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EFFECTS OF HARVESTING IMPACTS ON SOIL OF A DOUGLAS-FIR FOREST IN THE CASCADE MOUNTAINS, OREGON, U.S.A.

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ABSTRACT

The effects of forest harvesting impacts on soil properties were investigated at the old-growth Douglas-fir (*Pseudotsuga menziesii*) forest in the Cascade mountains. To clarify the mechanisms of soil change, soil profiles were described and soil chemical and physical properties were analyzed at 5 cm depth. Landform units were classified numerically. Direct impacts of forest harvest to the soil were evaluated as compaction, tillage, and accumulation and/or mixing of organic matter. Indirect impacts of harvest resulted in minerization of topsoil, decomposition of organic matter, repellancy revelation, and erosion. These direct and indirect impacts caused changes in soil properties that varied along landform units. On the Terrace landform unit, the saturated hydraulic conductivity rates decreased notably and bulk density increased. The Seepage Slope unit exhibited increased hardness of B horizon and decreased total porosity. Fine porosity increased and coarse porosity decreased as a result of compaction. The Convex Creepslope (I) experienced decreased exchangeable cations and saturated hydraulic conductivity by the repel-

lancy revelation after harvest. The Transportational Midslope (I) showed the highest contents of organic carbon and total nitrogen caused by mixing of organic matter. The Colluvial Footslope indicated to decrease the thickness of A and B horizon and increase the exchangeable cations A horizon.

INTRODUCTION

Douglas-fir (Pseudotsuga menziesii) - western hemlock (Tsuga heterophylla) forests, generally 350 to 750 years old, are common old-growth forests in the northwestern United States. These forests contain valuable timber, wildlife, and other resources. These old-growth forests are in increasingly short supply (Franklin et al.,1981).

Forest harvest affects forest ecosystems in various ways. Concerns have been raised about harvest effects on site productivity, water supply from the forest land and soil loss. It has been said that tree growth rate has decreased in the particular area, and water supply for human use has decreased, and soil losses by landslides have often occurred after forest harvesting (Wert et al.,1981; Froehlich et al.,1983; Miles et al.,1984).

Recently, scientific interest has focussed on effects of clearcutting in a variety of soil factors, such as the deterioration of soil physical properties (Dyrness, 1965, 1967; Wert et al.,1981; Froehlich et al.,1983; Gent et al., 1983, 1984), nutrient loss (McCall,1978; Arimitsu et al.,1981; Sollins et al.,1981; Mroz et al.,1985), organic matter decomposition (Ourgin,1980; Binkley,1984; Snider et al.,1985), and recovery of site productivity (Snyder et al.,1984; Froehlich et al.,1985).

Results of the studies vary with tree species, time of cutting, tree removal methods, local precipitation patterns, topography, soil characteristics, and the method of reforestation.

The purpose of this study was to clarify the mechanisms of soil change after forest harvesting and to determine the relationship between soil changes and landform, because soil changes do not occurr uniformly in the forest land.

SITE DESCRIPTION

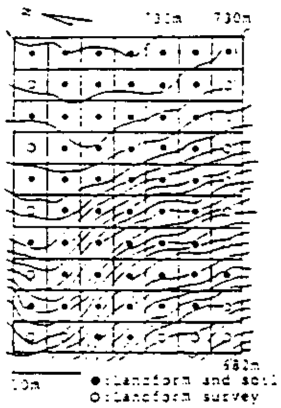

Figure 1. Study site

The study site is located at the H. J. Andrews Experimental Forest in the Cascade mountains about 80 km east of Eugene, Oregon U.S.A.. The topography of this site extends from a high terrace surface down a colluvial slope and ranges from 733 m to 683 m above sea levels.

This site is underlain by glacial deposits and is classified in Cryumbrept soil groups.

The climate is mild with wet winters and warm, dry summers. Annual precipitation normally exceeds 2,500 mm and is concentrated in the winter. Little or no rain falls during Jun, July, and August. Mean temperature in January is 2 C, and July is 20 C.

Before harvest, the forest consisted of Douglas-fir, western hemlock, and western red ceder (Thuja plicata). Douglas-fir was dominant with 43 stems/ha in density, averaging 56 m in height, 120 cm in D.B.H., and 490 years in age. Western hemlock was 84 stems/ha, 37 m in height, and 66 cm in D.B.H.; and western red ceder was 49 stems/ha, 35 m in height, and 75 cm in D.B.H. It was estimated that the forest fires occurred about 130, 310 and 500 years ago at this site..

