Effects of root mass and soil carbon stocks in old awn grasslands after artificial afforestation and grassland regeneration.

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Abstract

Recent years have seen an increase in frequent, large-scale landslides causing significant damage annually. Traditionally, forests were believed better than grasslands at controlling landslides due to their deeper roots. However, recent research (Koyanagi et al., 2018) suggests that forests may actually experience deeper collapses and produce more sediment due to their greater root depth. A study conducted in Japan's Minonohara Highlands Plateau compared 'old grasslands' (maintained for over 100 years), 'forests' planted post-war, and 'new grasslands' (forests cleared less than 100 years ago). Various methods, including soil cross-sections and core samples, were used to assess root mass and soil carbon stocks. Results indicated that grasslands generally had more surface roots and potentially lower landslide susceptibility compared to forests. A novel soil carbon assessment method, accounting for roots, was proposed for improved accuracy, particularly in surface layers. Borehole and cross-sectional sampling methods showed similar efficiency in assessing root volume, suggesting practical options for future assessments.

Key words; land use change, Soil carbon storage, Plant roots, Grassland

Introduction

In recent years, large-scale landslides have been frequent and have caused extensive damage every year. In the Noto Peninsula Earthquake of 2024, 230 landslides were confirmed as of 31 January of the same year. According to the Ministry of Land, Infrastructure, Transport and Tourism, the Hokkaido Bombei East Earthquake of 2008 caused an area of 440,000 km² of collapsed slopes, 36 deaths, 61 injuries and 44 houses completely destroyed, making it the largest earthquake disaster since the Meiji Era, and 227 landslides were confirmed. Landslides are thus a serious problem in Japan, an earthquake-prone country with 67% of its land covered by forests.

Landslides are generally considered to be better controlled in forests than in grasslands. This is because trees are said to have vertical roots of 1-1.5 m and can fix a lot of soil material. Tree rhizomes contribute to slope stability due to the effects of lateral bonding by the horizontal roots and vertical anchoring by the main roots (Sidle et al., 2006). However, the slope failure depth and sediment production in the Kumamoto earthquake were forest > grassland (Koyanagi et al., 2018). Therefore, this study considered that plant root mass and depth are important in landslides and characterised the distribution of roots in forests and grasslands by classifying roots.

In addition, a new method for evaluating soil carbon stocks that takes root mass into account was investigated using root samples that have not been used for soil carbon stock assessment in the past. We considered that the conventional method of assessing soil carbon stocks, which does not take roots into account (hereafter referred to as 'conventional method'), may not have been able to accurately assess subsurface carbon stocks. Therefore, in investigating plant root mass, we calculated soil carbon stocks using the results of analysing the carbon concentration of the roots themselves, using the novel method.

As vegetation and soil characteristics in grasslands and forests can differ by a few metres, more survey sites are required for accurate comparisons. However, soil cross-sectional surveys require digging to depths of up to 1 m, which is time-consuming and labour-intensive. Therefore, the possibility of using a transparent PVC cylinder (Fujiwara Corporation, for hand samplers) with a diameter of 5 cm and a length of 30 cm to simplify and increase efficiency was investigated.

Based on the above background, the aim of this study was to determine root depth and root mass in forests and grasslands.

Samples and methods.

1. study site and soil cross-sectional survey methods

The study sites were located in the Minonohara Kogen Plateau (Suzaka City, Nagano Prefecture, Japan) and consisted of an 'old grassland' where the grassland had been maintained for more than 100 years, a 'forest' planted after the war and a 'new grassland' where the forest had been cut down and converted to grassland less than 100 years ago. Before digging at all three sites, an Active Al test was conducted and the sites with reactions that were confirmed as volcanic ash-based soil (black box soil) were selected as survey sites. For the soil cross-sectional survey, a hole about 70 cm wide and 1 m deep was dug with a shovel and the cross-section was shaped flat with a grafting trowel. Stratification was then carried out and each layer was surveyed according to the Soil Section Survey Form of the Japanese Society of Pedology. The survey items were as follows: (stratigraphy, depth, soil colour, mottling and nodulation, soil properties, gravel, structure, cohesion, plasticity and denseness, pore size, roots, dryness and wetness, and presence of active Al reaction). Soil samples and core samples (1000 cm^3 and 100 cm^3) were taken for each stratum during the soil cross-sectional survey; for the 1000 cm^3 core samples, soil was cut at 10 x 10 x 10 cm in each stratum (10 x 10 x 7 cm for forest AB layers 1-3, 10 x 10 x 8 cm for new grassland B2 layers 1 and 2, 3 7 x 8 x 8 cm); 100 cm^3 core samples were taken using 100 ml stainless steel sample cylinders (Daiki-Rika Kogyo, DIK-1801) (hereafter referred to as metal cores).

In addition, borings were carried out to a depth of 60 cm using plastic cores at three sites at a radius of about 3 m from the point where the cross-sectional survey was carried out at the forest site.

2. sample preparation and analysis methods

Soil samples and metal core samples were used for the analysis of soil carbon and nitrogen concentrations, provisional specific gravity and carbon stocks.

