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Soil Organic Matter and Nutrient Accumulation at the Abandoned Fields

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Abstract : Since vegetation significantly influences on soil carbon and nutrient storage, vegetation change has been focused on terrestrial carbon and nutrient cycling studies. In this study we investigated soil carbon and major nutrient capitals at the abandoned fields, which had different vegetation composition: a three year abandoned field (AGR_3), two ten years abandoned fields (PD_{10} dominant with *Pinus densiflora* and *Fraxinus rhynchophylla* and PM_{10} dominant with *Populus maximowiczii*), and an over sixty years forest (FOR_{60}), which were located at Hongcheon-gun, Kangwon-do, South Korea. Both main effects for organic matter (%) were significant: shallow soil > deep soil and $FOR_{60} = PM_{10} > AGR_3 = PD_{10}$. Nitrogen concentrations at PM_{10} were the highest, while the lowest at PD_{10}. Available phosphorus concentrations were the highest at PD_{10}, which were over 10 times of site FOR_{60} and AGR_3 at 0-10 cm soil depth. The average organic matter (173 Mg ha^{-1}) and nitrogen contents (10 Mg ha^{-1}) of PM_{10} and FOR_{60} were higher than those of AGR_3 and PD_{10} by 57% and 42%, respectively. The available phosphorus contents above 30 cm mineral soil at PD_{10} (3.8 Mg ha^{-1}) and PM_{10} (1.3 Mg ha^{-1}) were over 120 times and 40 times more than at FOR_{60}. Calcium (3.7 Mg ha^{-1}) and magnesium contents (2.8 Mg ha^{-1}) at FOR_{60} were twice or three times higher than at other sites. Organic matter amounts in 0-10 cm and 10-30 cm soil had significant positive relationships with nitrogen, calcium, and magnesium contents, but not available phosphorus and potassium contents. This study could not identify the effect of chronological factor and vegetation composition on soil carbon and nutrient capital owing to diverse topography as well as limited study sites. However, this study suggests the accuracy of investigation for regional carbon and nutrient sequestration can be achieved by considering the period of abandoned time on the fields and the land use types. These results may suggest the benefits of forest restoration for soil carbon and nutrient accumulation in marginal agricultural lands in South Korea.

Key words : *bulk density, calcium, magnesium, nitrogen,* Pinus densiflora, Populus maximowiczii, *forest restoration*

Introduction

Land use change is universal in North and South America (Garcia-Montel and Scatena, 1994; Post and Kwon, 2000) and in Europe (Houghton, 1996) during 19^{th} and 20^{th} centuries. In Korea, area of agricultural abandonment has been increased since 1970s because of prohibition of fire-rotated cultivation, decrease of farmer's population, and increase of labor cost. These changes in land use are very important in local and global bio-geochemical cycles and vegetation dynamics. Vegetation recovery with tree species is very important in reducing greenhouse gas of atmosphere.

Because previous land management significantly influences on soil nutrient pools and vegetation trajectories, land use change persistently impacts on soil carbon, nutrient pools, and vegetation dynamics (Compton *et al.*, 1998; Johnson, 1992; Uri *et al.*, 2008). In studying vegetation patterns, historical land use change has been increasingly recognized throughout worldwide (Lee and Kim, 1995; Motzkin *et al.*, 1996; Whitney and Foster, 1988).

Generally, soil carbon and nutrient stocks decrease after conversion from pasture to conifer plantation (Gifford 2000, Guo *et al.*, 2007), but the storage of soil carbon and nutrient depends on climate conditions and landscape. For example, agricultural activity decreased soil carbon by 30% and soil nitrogen by 8% in temperate soils (Johnson, 1992; Post and Mann, 1993).

As succession progressed, vegetation has significantly influenced on soil physical and chemical processes and

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Table 1. Site characteristics and dominant vegetation at the study sites.

