# Comparison of the Composition, Population Density, and Diversity of the Soil Seed Bank and Standing Vegetation in Deciduous and Coniferous Forests in Korea

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https://doi.org/10.5109/1833812

出版情報：九州大学大学院農学研究院紀要. 62 (2), pp.323-328, 2017-09-08. Faculty of Agriculture, Kyushu University
バージョン：

J. Fac. Agr., Kyushu Univ., **62** (2), 323–328 (2017)

# Comparison of the Composition, Population Density, and Diversity of the Soil Seed Bank and Standing Vegetation in Deciduous and Coniferous Forests in Korea

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(*Received April 24, 2017 and accepted May 10, 2017*)

To determine the characteristics of a soil seed bank in a temperate forest, the composition, population density, and diversity of plant species in the soil seed bank, the similarity between the standing vegetation and the soil seed bank and the correlation between the soil seed bank and soil environmental factors (geographic and soil characteristics) that affect the species characteristics of the soil seed bank were investigated in Korean red pine (coniferous) and Mongolian oak (deciduous) forests, which represent the types of forests in Korea. There was no statistically significant difference in the population density and diversity of the species of soil seed bank between the two types of forests. A similarity in the species composition between the standing vegetation and the soil seed bank was found and was higher in the shrub layer than in the canopy and understory layers. The species characteristics of the soil seed bank, such as the species composition and the species diversity, seemed to be more relevant for the herbaceous plants in the shrub layer than for the dominant tree species in the canopy layer. The number of plant species and the population density of the species of the soil seed bank were considered to be affected by the organic content in the surface soil of the forests.

**Key words**: Herbaceous plant, Organic matter, Similarity index, Surface soil, Vegetation regeneration

## INTRODUCTION

The soil seed bank is the buried seeds in surface soil that have a germinative plant species that is dormant (Bigwood and Inouye, 1988). The soil seed bank plays a significant role in the regeneration of plant communities after a natural or anthropogenic disturbance of previous plant communities (Pickett and McDonnell, 1989). The soil seed bank is a potential source for vegetation regeneration and provides important information about previous species in the shrub layers and current standing vegetation species (Hopfensperger, 2007). Buried seeds are directly affected by the composition and diversity of the standing vegetation species (Roberts, 1981). Furthermore, understanding the potential of a soil seed bank has motivated researchers to compare the species composition of standing vegetation with that of the soil seed bank (Peco *et al*., 1998).

The density of the seed bank increases as the understory layer of vegetation ages, and especially due to rainfall, the density increases in the spring season. In addition, the tree crown is an indicator that forecasts the appearance of species from the seed bank (Pugnaire and Lazaro, 2000). The seed bank can mitigate habitat fragmentation as the seed bank resembles genotypes similar to those of the standing vegetation. As a forest stabilizes, the similarity between the seed bank and the standing vegetation is low in general because the disturbances decrease as the community stabilizes (Pugnaire and Lazaro, 2000), and the density of the seed bank is higher as ruderal species are frequently introduced in the younger forest (Hopfensperger, 2007).

The similarity between the soil seed bank and standing vegetation has been studied, and they differ in spatial and temporal scales because the soil seed bank is greatly affected by standing vegetation (Henderson *et al*., 1988). The relationship between the soil seed bank and standing vegetation has been studied in various regions, including temperate regions and a region of variety ecosystem (Wassie, 2006; Hopfensperger, 2007). In forests, relevant studies were conducted mainly in temperate and tropical forests in Europe, South America, and North America (Hopfensperger, 2007). These studies mainly examined species composition, population density, species diversity, and similarities between the soil seed bank and the standing vegetation in forests. However, few studies on the characteristics of the soil seed bank in a deciduous Mongolian oak forest and a coniferous Korean red pine forest, which represent the vegetation in temperate climate regions, have been conducted. Therefore, this study focused on the characteristics of the soil seed bank in the Mongolian oak (*Quercus mongolica*) forest and the Korean red pine (*Pinus densiflora*) forest. This study also focused on the soil environmental factors that affect the accumulation of the soil seed bank in the two types of vegetation.