Soil sample preparation methods were as follows. After collection, each soil sample was air-dried in a ventilated dryer (approximately 1 week, 35°C conditions) and measured for dry weight. Large soil clusters were then scraped with a mortar and gravels (≥2 mm) were removed using a 2 mm mesh sieve, and roots contained below 2 mm were removed using an electrostatically charged envipipe. This was repeated several times to remove as many roots as possible. The prepared soil samples were analysed by dry combustion method (Sumika Analysis Centre, NC-220F) to obtain carbon and nitrogen concentrations. Provisional specific gravity was calculated using metal core samples. First, the metal core is dried in a hot air dryer at 105°C for two days and the overall weight is measured. The soil was then removed and the weight of the container only was measured. The two values were then used to determine the weight of the dried soil, and using these values, the provisional specific gravity was calculated as dry weight (g)/volume (cm^3).

Soil carbon stocks were calculated as follows (Equation 1).

Volume (cm^3) x thickness of layer (cm) x provisional specific gravity (g/cm^3)/1000 x carbon concentration (g/kg)/1000... (Equation 1)

The carbon accumulation of the accumulation was calculated using the carbon accumulation determined by the aforementioned equation and the values for 10 cm, 30 cm, 50 cm and 100 cm were calculated.

1000 cm^3 core samples and metal core samples were used for the analysis of root carbon concentration, nitrogen concentration, root volume and root carbon accumulation.

The preparation of the 1000 cm^3 core samples were as follows. As with the soil samples, they were air-dried in a ventilated dryer (for approximately one week at 95°C conditions) after collection and measured for dry weight. Roots were then separated from the samples and classified as large-medium (X≥2 mm), small (0.5 mm ≤ X<2 mm) and fine (X>0.5 mm). Large, medium and small were sorted by hand or with tweezers. After a certain amount of roots were collected, the clusters were finely ground in a mortar and a 2 mm mesh sieve was used to remove the gravel (≥2 mm), and roots sieved to less than 2 mm were collected using an electrostatically charged envipipe. After this was repeated several times, samples of 2 mm or less were sieved through a sieve of 1.4 mm or less, and those that passed through the sieve were again held over an electrostatically charged envipipe to collect fine roots. Those that did not pass through the sieve were placed in deep vats filled with water and classified as suspended matter and sediment, and only the suspended matter was removed and dried using a ventilated dryer (about 1 week, 35°C) and classified as fine roots. The dried large, medium, small and fine roots were then crushed in a grinder and measured using the dry combustion method (Sumika Analysis Centre, NC-220F) to obtain carbon and nitrogen concentrations. The root mass (g/m^2) was calculated as follows (Equation 2).

Root weight (g)/volume (cm^3) x 1,000,000 x layer thickness (m)... (Equation 2)

As 1000 cm^3 core samples were only collected from layers A1+A2 and 2A3 of the old grassland, layers A1A2, AB and B1 of the forest and layers A1, B1 and B2 of the new grassland, root carbon accumulation in the lower layers was calculated using the results of root carbon concentration in the upper layers obtained by dry burning method and metal core samples. The method for extracting roots from the lower layer of the metal core samples was as follows. The sample, which had been dried at 105°C when the provisional density was determined, was finely ground in a mortar, the clusters were broken up and the sample was placed in a deep vat filled with water and the suspended matter was passed through a 500 µm mesh sieve with the water. Any residue remaining on the sieve was rubbed onto the sieve with the fingers while the water was poured off to wash away excess soil. The sample remaining in the vat was filled with water again and the suspended solids were passed through the sieve. The above series of steps was repeated until the suspended solids were removed. The carbon accumulation (Ckg/m^2)

was calculated as follows (Equation 3).

Root volume (kg/m^2) x root carbon concentration (g/kg)/1000... (Equation 3)

To calculate the root mass calculated from the borehole survey, sample preparation and calculation were carried out as follows.
Samples taken from the borehole survey were air-dried in a ventilated dryer (approx. 1 week at 35°C) and then each sample was cut at a maximum depth of 10 cm. They were then dried again in a ventilated dryer (approximately 1 week, 35°C). The clusters were then broken up in a mortar and the roots were removed using a 2 mm mesh sieve to remove large gravels. Samples smaller than 2 mm were then placed in deep vats filled with water and the suspended material was passed through a 500 µm mesh sieve with the water. Any residue remaining on the sieve was rubbed onto the sieve with a finger while the water was poured off to remove excess soil. The series of steps of filling the sample remaining in the bat with water again and passing the suspended solids through the sieve was repeated until the suspended solids were removed. The suspended solids were dried in a ventilated dryer (35°C) and weighed (g). The root mass (g/m^2) was calculated from this dry weight, volume and thickness of the layer using (Equation 4).

Root dry weight (g)/volume (cm^3) x 1000000 x thickness of layer (m)... (Equation 4)

Results.

1. carbon in soil cross-sections at each site

Characteristics of soil cross-sections at each site

Photographs of the soil cross-sections are shown in Figure 1. The old grassland was characterised by a thicker layer A, up to about 60 cm, while the forest and new grassland were thicker in layer B. As the colouration of layer 3A5 was similar to that of the surface layer in the old grassland, layer 3A5 was considered to be a buried humus layer. The fact that this feature was not observed at other sites and the close distance between all sites suggested that it was created by anthropogenic disturbance rather than by eruptive effects.

The results of the description table of the Japanese Society of Pedology are described below for each site.