This study site was clearcut harvested using tractor and cable skyline yarding systems in June, 1985.

METHODS AND LANDFORM CLASSIFICATION

Soils were surveyed in 54 pits in May, 1985 before harvest and in August after harvest (Fig.1). Morphological properties of the soil profiles were examined and soils were sampled from the surface to about 5 cm in depth for chemical and physical analysis. Soil hardness was determined by Yamanaka's hardness tester (Penetrometer). Soil pH was measured on 1 : 2.5 soil-water extract using a glass-electrode pH meter. Organic carbon and total nitrogen were analyzed by the dry-combustion method (CN corder, Yanaco MT500W). Cation exchange capacity was determined by a 1N ammonium acetate solution procedure with Peech's method. Exchangeable cations were extracted with a 1N solution of ammonium acetate (pH 7) and were determined using the atomic absorption spectrometer. Soil physical properties were determined for samples taken at the site with 100 cm^2 x 4 cm cores by Mashimo's method (1960).

Landform Classification

Nineteen landform parameters (Tab.1) were measured from the topographic map for each 10 m x 10 m unit area centered at each soil pit. Relief index was calculated as the sum of differences of elevation of the eight points of each unit area (Kobayashi et al., 1983). Principal Component Analysis was used for numerical classification of landform units based on these 19 parameters. The result indicated that two components had significant eigen values (larger than 1.00), and that these components explained 66.9 % of the total variance (Fig.2). The first component represented the main-toposequence parameters and the second represented the unit area (Fig.2B). Seven landform units were segmented: Terrace, Seepage slope, Convex creepslope (I) and (II), Transportational midslope (I) and (II), and Colluvial footslope. Characteristics of these landform units are summarized in Table 1. The Terrace occuring at the top of the study area, was gently convex, and had the smallest catchment height and length. The Seepage slope had straight slope, gently concavity, and the smallest surface curvature. Convex creepslope (I) was the most convex and had the widest dispersal area and smallest catchment area. Convex creepslope (II) differed from (I) on the point of lower location of slope. Transportational midslopes were the steepest slope. Transportational midslope (I) was gently convex and (II) was gently concave. The Colluvial footslope was located at the lowest part of this site, and was the most concave and widest catchment area.

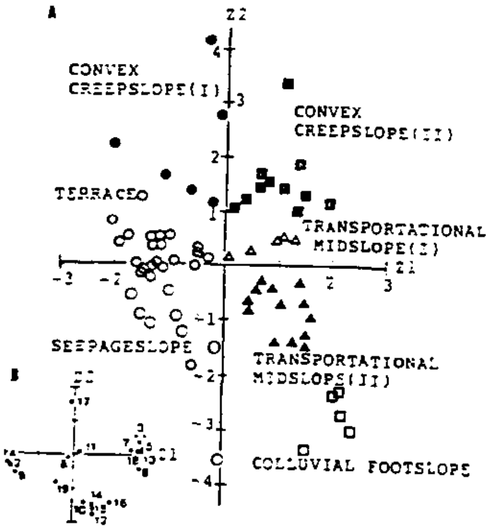

Figure 2. A: The score scatter diagram of 19 landform parameters.
Eigen value: Z1=8.77, Z2=3.93
Cumulative percent of total variance: Z1=46.1, Z2=66.9
B: The loading factor diagram.
Number refers to Table 1.

Table 1. Characteristics of landform units analyzed with P.C.A.

