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An Evaluation of the Effects of Rehabilitation Practiced in Coal Mining Spoils in Korea: 2. An Evaluation Based on the Physicochemical Properties of Soil

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ABSTRACT: The effectiveness of rehabilitation programs for coal mining spoils in Samcheok, Jeongsun, and Mungyung were evaluated based on the physicochemical properties of soil in the rehabilitated areas. These spoils were reclaimed by introducing plants such as black locust (*Robinia pseudoacacia*), pitch pine (*Pinus rigida*), birch (*Betula platyphylla* var. *japonica*), alder (*Alnus hirsuta*), bush clover (*Lespedeza cyrtobotrya*), and grass (*Lolium perenne*) in planting beds covered with forest soil. In the surface soil, the pH, organic matter, total N, available P, and exchangeable Ca showed significant changes over the years after reclamation. The pH and exchangeable Ca content decreased exponentially over time, whereas organic matter increased linearly and total N and available P increased exponentially. Changes in the physicochemical properties of subsurface soils displayed a different pattern. There were significant changes over time in the organic matter, available P, and exchangeable Ca and Mg contents of the soil. Organic matter increased logarithmically with years since rehabilitation and available P increased exponentially. Meanwhile, exchangeable Ca decreased exponentially, and Mg decreased logarithmically. The changes in the subsurface soil were not as dramatic as those in the surface soil. This result suggests that the ameliorating effects of the establishment and growth of plants more pronounced on the surface soil layer. Stand ordination data showed different relationships with time since rehabilitation in the early and later stages of the rehabilitation process. In the early stages of rehabilitation, stands tended to be arranged in the order of reclamation age. However, in the later stages, there was not a clear relationship between reclamation age and vegetation characteristics. This result suggests that soil amelioration is required for the early stages, after which an autogenic effect becomes more prominent as the vegetation becomes better established.

Key words: Autogenic effect, Coal mining spoils, Physicochemical properties, Rehabilitation, Soil

INTRODUCTION

Coal mining activities in Korea have been conducted by deep mining, as coal deposits are in deep underground. Therefore, coal mining activities usually lead to the production of large quantities of waste material, or spoils. Such mining debris is then piled up on mountains or discarded in mountain valleys. Therefore, acid mine drainage, barren unvegetated areas, and steep unstable piles of mining waste are frequently left behind after mining. Even when the damaged areas are re-vegetated, exotic species have usually been employed for rehabilitation (Lee et al. 2007a). Consequently, most rehabilitated mine areas form an ecological space dissimilar to the surrounding habitat.

This problem has occurred primarily because the ecology of the mined area is not well-understood by rehabilitation practitioners. In fact, untreated deep mining debris does not by itself function as soil because it does not include sufficient organic matter. Therefore, ecosystem development in these areas must progress in the same manner as primary succession: the process of ecosystem development on barren surfaces where severe disturbances have removed most vestiges of biological activity (Walker and del Moral 2004). Succession progresses as a result of interactions among plants growing in a given area. Early colonizers facilitate growth of new plant species, which promotes species compositional change to the next successional stage (Connell and Slatyer 1977, Van Andel et al. 1993).

Succession is a directional, cumulative change in the species that occupy a given area through time. Most plants modify their immediate environment in some way that can impact establishment and growth of both other species and other individuals of the same spe-

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cies. Differential responses to these environmental changes across species can drive succession (Wright and Muller-Dombois 1988).

Rehabilitation is closely linked to succession theory (Walker et al. 2007). Under natural conditions, successional processes or normal ecosystem development will provide an appropriate trajectory for recovery of damaged areas (Dobson et al. 1997, Zedler and Callaway 1999, Choi 2004). But natural recovery such as succession occurs very slowly. So, human intervention to accelerate this process, through rehabilitation efforts that facilitate the successional process, is often necessary.

A properly planned restoration project attempts to fulfill clearly stated goals that reflect important attributes of the reference ecosystem. Goals are attained by pursuing specific objectives and objectives are evaluated on the basis of performance standards, also known as design criteria or success criteria. These standards or criteria are conceived in large part from an understanding of the reference ecosystem (SERI 2004).