This study intended to clarify the characteristics of the soil seed bank: the number of plant species, the population density of the species, and the species diversity of the soil seed bank, the similarity of these characteristics between the soil seed bank and standing vegetation, and soil environmental factors that affect the species characteristics of the soil seed bank. A forest stand survey and an experiment involving the germination of seeds

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from the soil seed bank were performed in deciduous and coniferous forests in Korea.

## MATERIALS AND METHODS

### Selection of the survey region and overview of the region

Korean red pine and Mongolian oak forests are representative forest vegetation in the temperate climate regions of Korea, and 3 plots each of communities of Korean red pine (Plot 1, 2, 3) and Mongolian oak (Plot 4, 5, 6) were selected. The slope gradient, altitude, and aspect of the plots were measured with GPS (Oregon 300, Garmin Ltd.). The soil characteristics were measured by the Gyeongsangbuk–do Agricultural Research & Extension Services in Korea. The soil pH was measured by the glass electrode method. The total nitrogen content was determined using the micro–Kjeldahl method; organic matter was analyzed by the Tyurin's method; cation exchange capacity (CEC) and exchange bases were determined by the $NH_4^+$–acetate method and the 1 M $NH_4^+$–acetate extraction method at pH 7 (Spark *et al.*, 1996).

### Surface soil sampling and buried seed germination experiments

To sample the soil seed bank in each plot, four spots were randomly selected. The litter layer was removed first, and then the soil was sampled from the surface to a depth of 5 cm, where the accumulation rate of the soil seed bank was high (Robert, 1981; Young, 1985; Granström, 1982). The surface soil sampled from one plot was 32 L, and a total of 192 L was sampled from the six plots. The surface soil sampled was moved to an indoor greenhouse to conduct the soil seed bank germination experiment (Gross, 1990). An artificial lightweight soil layer was placed in the bottom of the germination experiment box (50 cm × 33 cm × 12 cm, Material: Styrofoam) to supply drainage and nutrients, and 8 L of surface soil was laid there. The germination experiment was repeated four times per plot, for a total of 24 times. Thereafter, the experimental box was watered based on the degree of dryness, and the indoor greenhouse was heated or cooled in response to extreme temperature changes in summer and winter. The germinated plant species were identified and removed once a week. The surface soil sampling was performed on March 27, 2010. The germination experiment was conducted for 18 months from June 2010 to November 2011.

### Vegetation survey

The forest layers were divided into three layers to analyze the standing vegetation structures. The layer composed of trees at least 2 m high with a canopy was classified as the canopy layer. The layer composed of trees ranging from 0.5 m to 2 m high was classified as the understory layer. The layer of trees that were less than 0.5 m tall was classified as the shrub layer. Three plots, each 10 m × 10 m (100 $m^2$), were installed in the Korean red pine forest and in the Mongolian oak forest. All plant species that appeared in the plots were surveyed. In the canopy layer and the understory layer, the tree diameter at chest height (1.2 m) was measured. In the shrub layer, the size of the crown (width × length) was measured.

### Data analysis

To compare the relative occupancy of each plant species in the layers in the plot, the importance value (Ⅳ) was calculated by using Curtis and McIntosh's method (1951). The total number of species and the population were derived in the soil seed bank germination experiment. The values were converted to the number of species per square meter and the population per square meter. The species diversity index (H) for the soil seed bank in the Korean red pine forest and the Mongolian oak forest was calculated by using Shannon's formula (Pielou, 1975). To examine the similarity index between the species of the individual layer in the standing vegetation and the species of the soil seed bank, Sörensen's (1948) formula was applied to the canopy layer, the understory layer, and the shrub layer:

$$\text{Sörensen} = \frac{2a}{b+c} \qquad (1)$$

Where 'a' is the number of species that commonly appear in the soil seed bank and the standing vegetation, 'b' is the number of species in the soil seed bank, and 'c' is the number of species in the standing vegetation.