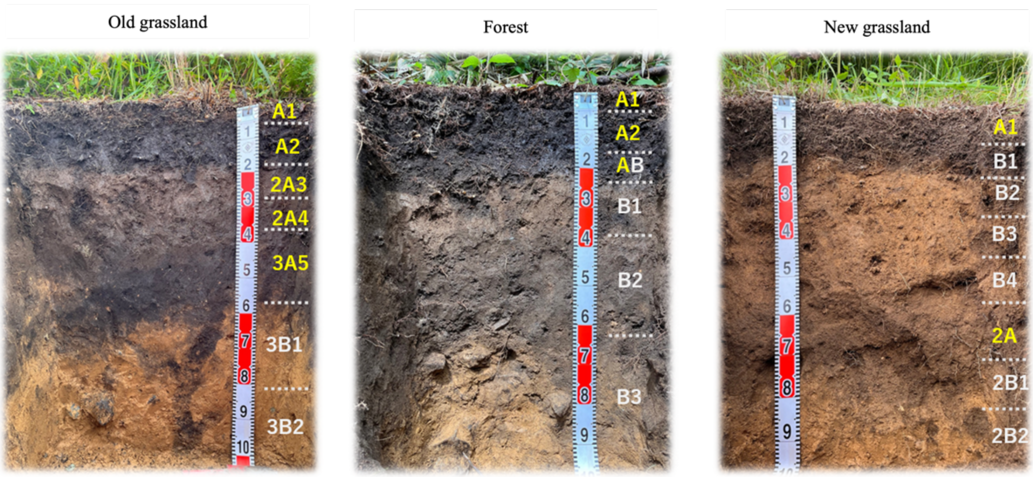


Figure 1: Photographs of soil profiles at three sites on the Mine-no-hara Plateau

Site name: Mine no Hara (1) Old grassland

Soil name: blackbark soil

Date of survey: 19 August 2023

Location:(36.5572149, 138.3509755)

Weather: sunny Weather before survey: sunny, rainy

Azimuth: S33°W Slope: 20.3°W

Base material: volcanic ash

Topography: central part of gentle slope of mountainside

Elevation: 1384 m

Erosion: minor Drainage: good Human: yes (ski resort)

Exposed rock: no

Vegetation: silver grass

A1: 0-3 cm, (10YR 2/2), CL, no gravel, structure: clusters 3-5 mm Weakly developed, Roots 0.5 mm≥ 30% , 5 mm≥ 5%

A2: 3-17 cm (10YR 2/1), CL, no gravel, structure: clumps ≥ 5 mm Weakly developed, Root 0.5 mm≥ 10% , 1 mm≥ 10% , 5 mm≥ 10%

2A3: 17-28 cm (10YR 3/4), CL, with 1~3 mm pumice, structure: SB 3~4 cm weakly developed, roots 0.5 mm≥ 10% , 1 mm≥ 5% , 5 mm≥ 1%

2A4: 28-36 cm (10YR 3/4), CL, no gravel, Structure: SB ≥ 1 cm Development extremely weak

Root 0.5 mm≥ 1% , 1 mm≥ 5%

3A5: 36-57 cm (10YR 1.7/1), CL, no gravel, Structure: SB ≥ 1 cm Development extremely weak,

Root 1 mm≥ 5%

3B1: 57-86 cm (10YR 4/6), CL, 2~3 mm pumice 3%, structure: SB 1~2 cm weakly developed, roots 1 mm≥ 1%

3B2: 86-100 cm (10TR 4/6), CL, subangular gravel 10 cm≥ 5%, Structure: weak SB 1 cm development, root 1 mm≥ 1%.

Site name: Minenohara (3) Forest

Soil name: blackbark soil

Date of survey: 21 August 2023

Location: (36.5572149, 138.3509755)

Weather: cloudy Weather before survey: clear

Azimuth: N70°E Slope: 7.3°E

Base material: volcanic ash

Topography: central part of gentle slope of mountainside

Elevation: unknown

Erosion: minor Drainage: good Human: yes (afforestation) Exposed rock: no

Vegetation: cedar, rust.

A1: 0-5 cm, (10YR 2/2), CL, 3 mm ≥ pumice 2%,

Structure: granular 4~5 mm Weakly developed,

Root 0.5 mm≥ 20% , 1 mm≥ 10% , 5 mm≥ 3%

A2: 5-16 cm (10YR 2/2), CL, 3 mm≥ Pumice 2%,

Structure: granular ≥ 3~4 mm Weak development, Root 0.5 mm≥ 15% , 1 mm≥ 15% , 5 mm≥ 3%

AB: 16-23 cm (10YR 2/3), CL, no gravel, Structure: SB ≥ 1 cm Development extremely weak,

Root 0.5 mm≥ 5% , 1 mm≥ 10%

B1: 23-37 cm (10YR 3.5/3), CL, 2~3 mm pumice 3%,

Structure: sb ≥ 2 cm Weak to medium development,

Root 0.5 mm≥3% , 1 mm≥3%, 10 mm≥3%.

B2: 37-68 cm (10YR 2.5/3.5), CL, 4~6 mm Pumice 2%,

Structure: 3~4 cm SA 5%, SB 1 cm weakly developed, root ≥1 mm 3%.

B3: 68-100 cm (10YR 5/6), LiC, 2~3 mm Pumice 5% ≥X,

Structure: 15~20 cm SA 45%, SB≥1 cm developmental weakness, roots≥1 mm 1%

Site name: Mine field (ii) New grassland

Soil name: blackbark soil

Date of survey: 20 Aug 2023

Geographical location:(36.5572149, 138.3509755)

Weather: sunny Weather before survey: rainy

Azimuth: N 126°E S 54°E Slope: 14.8°E

Base material: volcanic ash

Topography: central part of gentle slope of mountainside

Elevation: 1404 m

Erosion: minor Drainage: good Human: yes (ski resort)

Exposed rock: no

Vegetation: silver grass

A1: 0-12 cm, (10YR 2.5/3), L, 5 mm≤ SA 10%,

Structure: granular Development very weak 3 mm≥, roots 0.5≥ 20% , 1≥ 30% ,10≥ 2%.