Site	Year	Elevation (m a.s.l.)	Slope (°)	Dominant species
AGR_3	~3	690	10	***Lespedeza cyrtobotrya***, *Rubus crataegifolius*, *Stephanandra incise*, *Erigeron annuus*
PD_{10}	~10	620	3	***Pinus densiflora***, *Fraxinus rhynchophylla*, *Salix caprea*, *Lespedeza maximowiczii*, *Populus koreana*
PM_{10}	~10	625	6	***Populus maximowixii***, *Salix chaenomeloides*, *Weigela subsessilis*, *Sorbaria sorbifolia*
FOR_{60}	>60	705	10	***Fraxinus rhynchophylla***, *Pinus densiflora*, *Tilia amurensis*, *Fraxinus mandshurica*

*Species with bolded letters are major dominant trees.

vise versa soil properties originated from geology and topography influence on species composition and ecosystems production. These relationships between soil and vegetation are changed with succession stage, but changes in soil organic matter and nutrient pools after agricultural abandonment are not well understood because these are very site specific.

The purpose of this study was to compare soil organic matter and nutrient accumulation in the abandoned fields and adjacent mature forest. In this study we investigated soil carbon and major nutrient capitals at three abandoned fields, which had different vegetation composition, and an over sixty year forest.

Materials and Methods

1. Study sites

The study site was located at the gentle slope valley, named as "Elsoodong", in Nae-myeon, Hongcheon-gun, Kangwon-do, South Korea (37°44′ N, 128°30′ E). Ecological research has been operated in the valley by Korea Forest Research Institute (KFRI) to produce "Ecological Descriptive Map" from 2007 (KFRI, unpublished data). This region is one of branch of Odaesan Mt., which is one of Korea National Parks.

The annual temperature is 8.9°C. The lowest and highest monthly temperature are 3.6°C and 14.3°C, respectively, and annual precipitation is 134 cm, which is a little higher than the average of national precipitation (127 cm) (Korea Metrological Office, 2001).

The region is underlain by granite gneiss. Soils are classified as dry brown soil or wet brown soil (KFRI, unpublished data). Soils are deep, well drainage and fertile except ridges.

This study was conducted at the abandoned fields, which have been increased in the region because of tensed cold-war situation in 1960s, decreased local population in 1980s, and recently expansion of National Park. These were composed of a three year abandoned field, two ten years abandoned fields, and an over sixty years forest, which were located within 2 km in distance. These study sites were selected based on similarity of topography and aspect.

The three year abandoned field (hereafter called as 'AGR_3' for site name) was closely located with the over sixty years forest (hereafter called as 'FOR_{60}' for site name) by 30 m distance (Table 1). The former site was dominant by herbaceous species and *Lespedeza* spp. and the latter with no disturbance for 60 years was dominant by mature stage *Pinus densiflora* and *Fraxinus rhynchophylla*. Two ten years abandoned sites were closely located, but contrasted with each other in species composition: one site was dominant with sapling stage *Pinus densiflora* and *Fraxinus rhynchophylla* (hereafter called as 'PD_{10}' for site name) and the other site was dominant with sapling stage *Populus maximowiczii* (hereafter called as 'PM_{10}' for site name). Eight to fifteen sprouts per stool of *P. maximowiczii* were about 3 m in height at site PM_{10} and all harvested stems have been decomposed on the forest floor for 2 years (personal estimation).

2. Soil sample collection

One hundred transect was set vertically with slope at each site. The first sampling point was randomly selected and another five points were systematically located on the line every 15 m.

Soils for bulk density (g cm^{-3}) were sampled at 0-10 cm and 10-30 cm depth after removing litters on the transect. At the same locations, 500 g soils were also sampled to analyze physical and chemical properties. To reduce space variations in physical and chemical properties, additional two 500 g soils were sampled at either sides of 3 m distance and composited samples from the same depth (n = 6 per transect). All soil samples were kept in cool temperature until the analysis.

3. Soil analysis

Soil samples were analyzed at the soil physical and chemical analysis lab in KFRI. Bulk density was measured after drying samples for 3 days at 105°C. Soil texture and organic matter amount were measured by hydrometer method at 30°C and Tyurin method, respectively. Soils were analyzed for pH by 10 g soil mixing with distilled water with 1:5 ratio.

Total nitrogen was analyzed by Micro – Kjeldahl method with 1 g soil. Available phosphorus (P_2O_5) was measured by Lancaster method and exchangeable K, Ca, Mg were determined in 1 N NH_4OAc extracts with Atomic Absorption Spectrometer (AA280FS, USA). CEC was determined in 1 N HN_4OAc and 1 N CH_3COOH extracts with Brown method.