The differences in the number of species, population density, and species diversity index between the two types of vegetation (the Korean red pine and Mongolian oak forests) were analyzed using IBM SPSS Statistics (ver. 17) to test the statistical significance of the differences. The correlations between the values for the standing vegetation (the number of species and population), the soil seed bank (the number of species and population), and environmental factors (altitude, slope gradient, thickness of the litter layer, pH, organic content, total nitrogen, and CEC) were analyzed by using the Pearson correlation coefficient.

## RESULTS

### Overview of the plots

The Korean red pine forest is located on slope gradients of 15–38° at an altitude of 150–205 m (the regions around Sunji–ri, Wunmun–myeon, Cheongdo–gun, and Gyeongbuk; 35°43′N, 128°55′E). The litter layer of the forest was 4.0–5.0 cm thick. The slope gradient of plots 1 and 3 faced north, and the slope gradient of plot 2 faced south.

The Mongolian oak forest is located on a slope gradient of 5–36° at an altitude of 180–622 m (Shinwon–ri, Wunmun–myeon, Cheongdo–gun, and Gyeongbuk; 35°38′N, 129°02′E). The litter layer of the forest was 3.0–5.0 cm thick. The slopes faced south (Table 1). Three quadrat plots (10 m × 10 m each) were installed in each region. The vegetation and environmental factors were investigated at each plot, and the surface soils

**Table 1.** Stand structural and environmental characteristics of the six plots

| Plot | | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|---|---|---|---|---|---|
| Altitude (m) | | 205 | 150 | 152 | 180 | 594 | 622 |
| Slope (°) | | 15 | 38 | 23 | 36 | 5 | 13 |
| Aspect | | NW305 | SE162 | NW312 | NE73 | NW350 | NE34 |
| Depth of litter layer (cm) | | 5.0 | 4.0 | 4.0 | 3.0 | 5.0 | 4.0 |
| pH (1:5) | | 4.6 | 4.8 | 5.0 | 4.7 | 4.8 | 4.6 |
| Organic matter (%) | | 11.77 | 10.67 | 7.26 | 12.42 | 13.14 | 8.82 |
| Total–N ($g\ kg^{-1}$) | | 0.41 | 0.42 | 0.29 | 0.48 | 0.68 | 0.44 |
| CEC ($cmol\ kg^{-1}$) | | 18.11 | 15.32 | 12.66 | 18.35 | 24.69 | 19.55 |
| Number of species ($100\ m^2$) | | 25 | 16 | 19 | 22 | 33 | 31 |
| Main tree species | Canopy layer (IV, %)[†] | *Pinus densiflora* (73.58) | *P. densiflora* (100) | *P. densiflora* (82.57) | *Quercus mongolica* (53.20) | *Q. mongolica* (53.06) | *Q. mongolica* (33.65) |
| | Understory layer (IV, %)[†] | *Rhododendron mucronulatum* var. *mucronulatum* (26.45) | *Q. serrata* (39.85) | *R. mucronulatum* var. *mucronulatum* (59.47) | *R. mucronulatum* var. *mucronulatum* (51.17) | *Lindera erythrocarpa* (13.96) | *Weigela subsessilis* (31.74) |
| | Shrub layer (IV, %) | *Smilax china* (20.29) | *Spodipogon cotulifer* (50.40) | *R. mucronulatum* var. *mucronulatum* (30.05) | *Q. mongolica* (28.49) | *Lindera erythrocarpa* (24.91) | *Dryopteris bissetiana* (26.26) |

[†] The importance value (IV) was calculated by using Curtis and McIntosh's method (1951).

were sampled from the forest floors of each plot.

The pH of the soil in the study area, which is in the brown forest soil region, was 4.6–5.0. The organic matter (OM) content of the soil was 7.26–13.14%, and the total nitrogen (total N) content was 0.29–0.68%. Compared to a previous study on the region (Jeong *et al.*, 2002), the soil in the study site was more acidic and more fertile. The soil pH, organic content, and total nitrogen for the two forests did not show any statistically significant differences. However, the CEC of the Mongolian oak forest was statistically significantly higher than that of the Korean red pine forest ($p<0.01$).