Landform Parameter	Landform Unit TERR[1]	SEEP	CON(I)	TRA(I)	TRA(II)	CON(II)	COLL
1.MCH[2]	3.5	4.2	11.9	21.9	22.1	31.7	32.7
2.MDH	47.0	46.7	29.0	29.2	26.4	19.2	18.2
3.MCL	44.2	37.7	72.6	77.3	76.2	93.4	97.9
4.MDL	55.1	26.9	72.7	51.8	51.0	35.6	38.2
5.MCS	4.6	5.6	8.6	15.0	15.4	12.3	19.1
6.MDS	-25.3	-26.1	-26.2	-29.4	-29.4	-19.1	-25.0
7.MRL	-33.6	-22.3	-19.6	-14.4	-13.9	-10.8	-6.0
8.USU	11.4	13.7	14.2	30.6	33.6	27.4	39.6
9.USL	-13.6	-10.0	-25.5	-33.1	-31.7	-31.6	-24.2
10.USLE	[illegible]	6.2	-11.5	-1.3	8.2	-11.0	18.9
11.USR	[illegible]	-0.7	-1.9	-0.1	-3.8	2.7	-0.4
12.URI	-0.76	1.41	-6.12	-1.51	1.41	-2.53	6.59
13.USC	1.037	1.031	1.107	1.215	[illegible]	1.164	[illegible]
14.URL	-5.4	3.7	-11.3	-2.5	1.5	-4.4	15.4
15.UCL	-4.6	5.5	-13.6	-1.4	4.4	-9.4	14.5
16.UCA	11.8	54.5	26.5	43.9	48.9	27.8	52.2
17.UDA	45.9	32.9	59.1	46.9	41.7	49.5	29.4
18.URS	11.6	11.9	19.9	31.9	32.7	29.6	22.1
19.AZI	267	285	250	253	266	243	262

[1] TERR:Terrace, SEEP:Seepage slope, CON(I):Convex creepslope(I) TRA(I):Transportational midslope(I), COLL:Colluvial footslope

[2] MCH:Catchment height, MDH:Dispersal height, MCL:Catchment length, MDL:Dispersal length, MCS:Catchment slope, MDS: Dispersal slope, MRL:Relative linearity, USU:Unit area, slope to upper, USL: slope to lower, USLE:Slope to left, USR:slope to right, URI:Unit area, relief index, USC:Surface curvature URL:Radious linearity, UCL:Contour linearity, UCA:Unit area, catchment area, UDA:Dispersal area, URS:Relative slope, AZI: Azimuth.

RESULTS

Mechanisms of Soil Changes

After forest harvest, direct impacts on soil properties were observed to be the effects of compaction by tractors and log skidding, the tillage by log movement, mixture of organic matter, slash accumulation, and removal of

A_0, A, and B horizons. Following forest harvest, soil properties also changed by the indirect effects of processer such as changes of soil environment and the repellancy revelation, acceleration of soil mineralization by organic matter decomposition, and erosion caused by forest vegetation removal and direct rain fall.

Table 2. Means and standard deviations for soil soil properties before and after harvest.

Soil properties	Before harvest			After harvest			
(Profile)							
1.Thickness of A_0	4.5	±	4.1 1/	9.1	±	9.0	cm
2. of A	4.6	±	2.0	2.5	±	2.4	cm
3. of B	31.2	±	10.1	27.9	±	8.7	cm
4.Hardness of surface	0.9	±	0.4	0.5	±	0.3	Kg/cm^2
5. of B	1.3	±	0.7	1.7	±	1.9	Kg/cm^2
6.Root contents	3.2	±	2.6	3.0	±	2.2	g/400cc
7.Gravel contents	68.7	±	28.1	71.2	±	29.0	g/400cc
(Chemical properties)							
8.pH	5.14	±	0.40	5.21	±	0.33	
9.Organic Carbon	7.77	±	7.31	9.23	±	3.54	%
10.Total Nitrogen	0.23	±	0.05	0.25	±	0.06	%
11.C:N ratio	33	±	5	36	±	12	
12.C.E.C.	51.3	±	10.7	54.7	±	12.3	me/100g
13.Exchangeable Ca	7.28	±	7.31	8.20	±	7.69	me/100g
14. ex. K	0.58	±	0.21	0.75	±	0.24	me/100g
15. ex. Mg	1.05	±	1.20	1.36	±	1.43	me/100g
16. ex. Na	0.11	±	0.14	0.17	±	0.20	me/100g
(Physical properties)							
17.Water permeability 2/	254	±	187	53	±	79	cc/min.
18.Bulk density 3/	52.4	±	8.4	59.1	±	11.4	g/100c
19.Solid phase	27.5	±	2.5	29.3	±	2.9	%
20.Liquid phase	27.2	±	4.8	21.1	±	7.5	%
21.Gaseous phase	45.3	±	6.0	49.6	±	8.6	%
22.Water maximum	44.6	±	5.8	40.6	±	12.5	%
23.Air minimum	27.9	±	6.6	30.1	±	13.8	%
24.Total porosity	72.5	±	2.8	70.5	±	3.1	%
25.Fine porosity	24.0	±	3.4	25.4	±	4.7	%
26.Coarse porosity 4/	48.5	±	4.9	45.3	±	6.3	%

1/ Means ± standard deviation
2/ Saturated hydraulic conductivity measured with a 100 cm^2 x 4 cm core and a 2 cm water head.
3/ Without roots and gravel
4/ Coarse porosity is equivalent to pF 2.7 tension and/or less.