Soil organic matter and nutrient amount were calculated by multiplying concentrations at the sampling locations with bulk density and soil depth. Conversion factor, 0.58, was used to produce soil carbon concentration from soil organic matter. Even though coarse fraction ratio is important in calculating carbon and nutrient contents, this was not measured because of difficulty of digging soil. We assumed coarse fraction ratio was same among sites.

4. Statistic analyses

Bulk density, organic matter, pH, N, P, K, Ca, Mg concentrations, and CEC were compared among two main factors, site and soil depth. Analysis of variance (ANOVA) was applied to test the effects of site and soil depth on soil properties.

Organic matter, N, P, K, Ca, and Mg contents per unit area were not compared between soil depths because each soil increment was different. One way ANOVA with Duncan's multiple comparison tests was applied to contents comparison.

Correlation analyses were used to test the relationship between bulk density and nutrient concentrations and between bulk density and nutrient contents. All probabilities were tested at the significant level at 0.05.

Results

1. Soil physical and chemical properties

The soil texture of all study sites was loam or silt loam at both depths except site PD_{10}, which was sandy loam (Table 2). As expected based on soil texture, bulk density was the highest at PD_{10} and the lowest PM_{10} at 0-10 cm soil depth (Table 2 and 3). At 10-30 cm depth, bulk density was the highest at PD_{10}, but other sites were not different.

There was no interaction effect on organic matter, but both main effects were significant: shallow soil > deep soil and $FOR_{60} = PM_{10} > AGR_3 = PD_{10}$. The organic matter at FOR_{60} was more double than that of PD_{10}.

Soil pH did not have interaction effect, but FOR_{60} was the highest and other sites were not different. Acidity in shallow soil was lower than in deep soil (Table 2 and 3). Like pH, there was no interaction effect of site and soil depth for nitrogen (Table 2). Nitrogen concentrations at PM_{10} were the highest, but not significantly different with FOR_{60}, and the lowest at PD_{10}.

Available phosphorus and exchangeable potassium concentrations showed significant interaction effects. Avail-

Table 2. Soil physical and chemical characteristics at the study sites.

Soil depth (cm)	Site	Texture	Bulk density ($g\ cm^{-3}$)	Organic matter (%)	pH
0-10	AGR_3	L	0.76 (0.05)	6.5 (0.5)	5.2 (0.1)
	PD_{10}	SL	0.96 (0.07)	4.4 (0.6)	5.2 (0.1)
	PM_{10}	L / SiL	0.58 (0.02)	8.6 (0.3)	5.2 (0.1)
	FOR_{60}	L	0.80 (0.04)	9.2 (0.7)	5.4 (0.1)
10-30	AGR_3	L / CL	0.83 (0.05)	3.6 (0.4)	5.1 (0.1)
	PD_{10}	SL	1.07 (0.06)	3.4 (0.6)	5.1 (0.1)
	PM_{10}	L / SiL	0.83 (0.09)	7.5 (0.8)	4.9 (0.1)
	FOR_{60}	L	0.71 (0.03)	7.0 (0.7)	5.4 (0.1)

Soil depth	Site	N	P	K	Ca	Mg	CEC
(cm)		($g\ kg^{-1}$)	($mg\ kg^{-1}$)	------------------	$cmol_c\ kg^{-1}$	------------------	
0-10	AGR_3	4.5 (0.4)	124 (47)	0.38 (0.04)	2.8 (1.1)	3.6 (1.3)	18.0 (0.5)
	PD_{10}	2.8 (0.3)	2598 (450)	0.42 (0.04)	2.6 (0.3)	3.2 (0.4)	13.9 (0.9)
	PM_{10}	5.4 (0.2)	1471 (274)	0.85 (0.04)	3.7 (0.5)	4.8 (0.6)	20.5 (0.3)
	FOR_{60}	5.4 (0.5)	17 (2)	0.46 (0.03)	6.1 (1.2)	7.6 (1.4)	20.1 (0.7)
10-30	AGR_3	2.8 (0.2)	24 (7)	0.25 (0.02)	0.7 (0.2)	0.9 (0.2)	17.2 (0.6)
	PD_{10}	2.0 (0.2)	625 (326)	0.27 (0.04)	1.2 (0.2)	1.6 (0.3)	12.3 (0.9)
	PM_{10}	4.6 (0.5)	205 (151)	0.43 (0.01)	1.6 (0.4)	2.1 (0.5)	19.9 (0.3)
	FOR_{60}	4.1 (0.4)	12 (3)	0.24 (0.02)	2.9 (0.7)	3.8 (0.9)	20.1 (0.5)