In plots P1–P3 in the Korean red pine forest, the importance value of the pine trees was high, more than 74% or higher in the canopy layer. Korean rhododendron (*Rhododendron mucronulatum* var. *mucronulatum*) and Konara oak trees (*Quercus serrata*) were dominant in the understory layer. Greenbriers (*Smilax china*), Articulation–bearing Spodiopogon (*Spodiopogon cotulifer*), and Korean Rhododendron (*R. mucronulatum* var. *mucronulatum*) were dominant in the shrub layer. The average number of species in the Korean red pine forest plots was 20, which was similar to the number of species in the brown forest soil in the pine forest, which were 15–20 per $100\ m^2$ (Korea Forest Research Institute, 2005); see Table 1. In plots P4–P6 of the Mongolian oak forest, the importance value of the Mongolian oak trees was high, more than 33% in the canopy layer. Korean rhododendron (*R. mucronulatum* var. *mucronulatum*), Redfruit Spicebushes (*Lindera erythrocarpa*), and Korean Weigela (*Weigela subsessilis*) were the dominant species in the shrub layer. Mongolian oak (*Quercus mongolica*), Redfruit Spicebushes (*Lindera erythrocarpa*), and Dryopteris varia (*Dryopteris bissetiana*) were dominant in the ground layer. An average of 29 species appeared in the Mongolian oak forest, which was somewhat higher than the average number of species in the brown forest soil of the Mongolian oak forest communities, which is 20–25 per $100\ m^2$ (Korea Forest Research Institute, 2005); see Table 1. There was no statistically significant difference in the number of species between the Korean red pine forest and the Mongolian oak forest.

**Comparison of the soil seed bank between the coniferous and deciduous forests**

The average number of species germinated from the soil seed bank was $13.00/m^2$ in the coniferous Korean red pine forest and $17.3/m^2$ in the deciduous Mongolian oak forest. The average population density was 63.64/m2 in the coniferous forest and $77.27/m^2$ in the deciduous forest. The species diversity index was 0.90 in the coniferous Korean red pine forest and 1.09 in the deciduous Mongolian oak forest (Fig. 1). However, the differences in the number of species, population density, and species diversity index between the coniferous and deciduous forests were not statistically significant.

**Similarity between soil seed bank and standing vegetation**

The similarity of the species composition between the soil seed bank and the standing vegetation for each