Three strategies exist for conducting an evaluation: direct comparison, attribute analysis and trajectory analysis. In direct comparison, selected parameters are determined or measured in the reference and restoration sites. The parameters considered include aspects of both the abiotic environment and the biota. In attribute analysis, attributes such as species composition, percentage of indigenous species, stability of the system, the physical environment, the presence of normal developmental processes, harmony with the larger ecological matrix, potential threats to the habitat, resilience, and capacity for self-sustenance are used to judge the degree to which each goal has been achieved. Trajectory analysis is an evaluation of trends in restoration area to determine whether the restoration is following its intended trajectory towards the reference condition (SERI 2004).

In this study, we focused on abiotic parameters such as physicochemical properties of soil for attribute analysis and considered the changing trends of those factors in the years after reclamation for trajectory analysis. The same factors were also compared directly with reference information. In this respect, this study followed the typical procedure of restoration success evaluation.

This study aims to evaluate the effects of rehabilitation on coal mining spoils based on physicochemical properties of soil, and to use these results to identify effective restoration methods for coal mining spoils for future use.

MATERIALS AND METHODS

Study Area

This study was carried out in three areas located in Neukgu-ri Dogye-eup Samcheok-shi and Gohan-ri Gohan-eup Jeongseon-gun in Gangwon province, east-central Korea and Wangneung-ri Gaeun-eup and Oeeo-ri Maseong-myun Mungyung-shi in Gyungbuk province, central Korea. Ri, eup, myun, gun and shi are administrative units, which mean village, town, rural town, county and city, respectively. The sites in Dogye-eub range vertically from 200 m to 400 m above sea level (asl). The most common forest types in this area are Korean red pine (*Pinus densiflora*) and oak (*Quercus variabilis*) forests. Sites in Gohan-eub range vertically from 800 m to 1,000 m asl. Mongolian oak (*Q. mongolica*) forest is the most common forest type in this area, but birch forest dominated by *Betula costata* also appears in some nearby ravines. Sites in Mungyung-shi range vertically from 100 m to 300 m asl, and the most common forest types in this area are Korean red pine and oak (*Q. variabilis*) forests.

Sites that were reclaimed two, four, five, seven, fifteen, twenty-five, and thirty years prior to the study, were selected for this study (abbreviated as the 2-, 4-, 5-, 7-, 15-, 25-, and 30-year sites hereafter). In addition, two sites consisting of Korean red pine (*P. densiflora*) and oak (*Q. variabilis*) stands on normal forest soil in the vicinity of the restored sites were selected as reference sites. The rehabilitation history of each site was determined by counting tree rings using an increment borer and by interviews with the project makers. The ages of the reference Korean red pine and oak stands were 40 and 50 years, respectively.

The 2-year and 4-year sites were in Mungyung-shi. The 2-year stand was reclaimed through the introduction of grass (*Lolium perenne*), and the 4-year stand was reclaimed by introducing bush clover (*Lespedeza cyrtobotrya*). The 5-year stand, in Dogye-eub, was reclaimed by introducing birch (*Betula platyphylla* var. *japonica*), while the 7-year site, in Gohan-eub, was reclaimed using alder (*Alnus hirsuta*). The 15-year site, in Mungyung-shi, was reclaimed using black locust (*Robinia pseudoacacia*). The 25-year site, in Mungyung-shi, was reclaimed using pitch pine (*P. rigida*) and black locust (*R. pseudoacacia*). Finally, the 30-year site, in Dogye-eub, was reclaimed using black locust (*R. pseudoacacia*). Planting beds in all the reclaimed sites were prepared by covering the spoils with forest soil. However, by the time of this study, the forest soil had washed away from all of the sites except for the newly reclaimed sites, such as the 2- and 4-year sites. Sample plants for reclamation were usually three-year-old seedlings and they were generally planted at 1.5 m intervals. In the years since reclamation, the species diversity generally increased but the species composition did not show remarkable changes (Lee et al. 2007a).

Methods

In each site with a different rehabilitation history, three or five stands were selected for soil sampling. Soil samples were collected in September 2004, including samples of surface soil, which was defined as soil <5 cm from the surface, and subsurface soil, defined as soil 5~10 cm below the surface. Samples were collected from five randomly chosen points in each site, pooled, air-dried at room temperature, and sieved though 2-mm mesh. The pH of a 1:5 w/v mixture of soil and deionized water was measured with a bench-top probe. Organic matter (OM) concentration was estimated by loss of dry mass on ignition at 400℃. Total nitrogen was measured using the micro-Kjeldahl method (Jackson 1967). Available P and exchangeable K, Na, Ca, and Mg were extracted with 1-N ammonium acetate and measured by ICP (inductively coupled plasma atomic emission spectrometry; Shimadzu ICPQ-1000).

