Comparison of Organic Matter Dynamics between Natural Deciduous Broad-Leaved Forest and Adjacent Artificial Evergreen Coniferous Forest

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ABSTRACT : The purpose of this study is to clarify the effects of the conversion of the forest management type from a natural deciduous broad-leaved forest to an artificial evergreen coniferous forest based on organic matter dynamics. We investigated the amounts and carbon contents of the forest floor and the litterfall, soil chemical characteristics and cellulose decomposition rates in the natural deciduous broad-leaved forest and adjacent artificial evergreen coniferous forest. In the artificial evergreen coniferous forest were planted Japanese cypress (*Chamaecyparis obtusa*) on the upper slope and Japanese cedar (*Cryptomeria japonica*) on the lower slope. The soil carbon and nitrogen contents, CEC and microbial activity had decreased due to the conversion of the forest management type from a natural deciduous broad-leaved forest to an artificial Japanese cypress forest, and were almost the same for the conversion to a Japanese cedar forest. Under the same conditions, it is considered that the soil fertility was different by planting specific tree species because the organic matter dynamics were changed by them.

Key words : Deciduous broad-leaved forest, Evergreen coniferous forest, Organic matter dynamics, Planting, Soil fertility

INTRODUCTION

Forest soil fertility is affected by many factors including tree species, slope position, climate and so on (Kawada 1989). In order to develop various kinds of forests and the sustainable use of forest products, it is necessary to separate and evaluate each individual factor. There have been a few studies concerning the changes in soil fertility and organic matter dynamics with tree transformation under the same site conditions and stand histories.

In Japan, plantation forests of Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtusa*) represent approximately 70% of the artificial forests. It has been well-known that the Japanese cypress forests had decreased soil fertility and forest growth because of short rotation silvicultural management (Akinaga and Shibamoto 1933, Tutsumi 1987). Generally, Japanese cypress litter is easily broken into small pieces and accumulates less on the forest floor (Akai 1977, 1980, Harada 1969). Therefore, cypress litter and surface mineral soil are easily moved by raindrops (Yoshimura *et al*. 1981, Tsukamoto 1989) in the Japanese cypress forest. However, these phenomena were not reported in the Japanese cedar forest (Akai 1977, 1980, Harada 1969, Sawata and Kato 1991).

In Europe, the spruce (*Picea* spp.) plantation forests had decreased in soil pH(H_2O) and desaturation of the soil exchange complex (Ranger and Nys 1994), and proceeded to undergo podsolization (Grieve 1978). Spruce litter is low in nitrogen and high in recalcitrant compounds, with depression of the available soil nitrogen (Pastor *et al*. 1987). When a beech (*Fagus* spp.) forest is replaced by spruce, the upper soil horizon changes from mull to mor humus, the pH decreased with less exchangeable K and Ca, along with damage from podsolization (Nihlgård 1974). However, Phiha and Smolander (1997) examined the soil respiration, N mineralization and microbial biomass and found no differences in the soil under Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and silver birch (*Betula pendula*) at similar original field afforestation sites 23~24 years later. Saetre *et al*. (1999) examined the microbial biomass, microbial respiration and C, N and P mineralization rates and found no differences in soil under Norway spruce and mixed Norway spruce - birch stands. Rothe and Binkley (2001) reviewed and showed that foliage nutrient concentrations, rates of litter decomposition and pools of soil nutrients generally did not differ between mixtures and monocultures of tree species. Based on these results, when we do not consider the site conditions and stand histories, it suggests that we can not clarify the effect of tree species

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on soil fertility.

Thus, it is necessary to consider the site conditions and stand histories in order to clarify the changes in soil fertility affected by organic matter dynamics for different tree species. The purpose of this study is to clarify the effects of the conversion of the forest management type from a natural deciduous broad-leaved forest to an artificial evergreen coniferous forest based on organic matter dynamics.