*Parentheses represent standard errors (n = 6). Abbreviations: CL, Clay loam; L, loam; SiL, Silt loam; SL, Sandy loam.

Table 3. Probability of soil physical and chemical properties at the study sites.

Sources	BD	OM	pH	N	P	K	Ca	Mg	CEC
Site	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001
Depth	0.031	<0.001	0.041	<0.001	<0.001	<0.001	<0.001	0.005	<0.001
Site × Depth	0.032	0.349	0.543	0.478	<0.001	<0.001	0.604	0.586	0.571

*Abbreviations: BD, bulk density; OM, organic matter.

Table 4. Correlation analysis between organic matter, pH, and nutrient concentrations at 0-10 cm mineral soil in four study sites.

	Organic matter	pH	N	P	K	Ca	Mg
pH	0.486						
	(0.016)						
N	0.954	0.443					
	(<0.001)	(0.030)					
P	-0.366	-0.375	-0.408				
	(0.086)	(0.078)	(0.053)				
K	0.474	0.151	0.444	0.120			
	(0.019)	(0.482)	(0.030)	(0.587)			
Ca	0.729	0.853	0.670	-0.307	0.226		
	(<0.001)	(<0.001)	(<0.001)	(0.155)	(0.288)		
Mg	0.748	0.852	0.683	-0.320	0.258	0.998	
	(<0.001)	(<0.001)	(0.000)	(0.137)	(0.224)	(<0.001)	
CEC	0.869	0.302	0.875	-0.410	0.446	0.442	0.460
	(<0.001)	(0.151)	(<0.001)	(0.052)	(0.029)	(0.031)	(0.024)

*Parentheses are the probability of the correlation coefficients.

Table 5. Correlation analysis between organic matter, pH, and nutrient concentrations at 10-30 cm mineral soil in four study sites.

	Organic matter	pH	N	P	K	Ca	Mg
pH	0.026						
	(0.906)						
N	0.971	-0.010					
	(<0.001)	(0.963)					
P	0.019	-0.068	-0.068				
	(0.931)	(0.753)	(0.754)				
K	0.344	-0.263	0.386	-0.011			
	(0.108)	(0.225)	(0.069)	(0.961)			
Ca	0.595	0.609	0.551	0.041	0.106		
	(0.002)	(0.002)	(0.005)	(0.850)	(0.631)		
Mg	0.612	0.587	0.559	0.082	0.082	0.996	
	(0.002)	(0.003)	(0.005)	(0.705)	(0.709)	(<0.001)	
CEC	0.779	0.044	0.820	-0.296	0.161	0.316	0.328
	(<0.001)	(0.837)	(<0.001)	(0.160)	(0.463)	(0.133)	(0.118)

*Parentheses are the probabilities of the correlation coefficients.

able phosphorus was the highest at PD_{10} and the second at PM_{10}, which were above 10 times of site FOR_{60} and AGR_3 at 0-10 cm soil depth, but there was no difference among sites at 10-30 cm depth (Table 2 and 3). Exchangeable potassium was the highest at PM10 and other sites were not different at both soil depths.

The main effects, site and soil depth, were significant for exchangeable calcium and magnesium concentrations (Table 2 and 3). The calcium and magnesium concentrations at FOR_{60} and shallow soil were more twice than those at AGR_3 at both soil depths and deep soil, respectively.