We used the national standard data, which were derived from a multi-year study of normal forest soil in Gangwon province by the National Institute of Forest Science, as reference data (Chung et al. 2000).

Changes in the physicochemical properties of soil after restoration were analyzed considering both temporal changes in single factors and synthetic changes involving multiple factors. Single-factor changes were analyzed using regression analysis, and multi-factor changes were analyzed using ordination. For ordination of stands, the physicochemical properties of soil were subjected to DCA (Detrended Correspondence Analysis) (Hill 1979).

RESULTS

The pH, organic matter (OM), total N, available P, and exchangeable Ca in the surface soil showed significant changes in the years following reclamation (Fig. 1). Soil pH and exchangeable Ca decreased exponentially with the number of years since reclamation, while OM increased linearly, and total N and available P increased exponentially.

The physicochemical properties of subsurface soil showed a somewhat different pattern of changes over time (Fig. 2). The organic matter, available P, and exchangeable Ca and Mg contents in the soil changed significantly with time since reclamation. The organic matter increased logarithmically and the available P increased exponentially, while the exchangeable Ca decreased exponentially, and the Mg decreased logarithmically. The changes in the subsurface soil were not as substantial as those in the surface soil. This result suggests that facilitation effects due to establishment and growth of plants primarily affect the surface soil layer.

Ordination based on the physicochemical properties of surface soil arranged the sites in the order of time since reclamation for sites that had been reclaimed less than 7 years prior to the study. However, sites that had been reclaimed more than 15 years prior to the study were not arranged in order (Fig. 3). The result of ordination based on subsurface soil samples showed a similar pattern (Fig. 4).

DISCUSSION

Tools for Evaluation of Restoration Effects

Numerous ecological parameters can be used as quantitative criteria for evaluation of the success of restoration projects. Assessment of restoration practices includes evaluation of habitat conditions and the presence or absence of naturally occurring species (Strykstra et al. 1998). Restoration goals are usually set as benchmarks for the evaluation of restoration projects (Aronson et al. 1993, Jackson et al. 1995). Many anthropogenic sites subjected to rehabilitation share features with natural primary seral communities. Therefore, restoration ecologists have used Odum's (1969) succession trends to identify attributes for judging restoration success. Ewel (1987) listed five criteria for judging the success of ecosystem reconstruction: 1) self-sustainability, 2) resistance to invasion of undesirable species, 3) original productivity, 4) nutrient retention, and 5) integrated biotic interaction. Hobbs and Norton (1996) listed six ecosystem attributes that should be restored: 1) composition and relative abundance of species, 2) vertical arrangement of vegetation and soil components, 3) horizontal arrangement of ecosystem components, 4) heterogeneity of components, 5) ecosystem functions, such as energy transfer and matter cycling, and 6) succession dynamics and resilience.

Numerous ecological parameters can be used as quantitative criteria for evaluating restoration success. For example, Choi and Wali (1995) and Choi and Pavlovic (1998) used DCA to monitor succession trajectories in mine tailings in northern New York and restored sand prairie in Indiana, and Bishel Machung et al. (1996) and Zedler and Callaway (1999) used the total nitrogen content in soil as a parameter for evaluating restoration success in restored wetlands.

Confirmation of Restoration Effects in Reclaimed Coal Mines

Changes in the physicochemical properties of soil with developmental stage may be used for assessment of the effectiveness of restoration projects. Most soil parameters did not differ significantly in surface and subsurface soils (Figs. 1 and 2). However, total nitrogen, which increased significantly over time in surface soil, did not significantly change in subsurface soil. Organic matter also showed different patterns at different depths, increasing arithmetically in surface soils, but logarithmically in subsurface soils. These results suggest that soil amelioration due to biological processes such as the establishment and growth of vegetation progresses more quickly in surface soil than in subsurface soil.