B1: 12-23 cm (10YR 4.5/6), CL, 3~4 cm SA 3%,

Structural: SB developmental extreme weakness 1 cm≥, roots 0.5≥ 5% , 1≥ 20%

B2: 23-31 cm (10YR 4.5/6), CL, 1~3 cm SA 3%, Structure: SB developmental extreme weak 1 cm≥, Root 0.5≥ 5% , 1≥ 5%

B3: 31-43 cm (10YR 4/6), CL, 1~2 cm SA 3%, Structure: SB Development extremely weak

5 mm≥, roots 0.5≥ 5% , 1≥ 5%

B4: 43-58 cm (10YR 3.5/5), CL, 1~3 cm SA 5%, Structure: SB developmental extreme weak 1 cm≥, Root 0.5≥ 3% , 1≥ 5%

2A: 58-70 cm (10YR 3.5/5), CL, 1~2 cm SA 1%, 4~8 mm pumice 5%, Structure: SB developmental extreme weak 1 cm≥, roots 1≥ 2%

2B2: 70-83 cm (10TR 4/6), CL, angular gravel 2 cm≥ 1%, structure: weak SB development 1 cm, no roots

2B3: 83-100 cm (10YR 5/6), LIC~CL, subangular gravel 2 cm 5%, structure: weak SB development 1 cm, no roots

2. provisional specific gravity, soil pH and soil nitrogen concentration at each site

The provisional specific gravity of the top layer was 0.49 g/cm³ for old grassland, 0.41 g/cm³ for forest and 0.57 g/cm³ for new grassland, which were lower at all sites than in the lower layers, but the values increased with depth, with 0.84 g/cm³ for old grassland, 0.88 g/cm³ for forest and 0.97 g/cm³ for new grassland in the lowest layer (Figure 2). (Figure 2). This was thought to be because the upper layer had more roots and other organic matter and lower soil density (provisional density), whereas the lower layer had less organic matter and higher soil density. A comparison of the provisional specific gravity of the top layer at each site showed that both grasslands had higher values than the forest. This was considered to be due to the grasslands being semi-humid in fresh soil, whereas the forests were semi-dry.

Soil pH values of approximately 5 for pH (H_2O) and 4 for pH (KCl) were observed at all sites, which were similar to those of blackbark soil without a history of land use such as fields (Fig. 3).

