10–20 \, \text{cm} \text{ and } 20–30 \, \text{cm})\) were significantly different between the parent materials. However, P, K, and Ca stocks at the surface soil depth \((0–10 \, \text{cm})\) 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 (Wegiel et al. 2018; Verma and Garkoti 2019), stand basal area, and nutrient concentrations of the tree components (Rodriguez-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...
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

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**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 ha\(^{-1}\)) | K\(^+\) | Ca\(^{2+}\) | Mg\(^{2+}\) |
|----------------|-----------------|----------------------------|---------------------|----|-------|-------|------------------|-------|---------|---------|
| 0–10          | Basalt          | 0.48 (0.01)b              | 55                  | 4.59 | 13.6  | 0.96  | 7.2              | 0.31  | 1.02    | 0.57    |
|               | Sandstone       | 0.73 (0.04)a              | 36                  | 4.52 | 5.3   | 0.40  | 6.4              | 0.23  | 0.39    | 0.24    |
| 10–20         | Basalt          | 0.44 (0.02)b              | 38                  | 4.61 | 9.7   | 0.70  | 8.2              | 0.18  | 0.50    | 0.26    |
|               | Sandstone       | 0.90 (0.04)a              | 47                  | 4.50 | 3.0   | 0.24  | 6.5              | 0.15  | 0.14    | 0.11    |
| 20–30         | Basalt          | 0.44 (0.01)b              | 46                  | 4.70 | 8.4   | 0.57  | 9.5              | 0.12  | 0.44    | 0.18    |
|               | Sandstone       | 0.96 (0.03)a              | 41                  | 4.47 | 2.6   | 0.21  | 7.5              | 0.12  | 0.10    | 0.11    |

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at p < 0.05.

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

| Component      | Parent material | C (kg ha\(^{-1}\)) | N (kg ha\(^{-1}\)) | P (kg ha\(^{-1}\)) | K (cmolc kg\(^{-1}\)) | Ca (cmolc kg\(^{-1}\)) | Mg (cmolc kg\(^{-1}\)) |
|----------------|-----------------|-------------------|-------------------|-------------------|----------------------|----------------------|----------------------|
| 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 (14a)            | 8 (0.6)a             |
| Branches       | Basalt          | 52,132 (11,389)a | 480 (106)a        | 36.4 (8.0)a      | 208 (44.2)b          | 1277 (285a)          | 67 (14.8a)           |
|                | Sandstone       | 25,004 (2574)a   | 236 (25)a         | 55.4 (5.8)a      | 409 (44.2)a          | 370 (40a)            | 87 (9.0a)            |
| Leaves         | Basalt          | 8817 (1817)a     | 263 (54)a         | 15.6 (3.2)a      | 96 (19.8a)           | 153 (32a)            | 30 (6.1a)            |
|                | Sandstone       | 3630 (310a)      | 97 (8a)           | 6.5 (0.5)a       | 45 (3.8a)            | 49 (4a)              | 11 (0.9a)            |
| Total aboveground | Basalt   | 110,027 (23,610a) | 958 (206a)       | 59.8 (12.8a)     | 411 (86.6a)         | 1912 (417a)          | 132 (28.4a)          |
|                | Sandstone       | 73,071 (6267)a   | 491(45a)          | 68.3 (6.8a)      | 621 (59.0a)          | 787 (74a)            | 131 (12.7a)          |

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at p < 0.05.

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

| Component      | Parent material | C (kg ha\(^{-1}\)) | N (kg ha\(^{-1}\)) | P (kg ha\(^{-1}\)) | K (cmolc kg\(^{-1}\)) | Ca (cmolc kg\(^{-1}\)) | Mg (cmolc kg\(^{-1}\)) |
|----------------|-----------------|-------------------|-------------------|-------------------|----------------------|----------------------|----------------------|
| Forest floor   | Basalt          | 3391 (207)b      | 94 (2b)           | 7.4 (1.0a)       | 6 (0.3b)             | 85 (4a)              | 10 (0.6b)            |
|                | Sandstone       | 5763 (537a)      | 133 (12a)         | 19 (0.3b)        | 20 (2.1a)            | 95 (9a)              | 18 (2.5a)            |
| Soil (0–10 cm) | Basalt          | 57,301 (2708a)   | 3994 (189a)       | 3.0 (0.3a)       | 53 (3.6a)            | 8919a                | 28 (4.0a)            |
|                | Sandstone       | 33,318 (224b)    | 2521 (146b)       | 4.2 (0.7a)       | 57 (3.7a)            | 49 (5a)              | 18 (2.3b)            |
| Soil (10–20 cm)| Basalt          | 42,830 (2853a)   | 3043 (241a)       | 3.6 (0.3a)       | 29 (2.8b)            | 44 (6a)              | 13 (2.0a)            |
|                | Sandstone       | 22,132 (1224)b   | 1761 (99b)        | 4.8 (0.7a)       | 43 (4.1a)            | 21 (5b)              | 10 (0.8a)            |
| Soil (20–30 cm)| Basalt          | 34,050 (1152a)   | 2307 (31a)        | 8.4 (0.9b)       | 19 (1.1b)            | 36 (6a)              | 9 (1.1a)             |
|                | Sandstone       | 21,212 (2375b)   | 1724 (170b)       | 5.9 (0.9a)       | 37 (2.3a)            | 16 (2b)              | 6 (1.0a)             |
| Total soil     | Basalt          | 134,181 (3192a)  | 9323 (302a)       | 10.5 (0.6a)      | 101 (5.5b)           | 169 (24a)            | 52 (5.2a)            |
|                | Sandstone       | 74,895 (365b)    | 5864 (272b)       | 14.4 (2.1a)      | 134 (9.4a)           | 84 (9b)              | 35 (4.3b)            |

*Values in parenthesis are standard error.
Different letters represent a significant difference between parent materials at p < 0.05.
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 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, 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 Ca²⁺ and Mg²⁺ 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

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