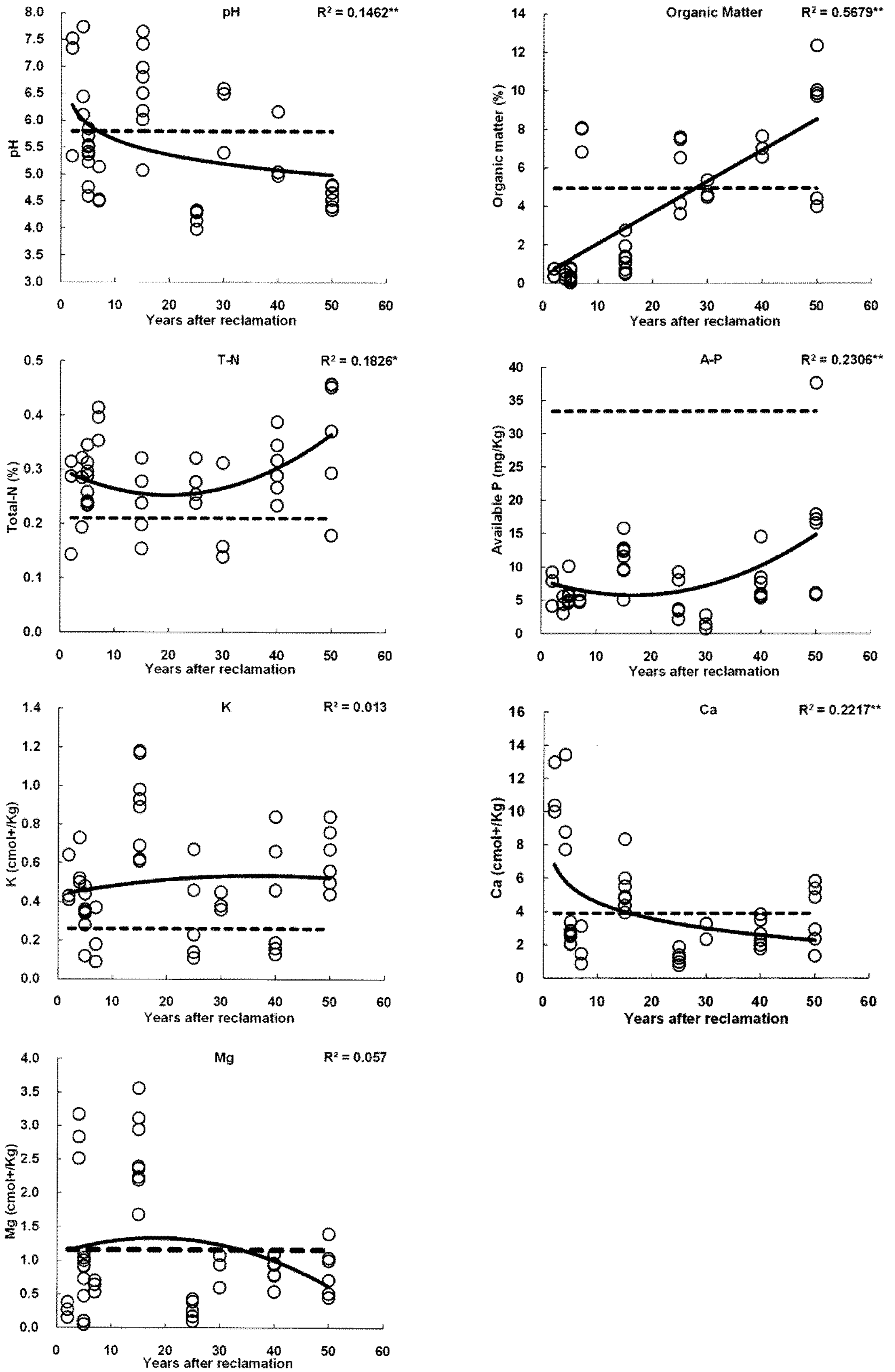

Fig. 1. Changes in the physicochemical properties of surface soil after reclamation. The dotted horizontal line in each graph indicates the reference value obtained from normal forest in Gangwon province.