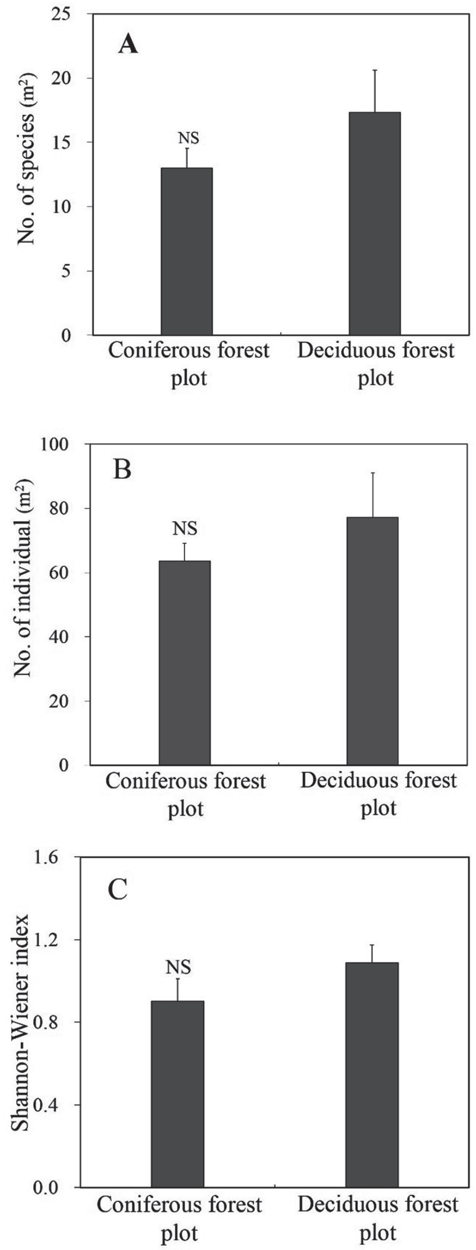


**Fig. 1.** Germinated number of species (A), number of individual (B) and Shannon–Wiener index (C) from the soil seed bank in the coniferous Korean red pine forest plot and the deciduous Mongolian oak forest plot. 'NS' indicates not significant difference ($p < 0.05$) between the treatments according to t–test. The error bars indicate standard error.

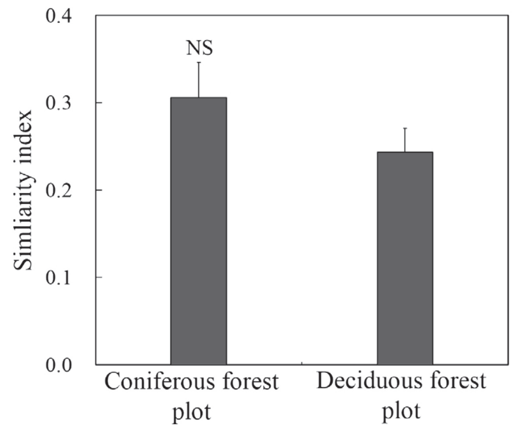


**Fig. 2.** Similarity index for the soil seed bank and the standing vegetation of both from the soil seed bank in the coniferous Korean red pine forest plot and the deciduous Mongolian oak forest plot. 'NS' indicates not significant difference ($p < 0.05$) between the treatments according to t–test. The error bars indicate standard error.

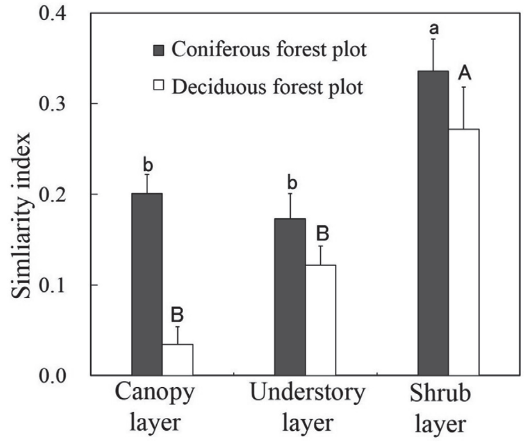


**Fig. 3.** Similarity index for the seed bank and the canopy layer, understory layer and shrub layer of the coniferous Korean red pine forest plot and the deciduous Mongolian oak forest plot. Different letters (a-b, A-B) above a column indicate statistical differences ($p < 0.05$) by Duncan's multiple range test. The error bars indicate standard error.

forest was 0.31 in the coniferous Korean red pine forest and 0.24 in the deciduous Mongolian oak forest. The difference in the similarity between the coniferous and deciduous forests was not statistically significant (Fig. 2). The similarity of the species composition between the standing vegetation and the soil seed bank was analyzed for each layer. According to the results, the similarity index value of the shrub layer was statistically significantly higher than those of the canopy and understory layers in both types of standing vegetation (Fig. 3).