These direct and indirect impacts produced changes in soil properties (Tab.2). Observations of soil profiles such as increased thickness of organic matter and decreased A and B horizons indicated harvest impacts. These were caused by slash accumulation more than normal litter fall and removal of A or B horizons by tractors or skidding logs. Surface soil exhibited decreased hardness, but the hardness of B horizon deeper than 5 cm increased clearly as a result of tillage and compaction. Decreased root contents of the topsoil was caused by removal of surface soil during logging.

Concerning soil chemical properties, concentrations of organic carbon, total nitrogen, and C/N increased. Cation exchange capacity and exchangeable cations, such as ex.Ca, ex.K, ex.Mg, and ex.Na also increased. These resulted from mixing of undecomposed organic matter with soil and accelerated the minerization of topsoil.

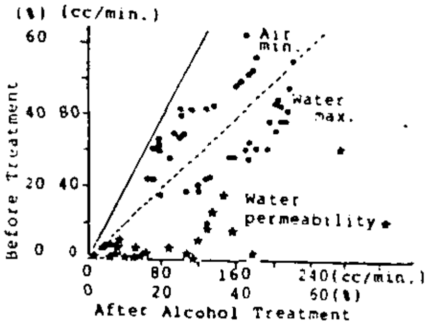

Figure 3. The inhibition of soil physical properties by the repellancy revelation after forest harvest.

Compaction and tillage of topsoil, including mixture of organic matter into the topsoil, changed soil physical properties. These two processes increased bulk density and ratio of solid phase. Total porosity decreased slightly, because coarse porosity was destroyed and fine porosity increased.

Harvest impacts resulted to decrease the saturate hydraulic conductivity rates notably. The mycelia were observed commonly in the topsoil of Douglas-fir forests. Top soil dries easily after forest vegetation cover is removed and the inhibition of saturated hydraulic conductivity wa arise by onset of the repellancy revelation of the topsoi (Fig.3). Before and after alchohole treatment of cor samples for eliminating the water repellancy, soil air minimum, water maximum, and saturated hydraulic conductivit were clearly different. These differences were interprete to be caused by the repellancy revelation of the topsoil.

Soil Changes related with Landforms

Changes of soil properties were not observed uniforml everywhere after harvest. Principal Component Analysis wa used to evaluate change in soil properties based on observations of soil profiles and chemical and physical propertie (Fig.4). On the profiles (Fig.4A), three patterns of chang were recognized. The first pattern was a shift from right t left in Fig. 4A which represented increased hardness of horizon and decreased thickness of A horizon caused by compaction and removal of A horizon. The second pattern wa from left to right and indicated the accumulation of slash The third pattern was a downward change, indicating in-