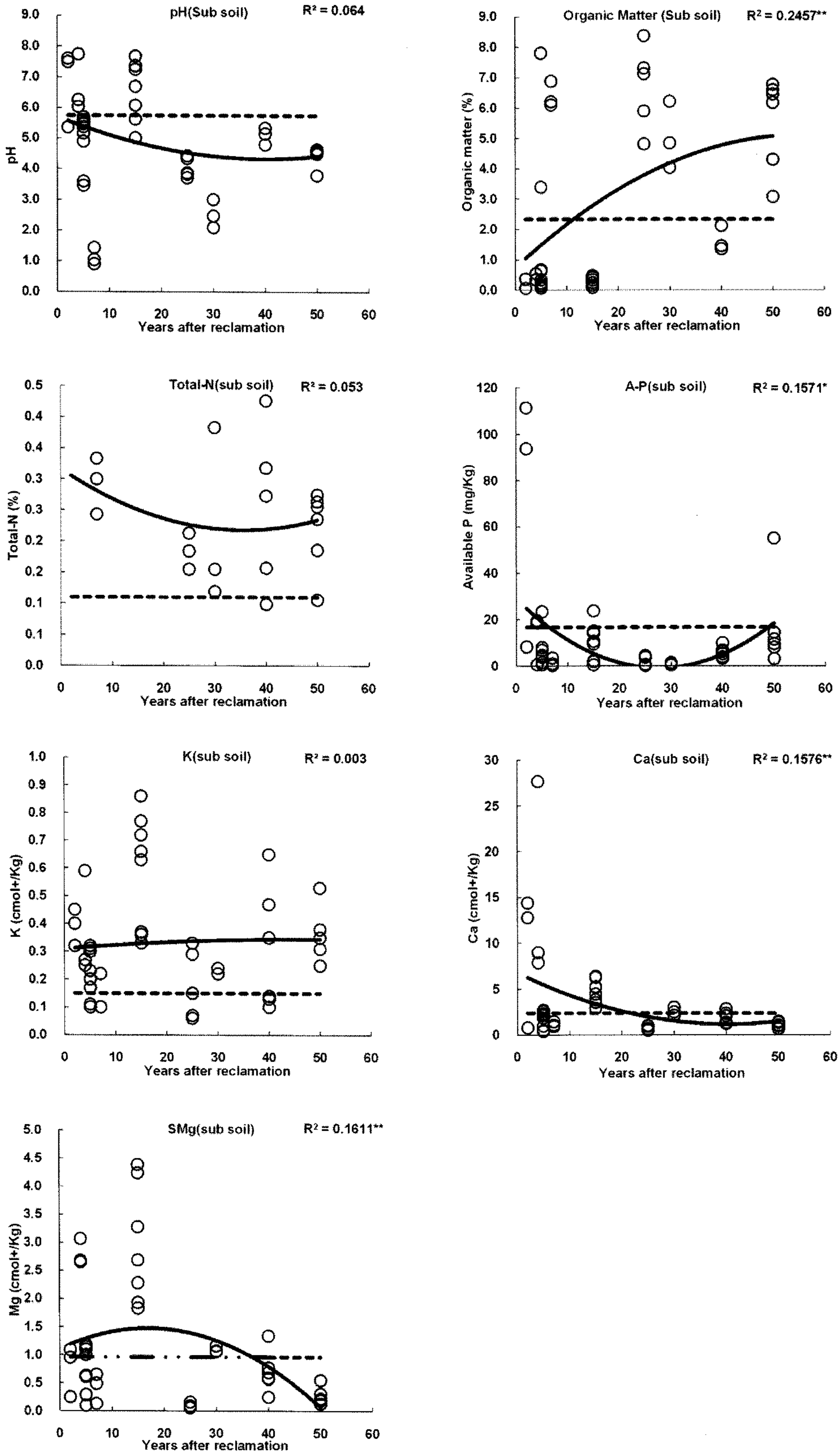

Fig. 2. Changes in the physicochemical properties of subsurface soil after reclamation. The dotted horizontal line in each graph indicates the reference value obtained from normal forest in Gangwon province.