Soil organic matter (%) had significant positive relationship with most soil properties measured in this study

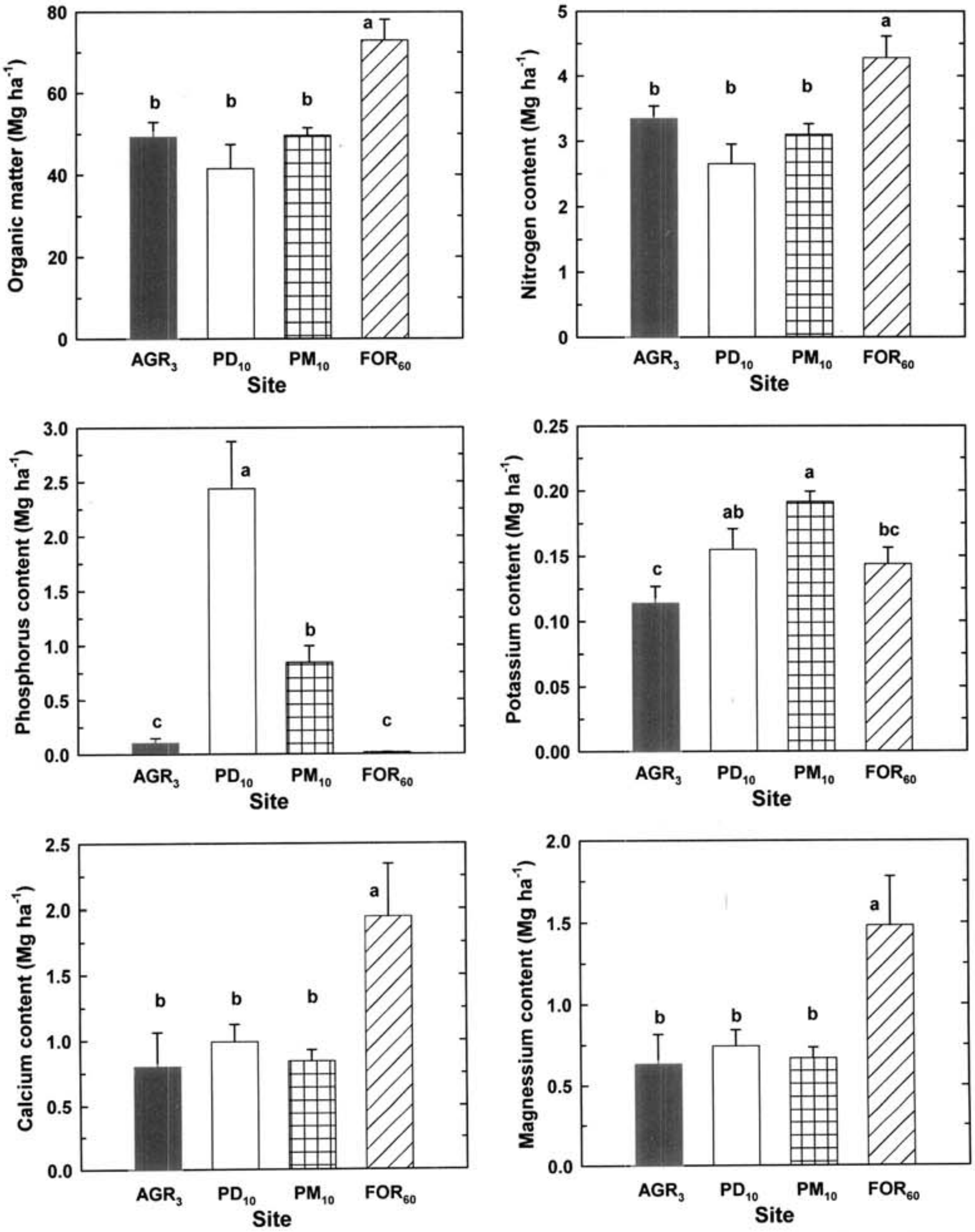

Figure 1. Organic matter and nutrient contents at 0-10 cm mineral soil at the study sites. Different letters in the figure show significant differences among sites at $\alpha = 0.05$.

(Table 4 and 5). However, available phosphorus at 0-10 cm and available phosphorus and potassium at 10-30 cm depth were not related with soil organic matter. The strength of the relationship among soil properties was relatively higher at 0-10 cm soil depth than at 10-30 cm.