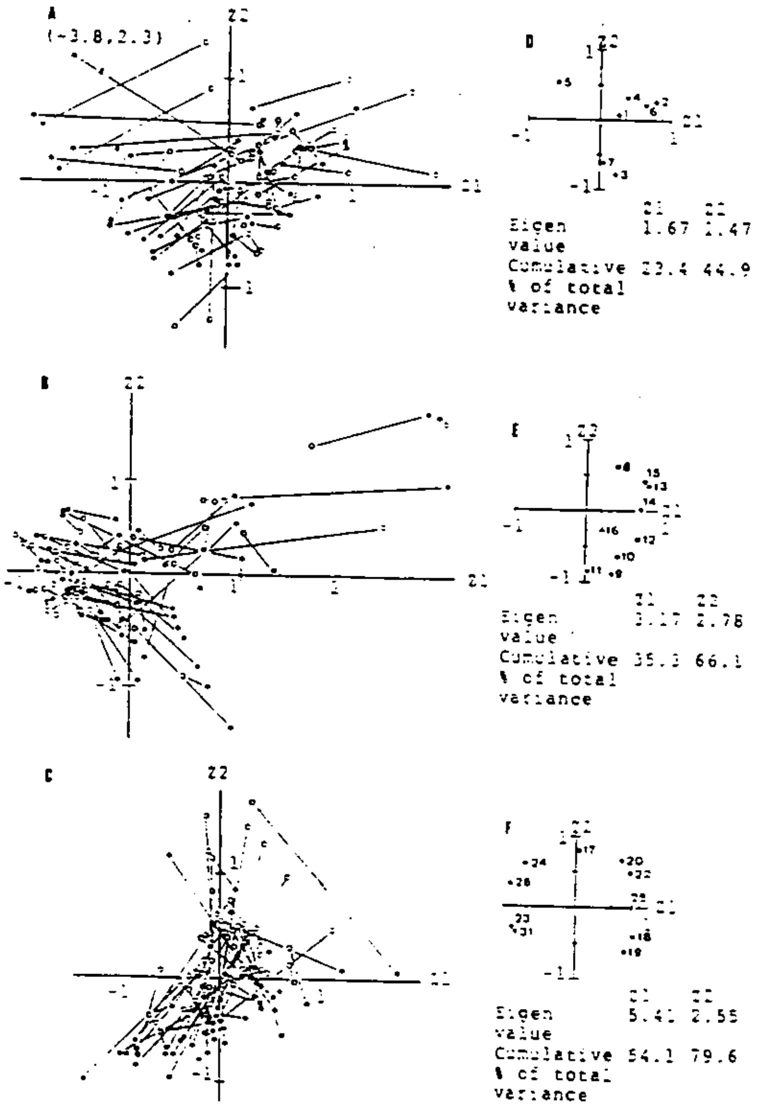

Figure 4. The score scatter diagrams of A: Soil profiles, B: Soil chemical properties, C: Soil physical properties, and the loading factor diagrams of D: Soil profiles, E: Chemical properties, F: Physical properties in which number of circle refer in Table 2.

○----- Before harvest, ●----- After harvest

creased thickness of B horizon.

For soil chemical properties (Fig.4B), three patterns were also recognized. The first moved from left to upper right which is explained as increased exchangeable cations and pH. The second changed from left to lower right which was interpretated as increased content of organic carbon, total nitrogen, C/N, and cation exchange capacity caused by mixing of organic matter. The third was from right to left, resulting from decreased soil organic matter and exchangeable cations caused by soil loss.

Changes of soil physical properties (Fig.4C) indicated typical trends. The first pattern was a downward shift caused by increased gaseous phase and air minimum in response to tillage and organic matter mixing. The second changed from above to lower right because of increased bulk density and solid phase caused by compaction. The other showed minor changes which were undisturbed areas. An overall pattern indicated substantially decreased saturated hydraulic conductivity caused by the compaction, disturbance, and the repellancy revelation.

Changes of soil properties revealed in the soil pits were related with landforms. Therefore, soil properties are summarized before and after harvest for each landform unit (Tab.3). The thickness of the organic matter layer decreased apparently at convex creepslope (I) and transportational midslope (I). Slash accumulated on terrace, seepage slope, and collovial footslope landform units. The thickness of A horizon also clearly decreased on the transportational midslope (II) and colluvial foot slope. Decreasing of the thickness of B horizon seemed to be caused by log skidding and erosion, particulary at the convex creepslope (I) and colluvial footslope. The hardness of soil decreased on sites disturbed by tillage, but in the B horizon became high notably at seepage slope, terrace and colluvial footslope. On the soil chemical properties, organic carbon and total nitrogen increased at all landform units except terrace and colluvial footslope. The cation exchange capacity increased at the seepage slope and exchangeable cations also increased

Table 3. Relationship between Landform Units, Soil properties, and Changing Rate before and after forest harvest. Landform units are in order to the toposequence.