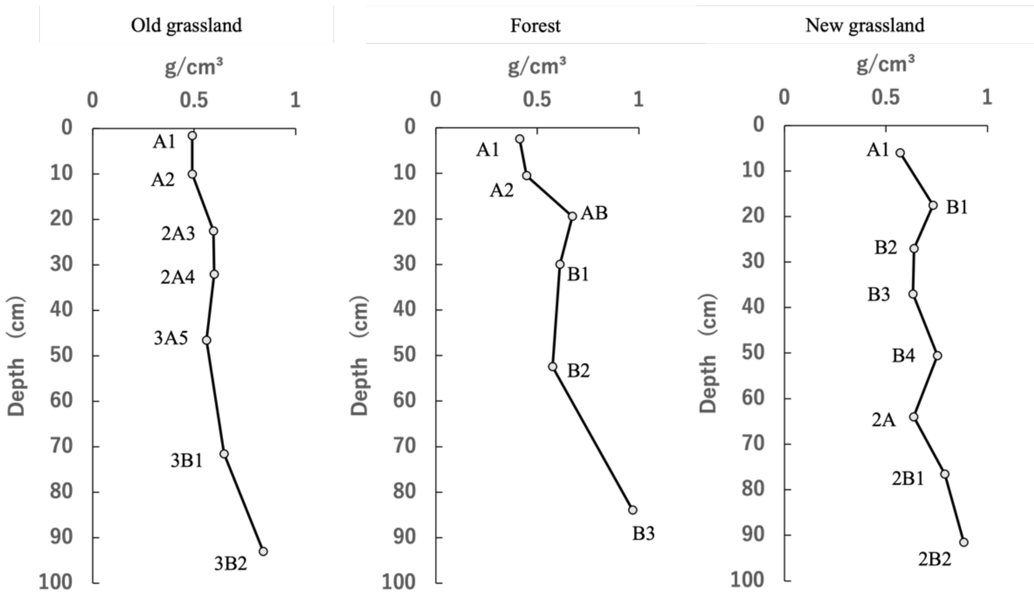


Fig. 2 Provisional specific gravity (g/cm³) at each site and layer

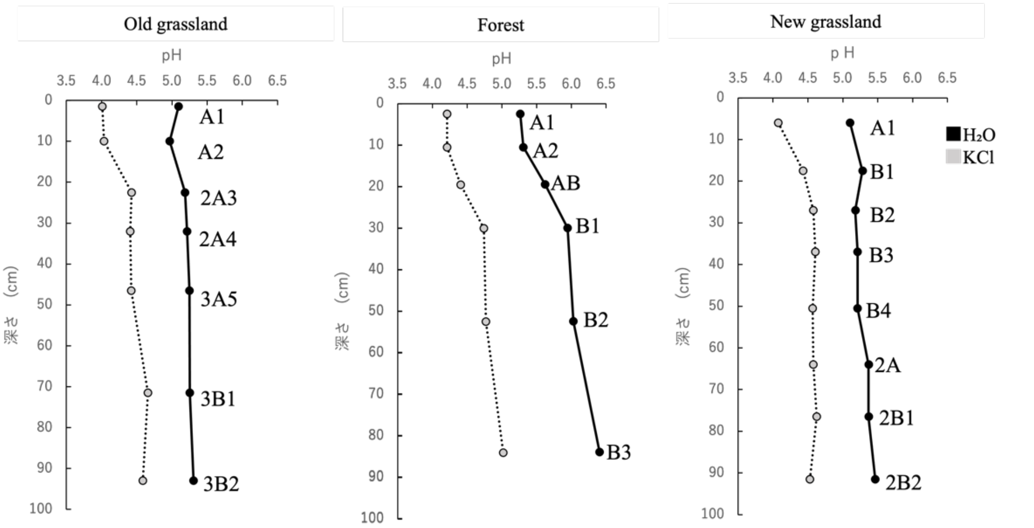


Fig. 3 Soil pH (H_2O) pHKCl) between strata at each site

Soil nitrogen concentrations were 12.2 g/kg in old grassland, 9.75 g/kg in forest and 7.9 g/kg in new grassland in the top layer, and 1.55 g/kg in old grassland, 1.77 g/kg in forest and 1.29 g/kg in new grassland in the bottom layer, showing that the top layer was highest and the bottom layer lowest at all sites (Figure 4). This was considered to be due to nitrogen cycling in the upper layers by nitrogen fixation and nitrification by soil micro-organisms and nitrogen assimilation by plants. In addition, the nitrogen concentration in the top layer was, in descending order from highest to lowest, old grassland > forest > new grassland. This suggests that the nitrogen concentration decreased when the area was converted to forest, and that even if the area was converted to grassland again, the nitrogen concentration had not recovered in about 50 years.

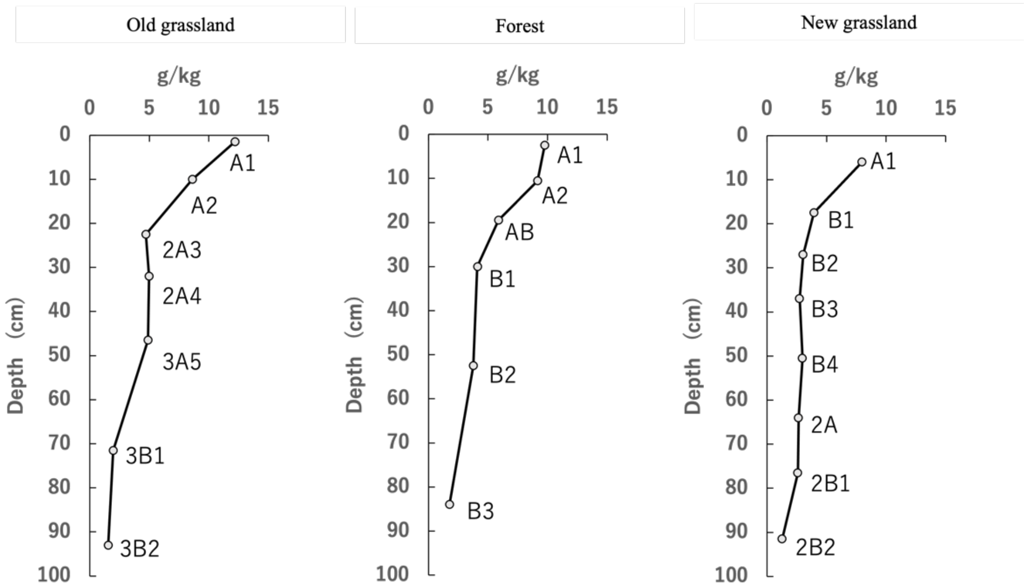


Fig. 4 Soil nitrogen concentration (g/kg) at each site and in each layer

3. soil carbon concentrations and soil carbon stocks at each site and in each layer

Soil carbon concentrations in the top layer were 177.2 g/kg in old grassland, 135.0 g/kg in forest and 113.2 g/kg in new grassland, and 22.7 g/kg in old grassland, 21.8 g/kg in forest and 17.2 g/kg in new grassland in the bottom layer (Figure 5). As with nitrogen concentrations, the highest carbon concentrations were found in the top layer and the lowest in the bottom layer. This was due to the presence of more humus derived from plant biomass in the upper layers. In addition, the order of carbon concentration was old grassland > forest > new grassland. This was considered to be due to topsoil disturbance and reduced carbon supply or increased carbon decomposition due to forestation.