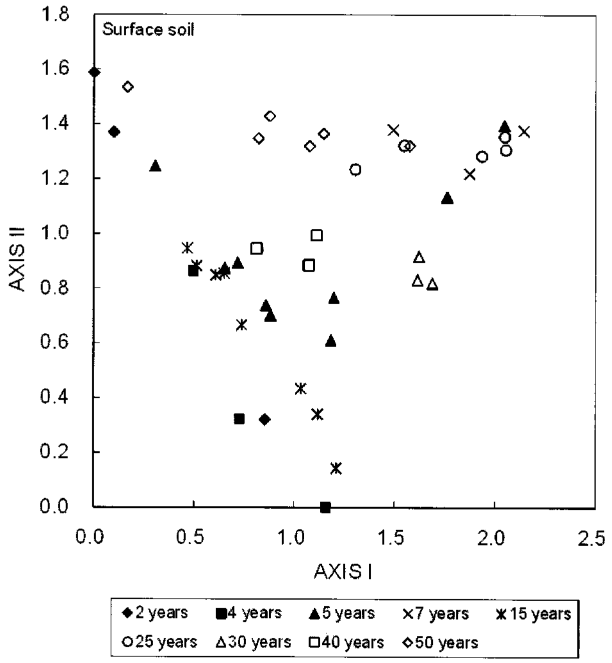

Fig. 3. Stand ordination based on physicochemical properties of surface soil.

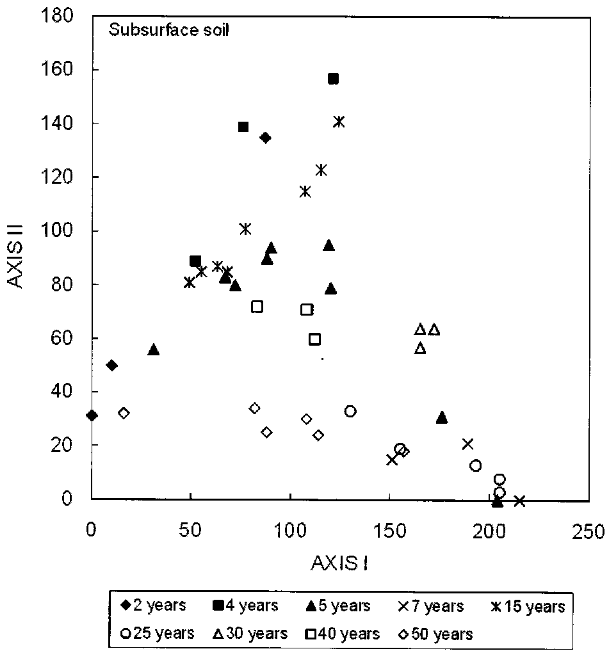

Fig. 4. Stand ordination based on physicochemical properties of subsurface soil.

The pH and available P were lower in restored soils than in typical soil from reference forests in the late successional stages, whereas the total N and exchangeable K were higher than the reference values. On the other hand, the organic matter and exchangeable Ca and Mg contents were similar in restored and reference soils. The organic matter content increased significantly in the restored soils with advancing developmental stage; it was lower in the early stages of succession in restored soil, but was higher than the reference level in the later stages of succession.

These results suggest that abiotic parameters in restored forests generally display desirable effects of restoration as introduced vegetation progresses through different developmental stages. Available phosphorus also increased significantly over time following reclamation, but the level fell much short of the reference value even after long periods of time had passed (Chung et al. 2000). This result suggests that supplemental phosphorus should be added to soils as a part of restoration projects. When we assessed restoration success in the study area based on biotic features, we confirmed that the restoration had been successful in promoting biodiversity but had not resulted in the target species composition (Lee et al 2007a). Abiotic conditions in coal mine spoils were very similar to those of an early successional stage habitat. Therefore, adding additional organic matter to the soil in the early stages of reclamation would likely improve restoration success. In particular, compost from livestock waste might be an excellent soil ameliorator as it contains high levels of available phosphorus as well as organic matter (Lee et al. 2007b).

The result of stand ordination based on the physicochemical properties of soil showed that stands tended to be arranged in the order of reclamation age in the early stages of rehabilitation, while stands that had been reclaimed more than 15 years prior to the study were not arranged in order. This result suggests that soil amelioration may be required in the early stages and that autogenic effects may become more important as the vegetation grows.

The ideal way to assess long-term changes in the physicochemical properties of soil following rehabilitation would be to repeatedly sample the same sites for many years or to identify rehabilitation sites of different ages in which all other factors are the same. Clearly, our study was not able to control for variation in factors other than time since rehabilitation, which may explain the substantial variation that we found in the physicochemical properties of rehabilitated soils. Nonetheless, we were able to identify consistent patterns of ecological changes in reclaimed coal mine spoils from our data, which therefore provide baseline data for ecological restoration of abandoned coal mine spoils.

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