Soil properties	Landform Unit						
	TERR[1]	SEEP	CONV(I)	TRAN(I)	TRAN(II)	CONV(II)	COLL
(Profile)							
A_0 thickness	3.8[2] (218.4)[3]	4.3 (183.7)	3.8 (71.1)	5.3 (50.9)	3.1 (122.6)	6.0 (198.3)	10.2 (184.3)
A thickness	5.1 (60.8)	4.7 (40.4)	6.6 (72.7)	3.7 (35.1)	2.9 (79.3)	4.1 (48.8)	6.1 (32.8)
B thickness	25.2 (94.8)	30.0 (88.0)	26.3 (76.0)	30.8 (110.4)	36.7 (85.0)	38.0 (89.5)	39.0 (71.3)
Surface hardness (0 – 5 cm)	0.9 (55.6)	1.1 (45.5)	1.2 (50.0)	0.7 (42.9)	0.7 (71.4)	0.7 (57.1)	0.5 (120.0)
B hardness (50cm –)	1.4 (142.9)	1.5 (226.7)	2.1 (75.0)	0.9 (100.0)	1.0 (110.0)	1.0 (100.0)	0.6 (183.3)
(Chemical pro.)							
pH	5.21 (101.7)	5.17 (99.0)	4.70 (105.5)	4.76 (107.1)	5.17 (99.6)	5.15 (101.4)	5.15 (106.0)
Organic Carbon	8.59 (100.5)	7.97 (139.1)	6.31 (128.5)	7.65 (135.4)	7.10 (128.5)	6.63 (127.1)	8.07 (107.2)
Total Nitrogen	0.25 (100.0)	0.23 (100.0)	0.20 (110.0)	0.22 (118.2)	0.23 (104.3)	0.22 (118.2)	0.23 (113.0)
C/N ratio	35 (97.1)	35 (111.4)	34 (121.3)	35 (114.3)	31 (119.4)	30 (110.0)	25 (97.1)
C.E.C.[4]	47.0 (99.8)	44.3 (116.9)	52.3 (120.8)	53.2 (113.3)	54.6 (101.3)	57.0 (113.5)	65.5 (105.3)
Exchangeable Ca	6.19 (101.0)	5.33 (102.4)	3.88 (87.3)	3.26 (251.3)	9.13 (89.7)	9.96 (132.6)	12.34 (131.8)
ex. K	0.64 (117.2)	0.66 (103.0)	0.79 (79.7)	0.56 (137.5)	0.94 (75.5)	0.44 (145.3)	0.77 (90.9)
ex. Mg	0.71 (146.5)	0.57 (135.1)	0.35 (77.6)	0.72 (181.9)	1.44 (105.6)	1.52 (140.3)	2.26 (115.9)
ex. Na	0.06 (233.3)	0.15 (53.3)	0.11 (463.6)	0.03 (733.3)	0.21 (189.5)	0.10 (120.0)	0.14 (42.9)
(Physical pro.)							
Water permeability	245 (7.8)	153 (18.3)	99 (34.7)	213 (55.9)	342 (14.0)	295 (19.8)	359 (29.3)
Bulk density	50.6 (117.8)	51.4 (115.6)	58.1 (59.5)	55.4 (111.2)	54.4 (111.3)	54.6 (107.9)	46.2 (111.5)
Solid phase	26.8 (111.6)	27.3 (108.8)	27.8 (95.0)	29.3 (102.0)	28.2 (106.0)	28.0 (106.3)	26.4 (98.1)
Liquid phase	25.8 (76.0)	23.1 (93.1)	26.5 (62.6)	30.6 (57.8)	29.8 (76.5)	29.6 (82.1)	28.8 (81.6)
Gaseous phase	47.4 (106.8)	49.6 (98.4)	45.7 (124.9)	40.1 (130.7)	42.1 (112.4)	42.4 (138.0)	44.9 (112.9)
Water maximum	42.7 (88.1)	38.8 (108.5)	42.7 (77.4)	46.5 (93.1)	48.2 (90.0)	48.2 (82.4)	47.4 (96.8)
Air minimum	30.5 (104.6)	33.9 (77.0)	27.6 (142.0)	24.3 (110.3)	23.7 (112.7)	23.6 (123.4)	26.3 (107.2)
Total porosity	73.2 (95.3)	72.7 (95.3)	72.2 (131.3)	70.7 (99.2)	71.8 (97.6)	72.0 (97.4)	73.2 (100.5)
Fine porosity	23.5 (103.4)	21.6 (117.1)	24.2 (100.8)	26.5 (98.2)	25.2 (100.8)	25.0 (110.6)	23.3 (113.3)
Coarse porosity	49.7 (92.4)	51.1 (88.3)	18.0 (102.5)	44.2 (99.8)	46.6 (95.9)	47.0 (90.2)	50.4 (94.8)

[1] TERR: Terrace, SEEP: Seepageslope, CONV(I): Convex creepslope(I), TRAN(I): Transportational midslope(I), TRAN(II): Transportational midslope(II), CONV(II): Conves creepslope(II), COLL: Colluvial footslope
[2] Before harvest.
[3] (After harvest) / (Before harvest) x 100 (%), changing rate.
[4] Cation Exchange Capacity

notably on the transportational midslope (I). Exchangeable cations seemed to have leached out at convex creepslope (I). The saturated hydraulic conductivity decreased at all landform units, most notably at the terrace which also had the greatest change in bulk density. The inhibition of water permeability by the repellancy revelation was notable at convex creepslope (I) where soil water maximum decreased, air minimum increased, and saturated hydraulic conductivity decreased greatly. Decreasing total porosity was observed at terrace and seepage slope which indicated increased fine porosity and decreased coarse porosity.