MATERIALS AND METHODS

Study site

The study sites included the natural deciduous broad-leaved forest and adjacent 65-year-old artificial evergreen coniferous forest established on the upper and lower slope, respectively, in the Northern Kanto region of Japan (36°32′40″N, 139°24′30″E) (Table 1, Fig. 1). In the artificial evergreen coniferous forest were planted Japanese cypress on the upper slope and Japanese cedar on the lower slope. The main species in the natural deciduous broad-leaved forest were *Quercus mongolica*, *Carpinus tschnoskii*, *Prunus jamasakura*, and *Hamamelis japonica*. The area of these plots was about 150 m^2. A plot was set up in each stand (*i.e.*, artificial evergreen coniferous forests and the natural deciduous broad-leaved forests on the upper and lower slope). The study sites were located at 730~790 m elevation and had steep slopes (27~38°). The parent soil material was hornfels. These soil types were weakly dried brown forest soil (B_C) on the upper slope, moderately moist brown forest soil (B_D) on the lower slope (Forest Soil Division 1976) and the two sides (B_C, B_D) included Inceptisol (Soil survey staff 1997). The average tree height and diameter at the breast height of the artificial evergreen coniferous forest regardless of the slope position were 24~25 m and 32~33 cm, respectively. The number of trees was about 500/ha in the cypress forest and about 900/ha in the cedar forest. The average tree height, diameter at the breast height and the number of trees were 12~13 m, 16~17 cm and 1000~1100/ha in the natural deciduous broad-leaved forest regardless of the slope position. The artificial evergreen coniferous forest included broad- leaved trees of 2,369 trees/ha on the upper slope, and 3,678 trees/ha on the lower slope, but these broad-leaved trees were understories and the basal area of the trees was not more than 1% of the artificial evergreen coniferous forest. Hence, it is considered that the effect of the artificial evergreen coniferous forest including broad- leaved trees on the organic matter dynamics in the artificial evergreen coniferous forest was slight. The main species of broad-leaved trees in the

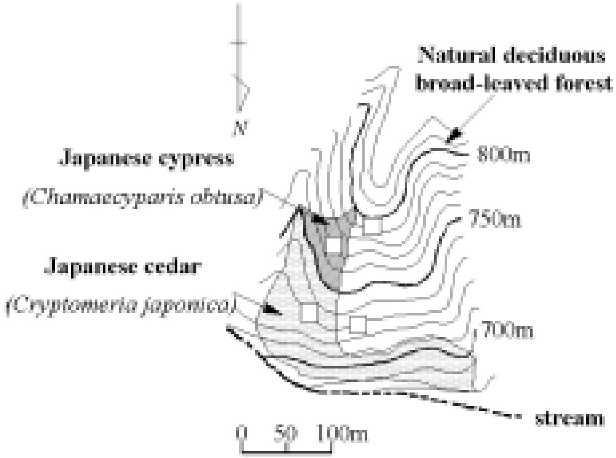

Fig. 1. Topograhical map of the experimental site and location of each plot. □, plot.

Table 1. Site characteristics

Slope	Plot	Altitude (m)	Slope (degree)	Soil type	Stand age (year)	Tree height*** (m)	Diameter at breast height*** (cm)	Number of trees (/ha)	Basal area (m^2/ha)
Upper	Artificial cypress forest	770	30	B_C	65	24.5±2.5* (2.0±0.6)	31.6±5.7* (1.2±0.7)	508* (2,369)	39.8* (0.3)
	Natural deciduous broad-leaved forest	790	27	B_C	-	12.5±3.9** (3.0±1.3)	16.9±11.2** (2.0±1.2)	1,022** (5,503)	22.9** (1.7)
Lower	Artificial cedar forest	730	38	B_D	65	24.1±2.2* (2.1±0.6)	32.9±7.1* (1.0±0.6)	897* (3,678)	76.3* (0.3)
	Natural deciduous broad-leaved forest	730	31	B_D	-	11.5±4.1** (2.7±1.0)	16.4±7.5** (1.9±1.4)	1,125** (4,022)	23.8** (1.1)

* Planted trees only, ** The upper trees only, *** Mean±SD.
The parentheses are the lower trees in each plot.

artificial evergreen coniferous forest were *Lindera praecox*, *Fraxinus mandshurica*, *Euonymus planipes*, and *Carpinus tschnoskii*.

Sampling

Litterfall samples were collected in a 1 meter in diameter circular littertrap at three points in each plot. The litterfall was collected from May 1998 to May 2000. The forest floors were collected in August 1997 within four squares of 50 cm at four points of each plot. The collected litterfall and forest floor were divided into leaves of the artificial evergreen coniferous trees, leaves of the natural deciduous broad-leaved trees, branches and bark, cones and others. These organic matters were measured using oven-dry weight (80℃). The cypress litter is easily broken down into small pieces and mixed with the soil (Sakai *et al*. 1987). Consequently, in tact mineral soil cores were collected from 0~4 and 4~8 cm depths using a 400 mL soil core sampler at six points in the cypress forest. Cypress leaves in the soil cores were measured based on their oven-dry weight (80℃), and the cypress leaves were classified by hand. The mineral soil samples for chemical analysis were collected in August 1997 from 0~10, 10~20 and 20~30 cm depths at six points in each plot.