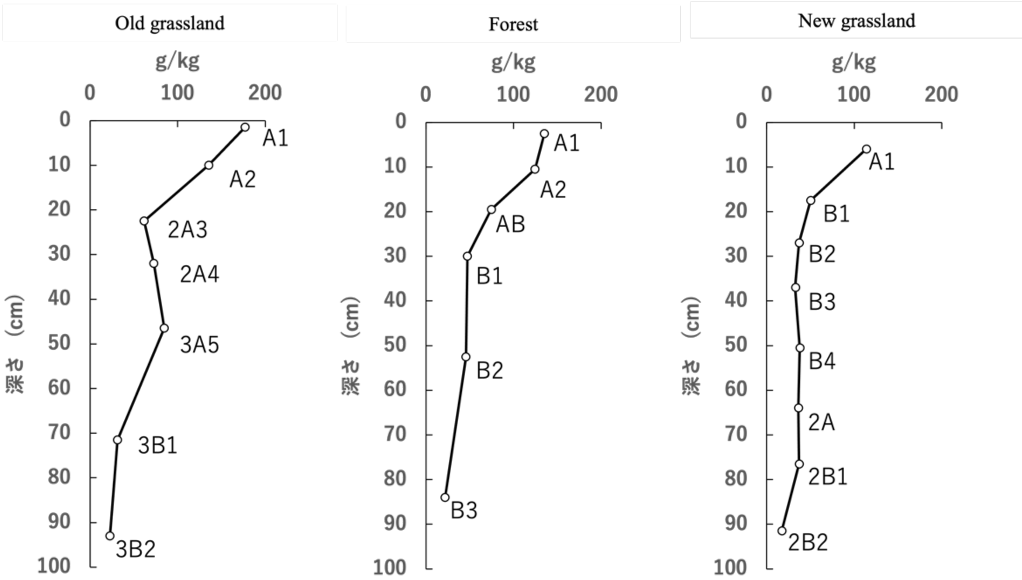


Fig. 5 Soil carbon concentration (g/kg) at each site and in each layer

Soil carbon stocks tended to be surface > sub-surface in old grasslands and forests, but not in new grasslands (Fig. 6). This was considered to be due to the fact that the thickness of each stratigraphic level was used to determine carbon stocks. The thickness of the top layer was 3 cm in the old grassland, 5 cm in the forest and 12 cm in the new grassland, with the new grassland tending to be much thicker. The reason for the tendency of surface > sub-surface layers in the old grassland and forest was considered to be that the top layer had a high carbon concentration but a low pseudo-specific gravity, and the layer was thin. The fact that the carbon accumulation in the next surface layer was palaeoprairie > forest suggests that the transition to forest affects the carbon accumulation in the next surface layer.

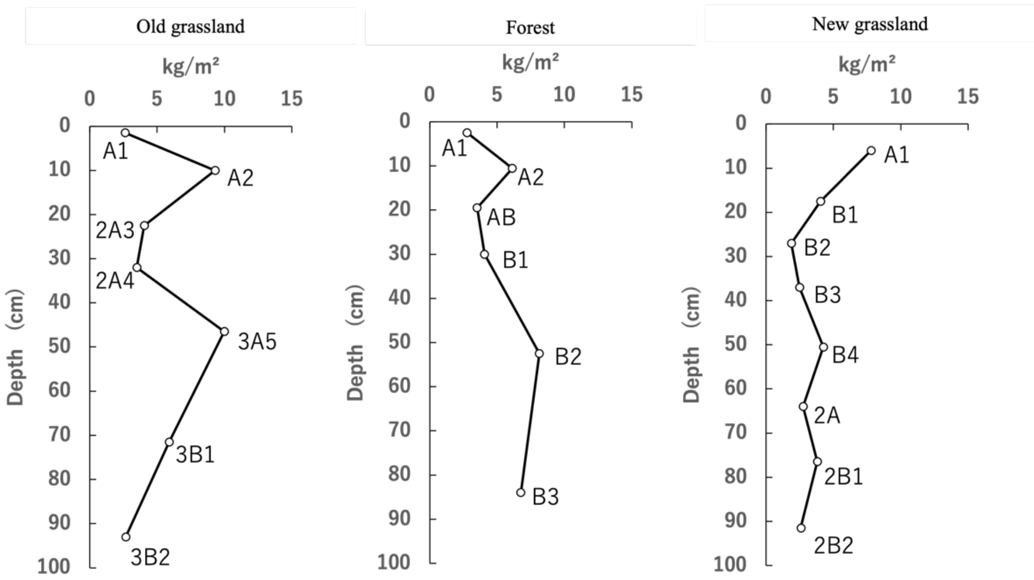
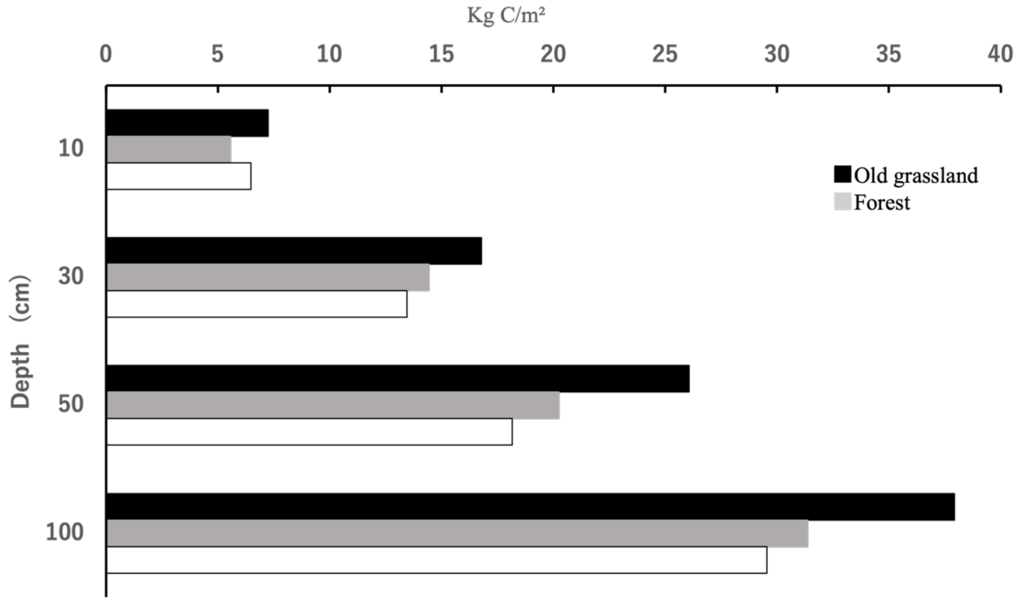