DISCUSSION

Activities of forest harvest cause surface soil disturbance and soil properties vary directly with the degree of disturbance caused by timber removal. Dyrness(1965) identified four classes of soil disturbance and four classes of slash accumulation, based on the degree of removal of A_0, A, B horizons, the mixing of organic matter, amount of slash accumulation, and compaction. We considered these disturbances, which also included the tillage by timber transportation, as direct impacts to the soil at the time of forest harvest. Following forest harvest, indirect impacts accelerated change in soil properties. These indirect impacts trigger important soil changes in response to decompositior of organic matter (Kobayashi,1982), soil mineralization, erosion, and repellancy revelation. From this perspective, long term monitoring of soil properties is an important par of evaluating long-term soil productivity and prediction o tree growth.

Decreased thickness of the A_0, A, and B horizons caus the changes of soil chemical and physical properties Kobayashi(1982) found that organic matter in the topsoi decomposed rapidly in the first six months after harvest Binkley(1984) observed rapid decomposition at the interfac of the humid layer and mineral soil in a clearcut site using cellulose filled litterbags. Following harvest b clearcutting, the concentrations of organic carbon and tota nitrogen increased in this study. This occured in soil mixe with organic matter when there was little rainfall during period of a month after harvest. Kobayashi(1982) and Mroz e al.(1985) found that the exchangeable cations such as ex.K ex.Ca, and ex.Mg, decreased in solum after harvest

McColl(1978) and Arimitsu et al.(1980) pointed out that the exchangeable cations in solution increased initially and then rapidly decreased following forest harvest. The results of this study indicate increased exchangeable cations which are presumably due to high mineralization of soil initially without leaching losses. Further work is required to determine whether massive losses of exchangeable cations will occurs during the rainy season (Mroz et al.,1985) or if a large influx of exchangeable cations associated with surface decomposition will be accumulated into the mineral soil (Snyder et al.,1985).

Many studies have examined forest harvesting impacts on soil physical properties (e.g., Dyrness,1965,1967; Wert et al.,1981; Froehlich et al.,1983; Gent et al.,1983,1984). While the studies of the saturated hydraulic conductivity, bulk density, and porosity structure are valuable indicators of harvesting effects on the forest soils and are useful in predicting the deterioration of soil, they may be insensitive to change in soil water conditions. Generally speaking, the saturated hydraulic conductivity rate decreases, the bulk density increases, and total porosity decreases after forest harvest. We observed these soil changes and interpret them as resulting from both direct and indirect effects.

Changing soil properties as a result of forest harvest also depend on characteristics of landforms, so we classified landform units and related them to the soil changes in this study. Dyrness (1965, 1967) discussed slope steepness, Sollins et al.(1981) also pointed out the importance of slope position, and Binkley(1984) suggested the elevation influenced harvest impacts and soil changes. We tried to classify the landforms numerically and to describe them explicitly and objectively, so changing soil patterns could be associated with landform units effectively. Seepage slope, convex creepslope, and transportational midslope are considered to be the most damaged units so that the forestry practice will be payed attention to these units.

CONCLUSION

1. After forest harvest, changes of soil properties were caused by direct influence of compaction, tillage, mixture of organic matter, slash accumulation, and the removal of A_0, A, B horizons. Following forest harvest, soil properties also changed by indirect influence of repellancy revelation, acceleration of soil mineralization and organic matter decomposition, and erosion. Organic matter decomposition rate did not clearly increase in this study.
2. These impacts decreased the thickness of A and B horizons and increased the hardness of B horizon, organic carbon, total nitrogen, C.E.C., and exchangeable cations. Changes of soil physical properties were mainly represented by decreased saturated hydraulic conductivity rate and total porosity, and increased bulk density and fine porosity.
3. These changes of soil properties varied among the seven numerically-classified landform units at this site.
4. Seepage slope, convex creepslope (I) and transportational midslope (I) had the greatest change of soil properties and were considered the most damaged slope units.

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