2. Soil organic matter and nutrient accumulation

Soil organic matter, nitrogen, calcium, and magnesium storage at 0-10 cm soil depth were the highest at FOR_{60} and these were not different among other sites (Figure 1). At 0-10 cm soil depth, available phosphorus and potassium contents were the highest at PD_{10} and PM_{10}, respectively.

Unlike 0-10 cm soil depth, both organic matter and nitrogen contents were the highest at PM_{10} and the second at FOR_{60} at 10-30 cm soil (Figure 2). Organic matter amount was the lowest at AGR_3. As 0-10 cm soil depth, available phosphorus contents were the highest at PD_{10} and potassium contents were the highest PM_{10} (Figure 2). Both calcium and magnesium contents at 10-30 cm soil were the highest FOR_{60}.

The total organic matter and nitrogen contents above 30 cm mineral soil were not different between PM_{10} (171 Mg ha^{-1} for organic matter contents and 10.6 Mg ha^{-1} for nitrogen contents) and FOR_{60} (174 Mg ha^{-1} for organic matter contents and 10.6 Mg ha^{-1} for nitrogen

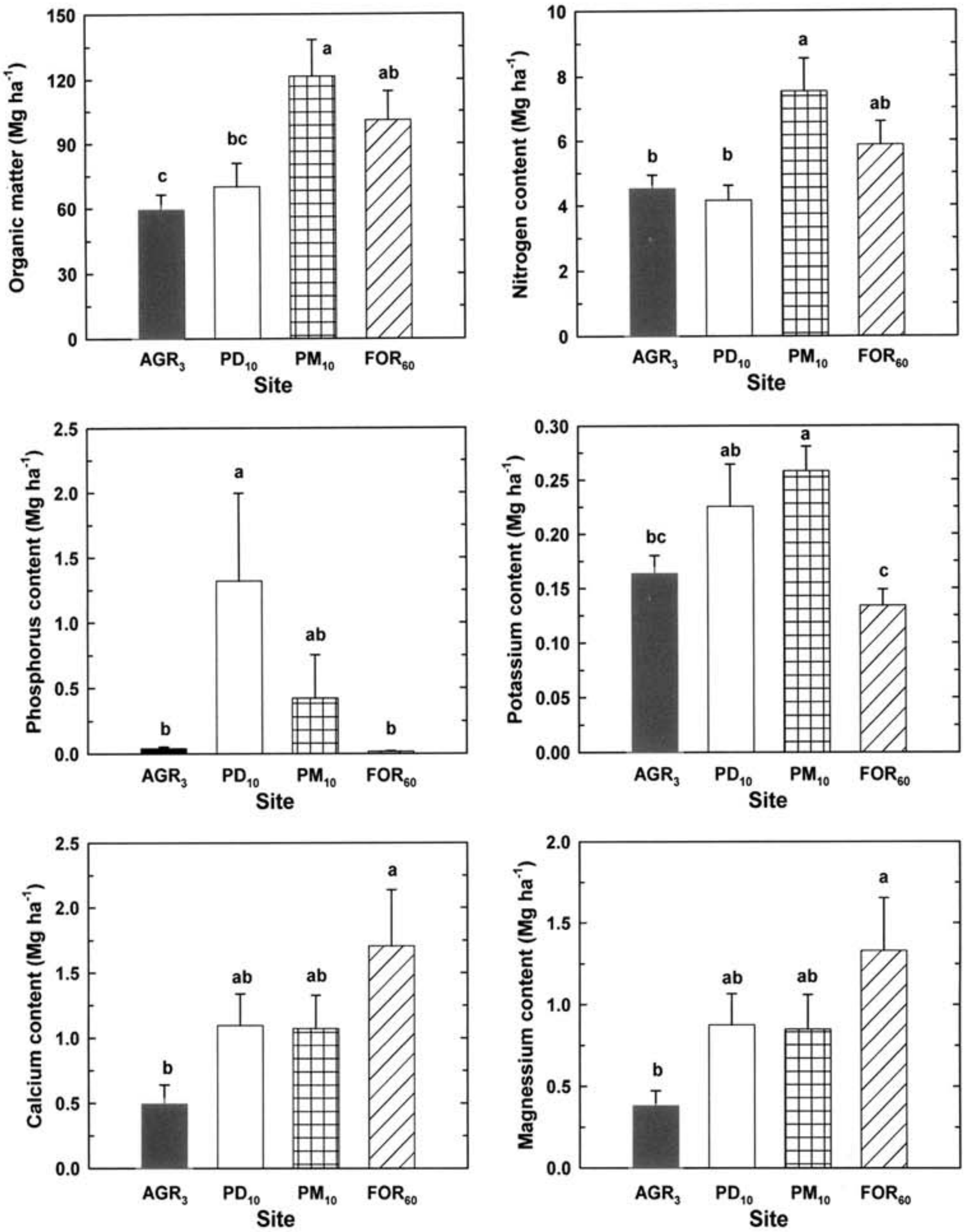

Figure 2. Organic matter and nutrient contents at 10-30 cm mineral soil at the study sites. Different letters in the figure show significant differences among sites at $\alpha = 0.05$.

contents) because organic matter at PM_{10} was lower by 32% in 0-10 cm soil, but higher by 20% in 10-30 cm soil than at FOR_{60} and like organic matter amounts, nitrogen contents at PM_{10} were lower by 28% in 0-10 cm soil, but higher by 28% in 10-30 cm soil than at FOR_{60} (Figure 1 and 2). The average of PM_{10} and FOR_{60} for organic matter and nitrogen contents was higher than the average of AGR_3 and PD_{10} by 57% and 42%, respectively.

The available phosphorus contents above 30 cm mineral soil at PD_{10} (3.76 Mg ha^{-1}) and PM_{10} (1.27 Mg ha^{-1}) were 123 times and 41 times more than at FOR_{60}. Calcium (3.65 Mg ha^{-1}) and magnesium contents (2.82 Mg ha^{-1}) at FOR_{60} were twice or three times higher than at other sites.

Like the relationship between organic matter (%) and soil properties, organic matter amounts in 0-10 cm and 10-30 cm soil had significant positive relationship with nitrogen, calcium, and magnesium contents, but not available phosphorus and potassium contents (Table 6 and 7).