Fig. 6 Soil carbon accumulation (kg/m²) at each site and in each laye

Cumulative soil carbon stocks were palaeoprairie > new prairie > forest from the surface layer to 10 cm depth, and palaeoprairie > forest > new prairie to 30 cm, 50 cm and 100 cm depths (Fig. 7). Tukey's one-way ANOVA showed no significant differences ($p \leq 0.05$) between sites. However, there was a slight difference between the old grassland and the other two sites, as the p-value for forest and new grassland was 0.991, higher than the $p=0.867$ for old grassland and forest and $p=0.803$ for old grassland and new grassland.



図Fig. 7 Cumulative soil carbon accumulation at each soil depth at each site (kgC/m²)

Statistical treatments were performed using Tukey one-way analysis of variance ($p \leq 0.05$).
(old grassland vs forest p=0.867, old grassland vs new grassland p=0.803, forest vs new grassland p=0.991)

4. root-derived carbon concentrations in air-dried soil at each site and in the upper layer and

root mass and classification and breakdown (Figure 8). The highest root mass in the surface layer was observed at all sites. 'Fine' was the most abundant at all sites and in each layer, and the breakdown in the surface layer was fine > large-medium > small in the grassland at two sites and fine > small > large-medium in the forest. In the surface layer, root mass was two grasslands > forests, and the next most common root types were large-medium for grasslands and small for forests. This suggests that grasslands have more fine roots in the surface layer than forests, which may limit cracking of the surface layer due to earthquakes, as the grasslands have stronger rooting and fix more soil.

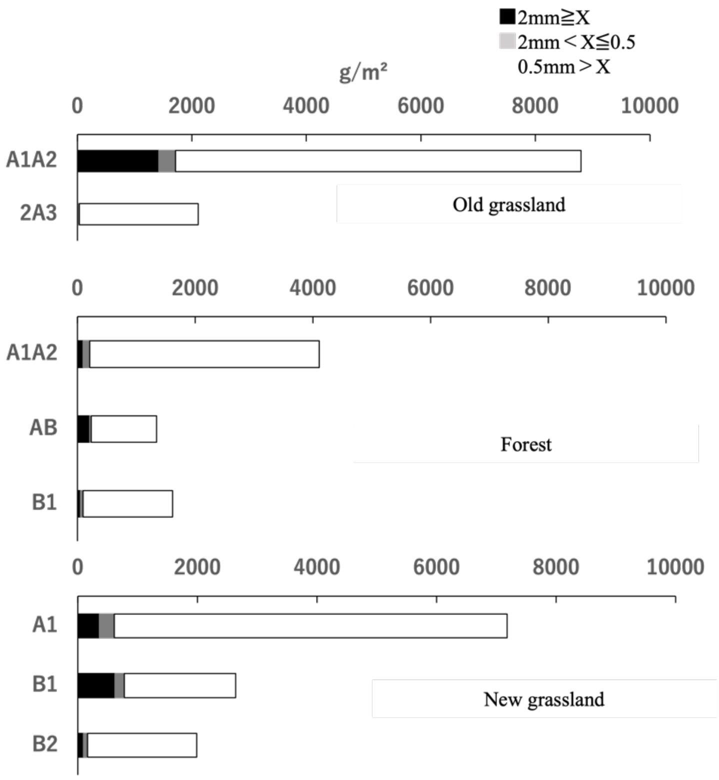


Figure 8 Upper layer root mass (g/m²) from 1000㎤ core sampling

The concentration of root-derived carbon in the upper layers was top surface > next surface in the old and new grasslands (Fig. 9). This could be due to an increase in the amount of mineral soils attached to roots that were not removed, rather than a decrease in the carbon concentration of the roots themselves, or the attachment of mineral soils with lower carbon concentrations in the lower layers. No difference in concentration was observed between the surface and sub-surface layers in the forest (Fig. 9). This could be due to the small temporary density of the forest and the gaps between roots and soil, as well as the semi-dry soil, which may have prevented soil from attaching to the roots. Tukey's one-way ANOVA between sites showed no significant differences ($p \geq 0.05$).

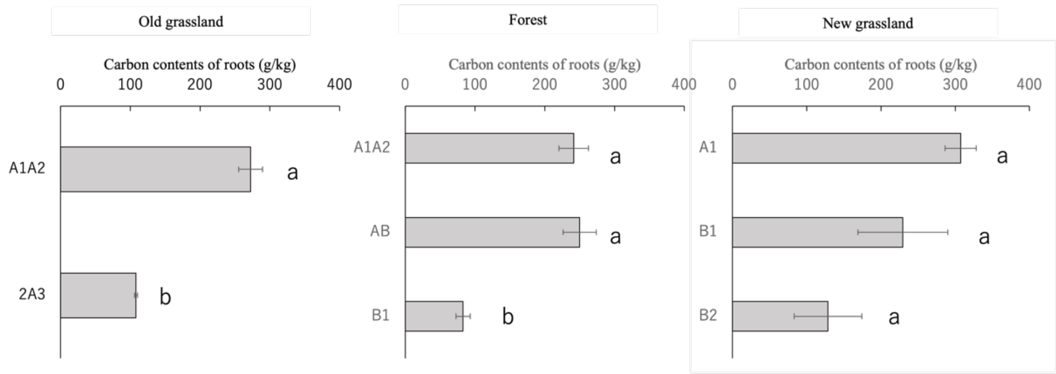


Figure 9 Carbon concentration in roots at each site (g/kg)