Chemical analysis

The pH(H_2O) of the mineral soil was potentiometrically measured in a suspension with a 1:2.5 ratio of fresh soil to water (F-21, Horiba Co., Japan) (Kamewada 1997). The total carbon and nitrogen contents in the litterfall, forest floor and mineral soil were measured by the CN coder method (MT-500, Yanagimoto Co., Japan) (Yamada 1997). The cation-exchange capacity (CEC) of the mineral soils was measured by the semimicro-Schollenberger method (Bremner and Keeney 1966). The exchangeable base (K^+, Ca^{2+}, Mg^{2+}, Na^+) concentrations of the mineral soil were measured by atomic absorption spectrophotometry (170-10, Hitachi, Tokyo, Japan) (Yamasaki 1997) after extraction with 1 M CH_3COONH_4 (pH 7.0). Total carbon, nitrogen and CEC were measured on samples mixed within each plot and depth. The pH(H_2O) and exchangeable base concentrations were measured for each collected sample.

Cellulose decomposition activity

The cellulose decomposition activity was measured using buried benchkote-paper (polyethylene-backed absorbent paper) (Yamamoto 1992). From May 1999 to April 2000, 25 pieces of the benchkote-paper (5cm×20cm) were horizontally buried at depths of 0~10, 10~20 and 20~30cm without disturbing the soil surface in each plot, they were then collected during one month (four months from December to March because the soils were frozen). The collected benchkote-papers were carefully washed to remove the soil, and their dry weights were measured. The rate of decrease in the paper part was defined as the decomposition rate.

Soil temperature

The soil temperature was measured at 5, 15 and 25 cm depths in each plot for one hour.

Statistical analyses

The results described above were compared using the *t*-test at a probability level of 5% between the natural deciduous broad-leaved forest and adjacent artificial evergreen coniferous forest. The soil carbon and nitrogen contents, CEC and base saturation were excluded from the above comparison.

RESULTS AND DISCUSSION

The amounts of annual litterfall and forest floor, and turnover rates are shown in Table 2. The amount of annual litterfall in the cypress forest was 0.8 times that in the natural deciduous broad-leaved forest on the upper slope. The amount of annual litterfall in the cedar forest was 0.7 times that in the natural deciduous broad-leaved forest on the lower slope. The amount of annual litterfall in the artificial evergreen coniferous forest decreased compared to that in the natural deciduous broad-leaved forest. The amount of forest floor in the artificial evergreen coniferous forest and natural deciduous broad-leaved forest were 9.5 and 7.1 Mg/ha, respectively. The turnover rates (amount of forest floor / amount of annual litterfall) (Saitou 1974) in the natural deciduous broad-leaved forest, cypress forest and cedar forest were 1.6, 2.6 and 3.1 years, respectively. The turnover rate of leaf litter and branches in the artificial evergreen coniferous forest was 2 times that of the natural deciduous broad-leaved forest. Litterfall in the artificial evergreen coniferous forest decomposed slower than that in the natural deciduous broad-leaved forest. In general, the decomposition rate of the deciduous broad-leaves is much greater than for the litter of the coniferous leaves (Kawada 1989).

The amounts of the elements in the annual litterfall, forest floor and mineral soil are shown in Table 3. The pH(H_2O) in the cypress forest and cedar forest were comparable to that in the natural deciduous broad-leaved forest. The pH(H_2O) in the artificial evergreen coniferous forest was not different from that in the natural deciduous broad-leaved forest. The base saturation (Table 3) and net nitrification ratio to net nitrogen mineralization *in situ* (unpublished data) were factors affecting the soil acidity and were not different between the artificial evergreen coniferous forest and the natural deciduous broad-leaved forest for each slope. Therefore, the one cause of the low pH(H_2O) regardless the tree species and slope posi-