Discussion

The previous agricultural activity such as fertilization seems to influence on soil chemical properties at the abandoned agricultural lands. The lowest nitrogen concentrations in PD_{10} may be explained by partly vegetation and by partly fertilization. Because major components

Table 6. Correlation analysis between organic matter and nutrient contents at 0-10 cm mineral soil in four study sites.

	Organic matter	N	P	K	Ca
N	0.950				
	(<0.001)				
P	-0.297	-0.352			
	(0.168)	(0.100)			
K	0.045	-0.055	0.103		
	(0.834)	(0.799)	(0.640)		
Ca	0.748	0.703	-0.197	0.190	
	(<0.001)	(<0.001)	(0.368)	(0.374)	
Mg	0.761	0.710	-0.224	0.212	0.998
	(<0.001)	(<0.001)	(0.305)	(0.321)	(<0.001)

*Parentheses are the probability of the correlation coefficients.

Table 7. Correlation analysis between organic matter and nutrient contents at 10-30 cm mineral soil in four study sites.

	Organic matter	N	P	K	Ca
N	0.967				
	(<0.001)				
P	0.303	0.228			
	(0.151)	(0.284)			
K	0.078	0.122	0.222		
	(0.723)	(0.579)	(0.308)		
Ca	0.572	0.526	0.234	0.096	
	(0.004)	(0.008)	(0.272)	(0.664)	
Mg	0.605	0.550	0.290	0.074	0.994
	(0.002)	(0.005)	(0.170)	(0.738)	(<0.001)

*Parentheses are the probability of the correlation coefficients.

at fertilizer used in farming are nitrogen and phosphorus, nitrogen could be in soil as like as phosphorus. However, because pine trees dominant at PD_{10} have low nitrogen accumulation capacity in forest floor relatively to deciduous species (Compton *et al.*, 1998; Finzi *et al.*, 1998) and movement of nitrogen is faster than that of phosphorus (Brady and Weil, 2002), nitrogen could be leached and exported to stream. Second reason is increased soil organic amount at PM_{10} and FOR_{60} compared to PD_{10}, which increased nitrogen availability in the forest floor (Table 4 and 5). In the initial stage of succession, vegetation mostly influenced on top soil layer, but soil microbes and plant roots improved circulation nitrogen to deep soil and leached nitrogen was accumulated in the deep soil (Ross *et al.*, 1999).