**Factors affecting the size and composition of the soil seed bank**

To clarify the soil environmental factors that affect soil seed bank accumulation, correlations among the geographic characteristics (altitude, slope gradient), soil (depth of the litter layer, pH, organic content, total N, CEC), and the standing vegetation (the number of each species and the population density) of the study site were analyzed. The results showed a positive correlation between the number of species in the soil seed bank and the organic matter content and the number of species in the standing vegetation. The organic matter content and

**Table 2.** Correlation coefficients for the relations between the soil seed bank and geographic and soil characteristics

| | | Soil seed bank | |
|---|---|---|---|
| | | No. of species | No. of individual |
| Altitude | | 0.234 | 0.371 |
| Slope | | –0.330 | –0.315 |
| Depth of litter layer | | 0.220 | 0.395 |
| pH | | –1.000 | –0.006 |
| Organic matter | | 0.825** | 0.827** |
| Total N | | 0.786 | 0.930** |
| CEC | | 0.731 | 0.790 |
| Standing vegetation | No. of species | 0.815* | 0.686 |
| | No. of individual | –0.780 | –0.866* |

* and ** : significant at 5 and 1 % levels, respectively

the total nitrogen content showed a positive correlation with the population density in the soil seed bank; however, they showed a negative correlation with the population density in the standing vegetation (Table 2).

## DISCUSSION

Few differences were observed in the number of species, the population density of the species, and the species diversity of the soil seed bank for the coniferous Korean red pine forest and the deciduous Mongolian oak forest. However, according to previous studies, the number of species and the species density of the soil seed bank in coniferous forests are low (Granström, 1982), while those of the soil seed bank in deciduous forests are high (Leckie *et al*., 2000). Pugnaire and Lázaro (2000) reported that the species composition of the soil seed bank is not affected by the dominant species in standing vegetation. The present study also showed that the number of species and the dominant species in the standing vegetation were not related to the number of species and the population density of the soil seed bank.

According to previous studies on soil seed banks (Jalili *et al*., 2003), similarities between standing vegetation and the soil seed bank vary across regions. In general, the similarity value was around 0.31 in forests, 0.47 in swamps, and 0.54 in grasslands (Hopfensperger, 2007). The results of the present study also showed that the similarity value was close to these values. The lower similarity value in the forest compared with other regions was caused by the larger plant seeds and greater seed predation in forests (Yorks *et al*., 2000). Larger seeds are more vulnerable to predation by mammals (Gashaw *et al*., 2002); thus, seed banks are difficult to maintain (Yorks *et al*., 2000).

In the present study, the similarity value between the standing vegetation in each layer and the soil seed bank was lowest in the canopy layer and highest in the shrub layer. The same results were reported by Pugnaire and Lazaro (2000). This is because the population density of the species and the number of species of herbs are greater than those of trees (Schneider and Sharitz, 1986). In addition, herb species in the shrub layer produce more seeds and are more likely to be preserved in surface soil as a seed bank than tree species in the canopy and understory layers (Hosogi *et al*., 2004).

The number of species and the population density of the soil seed bank were found to be closely related to the organic matter content (Table 2). This is because the decomposition of fallen leaves increases the organic matter content. Increased organic matter increases the soil porosity. Surface soil with higher soil porosity is more favorable for seed accumulation than soil with lower porosity. Further study on the effect of the organic matter content on soil seed bank accumulation is necessary.

## CONCLUSIONS

The following conclusions were drawn from the study.

There was no statistically significant difference in the number of germinated species, the population density, and the species diversity of the soil seed bank between the deciduous Mongolian oak and coniferous Korean red pine forests. Therefore, the dominant plant species did not seem to affect the species composition of the soil seed bank.

The similarity between each layer of the standing vegetation and the soil seed bank was higher in the shrub layer than in the canopy and understory layers. This finding was probably because the population density and the number of herb species in the shrub layer were higher than those of the tree species in the standing vegetation.

The number of species and the population density of the soil seed bank were closely related to the organic matter content of the soil. Organic matter in the forest floor, composed of fallen leaves, for example, increases the soil porosity and aids in the accumulation and preservation of buried seeds in surface soil.

## AUTHOR CONTRIBUTIONS

M.H. Yi designed the study, performed the histologi-

cal experiments, analyzed the data and wrote the paper. S.G. Park designed the study, supervised the work, wrote the paper. M. Matsumoto supervised the work, wrote the paper. All authors assisted in editing of the manuscript and approved the final version.

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