Table 2. Amounts of annual litterfall and forest floor, and turnover rate

Slope	Plot		Dry weight						
			Needles	Needles in Soil	Broad-leaves	Branches and Barks	Cones	Others	Total
			(Mg/ha)						
Upper	Artificial cypress forest								
		Litterfall***	1.6±0.2**	–	1.5±0.1**	0.4±0.1	trace	0.1±0.0*	3.6±0.4*
		Forest floor***	2.0±0.7**	1.9±0.5	1.7±0.4**	3.2±0.8	0.5±0.0**	0.2±0.0*	9.5±2.5**
		Turnover rate****	2.4*****	–	1.2	9.7	–	1.6	2.6
	Natural deciduous broad-leaved forest								
		Litterfall***	trace	–	3.2±0.3	0.6±0.4	0.5±0.5	0.1±0.1	4.4±1.2
		Forest floor***	0	–	4.2±0.5	2.7±1.0	0	0.1±0.0	7.1±1.6
		Turnover rate****	–	–	1.4	4.4	–	1.0	1.6
Lower	Artificial cedar forest								
		Litterfall***	1.2±0.1**	–	1.3±0.1**	0.3±0.1	0.1±0.0*	0.2±0.0**	3.1±0.4**
		Forest floor***	3.7±1.3**	–	2.3±0.6**	3.1±0.8*	0.3±0.0**	0.2±0.0	9.5±2.7*
		Turnover rate****	3.0	–	1.8	12.4	2.1	0.8	3.1
	Natural deciduous broad-leaved forest								
		Litterfall***	0	–	4.0±0.2	0.4±0.1	trace	trace	4.4±0.3
		Forest floor***	0	–	4.9±1.4	2.0±0.4	0	0.1±0.0	7.1±1.8
		Turnover rate****	–	–	1.2	4.7	–	–	1.6

* p<0.05, ** p<0.01 (litterfall, n=3 ; forest floor, n=4), *** Mean±SD, **** amount of forest floor/amount of annual litterfall,
***** (Needles of forest floor+Needles in soil)/Needle of annual litterfall.

tion, the organic acid was produced by organic matter decomposition because this study site was located on the north slope.

The soil carbon content in the cypress forest at a 0~30 cm depth was 0.6 times that of the natural deciduous broad-leaved forest on the upper slope. On the other hand, the soil carbon content in the cedar forest at a 0~30 cm depth was comparable to that of the natural deciduous broad-leaved forest on the lower slope. The carbon content of the annual litterfall in the cypress forest was 0.9 times that in the natural deciduous broad-leaved forest on the upper slope. The carbon content of the annual litterfall in the cedar forest was 0.8 times that in the natural deciduous broad-leaved forest on the lower slope. The degree of decrease in the soil carbon content was greater when compared with the carbon content of the annual litterfall by conversion of the forest management type to a cypress forest. The degree of decrease in the carbon content of the annual litterfall did not exert an influence on the soil carbon contents by conversion of the forest management type to a cedar forest. From the carbon contents of the annual litterfall and soil, it is considered that the cypress litterfall had been easily mineralized and had been difficult to accumulate relative to the litterfall in the broad-leaved forest on the upper slope, while the cedar litterfall had been mineralized with difficulty which provided a rapid accumulation relative to the litterfall in the broad-leaved forest on the lower slope.

The soil nitrogen content in the cypress forest at a 0~30 cm depth was 0.3 times that of the natural deciduous broad-leaved forest on the upper slope. The soil nitrogen content in the cedar forest at a 0~30 cm depth was comparable to that of the natural deciduous broad-leaved forest on the lower slope. The nitrogen content of the annual litterfall in the cypress forest was 0.6 times that in the natural deciduous broad-leaved forest on the upper slope. The nitrogen content of the annual litterfall in the cedar forest was 0.5 times that in the natural deciduous broad-leaved forest on the lower slope. This tendency was analogous to the soil carbon content. One cause of this tendency is that most of the nitrogen were from organisms in the soil and were moved by biological (*i.e.*, organic) factors (Kawada 1989).

Table 3. Amounts of elements in the annual litterfall, forest floor and mineral soil