In this study, the major reason for the highest phosphorus concentrations at PD_{10} may be the previous fertilizer even though 10 years was passed after abandonment. Because bedrock in this area is covered by granite (KFRI, unpublished data), which has tiny phosphorus amount (Blum *et al.*, 2008), soil developed from this bedrock has very low available phosphorus. Under very low phosphorus concentrations, vegetation cannot uptake and circulate large amount of phosphorus. So phosphorus concentrations should be low if there was no phosphorus importing from the outside.

Another reason is phosphorus natural properties why we assumed that fertilization caused high available phosphorus at both 0-10 cm and 10-30 cm soil depth at PD_{10} and PM_{10}. Applied phosphorus as a fertilizer accumulated at the shallow soil for long period time owing to low solubility and high adsorption capability (Brady and Weil, 2002). Some of them used by vegetation and small amount of phosphorus was leached to deep soil.

Soil texture is one of influential factor for soil chemical properties in this study. Soil texture as well as organic matter showed high correlation with nitrogen, calcium, and magnesium concentrations, but not with accumulated phosphorus and potassium (Table 4 and 5) because of high mobilization of potassium and fertilizer effect for phosphorus as mentioned above (Table 4 and 5). Calcium and magnesium should be from bedrock and deposition from atmosphere because these nutrients were not major components in agricultural fertilizer. Unfortunately, we cannot chase the source of these and also do not have data of deposition amount of calcium and magnesium. Long term research should be done to improve understanding of biogeochemical cycling in abandoned fields. Even though calcium and magnesium was small from deposition and bedrock, uptake and circulation for a few decades by vegetation increase these nutrients at the organic and top mineral soil horizons (Figure 1 and 2).

The topography and landscape should be considered to understand the results in this study. Two study sites, PD_{10} and PM_{10}, which are very closely located, but soil texture is very different. If there were not soil dressing at these sites, stream effect may be significant in soil texture. Stream was very near from the sites, about 20 m in distance. PM_{10} is higher in elevation than PD_{10} by about 5 m. For ten years, PD_{10} may get overflow and sands be deposited in this site by observation small sand dune in the site and stream direction. So we assumed overflow is one of reason why soil texture is so different between two sites. Therefore, the effect of the landscape and form of stream should be considered to understand, especially overflow normally happened in the first and second stream in summer storm seasons in Korea. Different vegetation composition could influence on texture in these sites, but ten years are not long to change soil texture (Brady and Weil, 2002).

Different plant species significantly influence on soil organic matter accumulation for relatively short time period in this ecosystems. For instance, soil organic matter in PM_{10}, which is only 10 years abandoned, is similar to that in FOR_{60}, which is mature forest, in both shallow and deep soil depths. It is impossible to identify the effect of vegetation with previous agricultural activities such as tillage and organic fertilizer application in this study. Lots of decomposing felled trees on the forest floor is one of reason of increasing soil organic matter for the short period since leaching of organic carbon during decomposition. Furthermore, *Populus* species have high decomposition rates and increase soil organic matter (Berg and Matzner, 1997; Perala and Alban, 1982).

We changed the original purpose of our study, which were comparing the effects of vegetation composition and topography on soil carbon and nutrient accumulation chronogically, because we could not get enough sample sizes to be similar in vegetation composition and topography. So we removed one main factor, topography, and chose several sites with similar aspect and slope. Even though we selected similar sample sites after surveying as well as reference digital maps, we could not identify several influential factors such as amount of soil dressing, amount and application frequency of fertilizer, and cultivated species.

This study could not identify the effect of chronological factor and vegetation composition on soil organic matter and nutrient capital. However, this study suggests the accuracy of investigation for regional soil carbon and nutrient sequestration can be achieved by considering the period of abandoned time on the fields and the land use types. These results may suggest the benefits of forest restoration for soil carbon and nutrient accumulation in marginal agricultural lands in Korea.

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