Slope	Plot		pH(H_2O)***	Carbon (Mg/ha)	Nitrogen (kg/ha)	C/N	CEC (kmol(+)/ha)	Exchangeable bases*** (kg/ha)	Base saturation (%)
Upper	Artificial cypress forest	Litterfall	–	1.7	25	66	–	–	–
		Forest Floor	–	4.7	102	46	–	–	–
		Mineral soil depth 0~10cm	4.18±0.15	27.1	930	30	87.7	80.8±17.2	4.0
		10~20cm	4.53±0.15	19.7	140	140	70.9	35.6±13.2	2.2
		20~30cm	4.72±0.06*	13.3	0	–	53.4	22.4±6.3**	1.8
		Total of Mineral soil	–	60.1	1,070	56	212.0	139±37	3.0
	Natural deciduous broad-leaved forest	Litterfall	–	2.0	43	47	–	–	–
		Forest Floor	–	3.7	100	37	–	–	–
		Mineral soil depth 0~10cm	4.41±0.19	43.8	1,930	23	104.2	96.7±33.3	3.9
		10~20cm	4.58±0.05	37.6	1,240	30	89.5	39.8±11.8	1.8
		20~30cm	4.59±0.06	20.5	280	74	63.3	27.1±9.2	2.0
		Total of Mineral soil	–	101.9	3,450	30	257.1	164±55	2.8
Lower	Artificial cedar forest	Litterfall	–	1.5	27	55	–	–	–
		Forest Floor	–	4.9	87	56	–	–	–
		Mineral soil depth 0~10cm	4.30±0.16	38.3	2,000	19	109.5	175±49.9	7.3
		10~20cm	4.72±0.14	23.3	1,140	20	66.2	64.6±18.7**	4.7
		20~30cm	4.81±0.18	23.3	990	24	73.4	72.2±21.5**	4.9
		Total of Mineral soil	–	84.9	4,130	21	249.1	312±91**	6.1
	Natural deciduous broad-leaved forest	Litterfall	–	2.0	55	36	–	–	–
		Forest Floor	–	3.6	123	30	–	–	–
		Mineral soil depth 0~10cm	4.41±0.11	35.6	1,760	20	93.8	123±43.9	6.0
		10~20cm	4.59±0.14	26.0	1,180	22	62.1	49.6±13.4	3.3
		20~30cm	4.79±0.17	23.0	730	31	62.8	45.4±14.3	3.3
		Total of Mineral soil	–	84.6	3,670	23	218.8	218±71	4.5

* $p<0.05$, ** $p<0.01$ ($n=6$). *** Mean±SD.

The CEC in the cypress forest at a 0~30 cm depth was 0.8 times that of the natural deciduous broad-leaved forest on the upper slope. The CEC in the cedar forest at a 0~30 cm depth was comparable to that of the natural deciduous broad-leaved forest on the lower slope. The positive correlations between the total C concentrations and CEC are known for the forest soil of Japanese cedar (Kato *et al*. 1989); this study was the same as that mentioned above. The soil carbon and nitrogen contents and CEC in the cypress forest were less relative to those in the natural deciduous broad-leaved forest. It shows that the soil fertility decreased in the cypress forest.

The cellulose decomposition rates are shown in Fig. 2. In each plot for each soil depth, the highest cellulose decomposition rates occurred in the summer, while the lowest cellulose decomposition rates occurred in the winter. The relationships between the monthly mean soil temperature at the 5 cm soil depth and monthly cellulose decomposition rates at the 0~10 cm soil depth are shown in Fig. 3. The cellulose decomposition rates are affected by the soil temperature and were suppressed by 5℃ or less. This tendency was the same as that except for the 0~10 cm depth (data not shown). Hence, the cellulose decomposition rates reflected the microbial activity

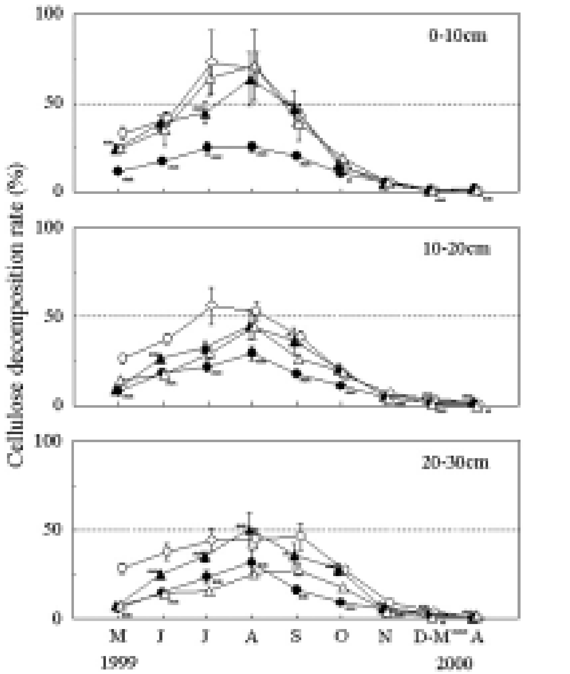

Fig. 2. Seasonable changes in monthly cellulose decomposition rates. ●, artificial cypress forest ; ○, natural deciduous broad-leaved forest on the upper slope ; ▲, artificial cedar forest ; △, natural deciduous broad-leaved forest on the lower slope. Vertical lines, standard deviations *, $p<0.05$; **, $p<0.01$ ($n=25$)

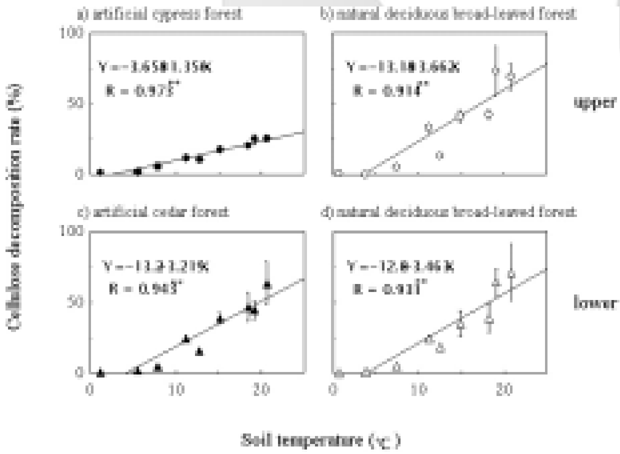

Fig. 3. Relationships between monthly mean soil temperature at 5 cm soil depth and monthly cellulose decomposition rates at 0~10 cm soil depth. *, $p<0.05$; **, $p<0.01$ ($n=9$)

in the soil. The cellulose decomposition rate in the cypress forest at each depth was 0.3~0.5 times that of the natural deciduous broad-leaved forest on the upper slope. The cellulose decomposition rate in the cedar forest except for the 20~30 cm depth was 0.7~1.2 times that of the natural deciduous broad-leaved forest on the lower slope.

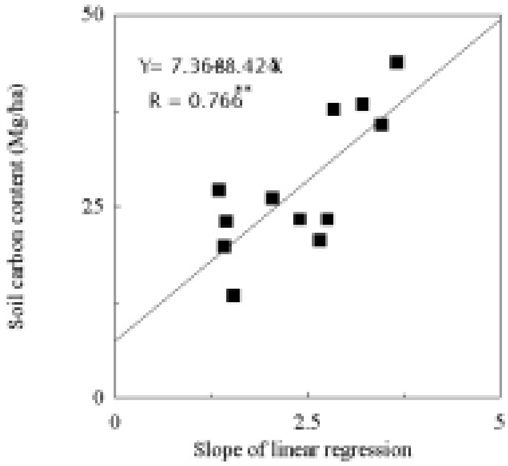

Fig. 4. Relationships between slope of linear regression and soil carbon content in each plot and each soil depth. **, $p<0.01$ ($n=12$)

The cellulose decomposition rate in the cedar forest at the 20~30 cm depth was 1.0~2.0 times that of the natural deciduous broad-leaved forest on the lower slope. The slope of the linear regression in the cypress forest was 0.4 times that of the natural deciduous broad-leaved forest on the upper slope. The slope of the linear regression in the cedar forest was comparable to that of the natural deciduous broad-leaved forest on the upper slope. Changes in the linear regression slope had the same tendency for the soil carbon contents caused by the conversion of the forest management type from a natural deciduous broad-leaved forest to an artificial evergreen coniferous forest. The linear regression slope was significantly correlated to the soil carbon content (Fig. 4). Therefore, the cellulose decomposition rates were reflected by the soil carbon contents. In the cypress forest, the decreasing soil carbon content resulted in a decreasing soil microbial activity relative to those of the natural deciduous broad-leaved forest on the upper slope. In the cedar forest, the soil carbon content and soil microbial activity were almost the same as the natural deciduous broad-leaved forest on the lower slope.

CONCLUSION

We investigated the organic matter dynamics (*i.e.*, the amounts and carbon and nitrogen contents of the forest floor and the litterfall, soil chemical characteristics and cellulose decomposition rates) in the natural deciduous broad-leaved forest and adjacent artificial evergreen coniferous forest to clarify the effect of the soil carbon dynamics.

The soil carbon and nitrogen contents, CEC and microbial activity decreased due to the conversion of the forest management type from a natural deciduous broad-leaved forest to a cypress forest. It is thought that the planting of the Japanese cypress decreased the soil fertility. However, these phenomena were not observed with planting of the Japanese cedar. The soil fertility was different based on the planting of the tree species in this study. Therefore, when the site conditions and stand histories are the same, the differences in the organic matter dynamics and soil fertility that changed with the tree species were clarified.

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