Tukey Unitary Configuration Dispersion Analysis (p≦0.05)
(Ancient Steppe A1A2 vs New Steppe A1 p=0.471, Ancient Steppe A1A2 vs Forest A1A2 p=0.545, Forest A1A2 vs New Steppe A1 p=0.123, Ancient Steppe 2A3 vs New Steppe B1 p=0.134, Ancient Steppe 2A3 vs Forest AB p=0.082, New Steppe B1 vs Forest AB p=0.922, New Steppe B2 vs Forest B1 p=0.382)

A trend of surface > subsoil was observed for root-derived carbon accumulation at all sites (Fig. 10). This was considered to be due to the fact that the number of roots in the lower layer was not collected in the quantities required for the analysis and was calculated using the small amount of roots and the carbon concentration in the surface layer. The trend of grassland > forest in the surface layer at the two sites was also considered to be due to differences in vegetation, with silver grass in the grassland and cedar and rust in the forest.

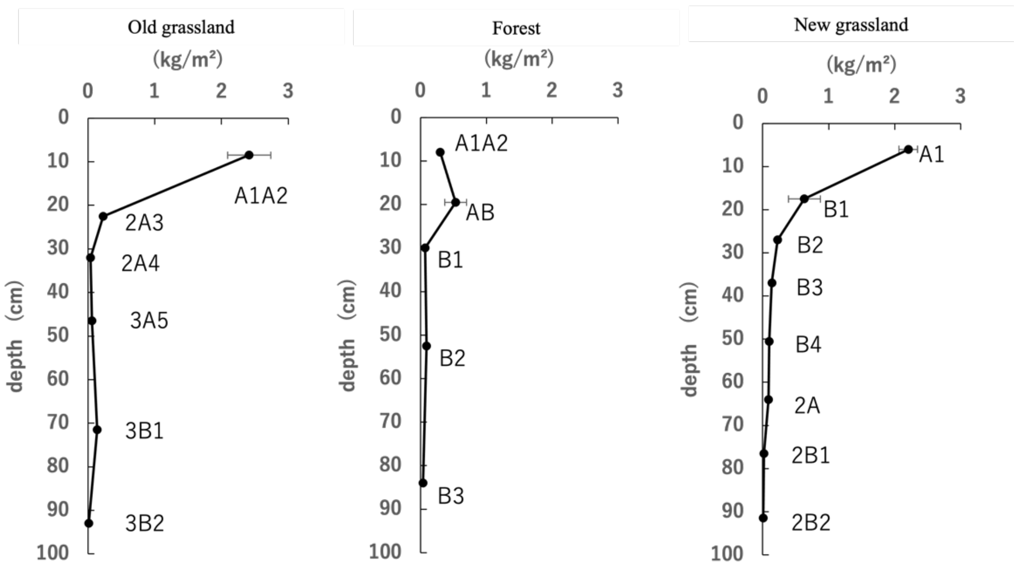


Fig. 10 Root-derived carbon accumulation in air-dried soil at each location and layer (kg/m²)

5. provisional density and root mass from core sampling

The provisional specific gravity of the soil in the 1000 cm³ core samples tended to be lower in the upper layers and higher in the lower layers (Fig. 11), similar to the values calculated from the soil samples (Fig. 2).

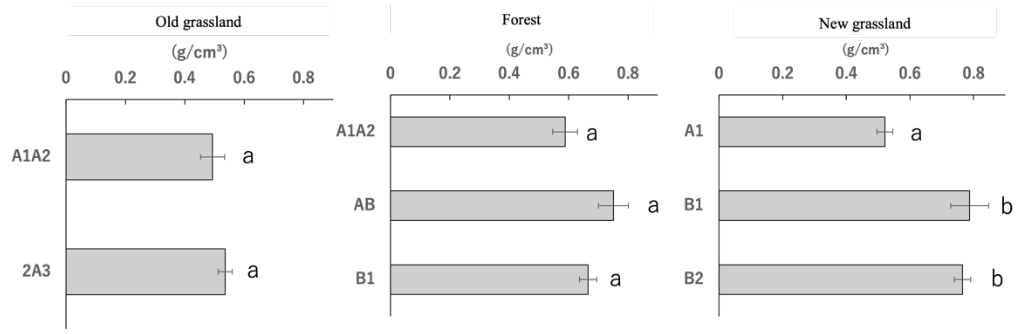


Fig. 11 Tentative specific gravity (g/cm³) based on 1000㎤ core sampling

Root volume at all sites and in all layers was calculated using root weights (g), volumes (cm³) and layer thicknesses (m) from 1000 cm³ core samples in A1A2 and 2A3 in old grassland, A1A2, AB and B1 in forest and A1, B1 and B2 in new grassland (Fig 12). Tukey's one-way analysis of variance between sites for the stratigraphic levels taken from the 1000 cm³ core samples showed significant differences ($p \leq 0.01$) between the old grassland and forest and forest and new grassland. This difference was attributed to differences in vegetation between the two grassland and forest sites. The low root mass in the understorey at all sites may be due to the fact that the grassland site had many shallow-rooted plants such as Miscanthus sinensis, while the forest site was surveyed at a location where trees were avoided (between trees) when the cross-sectional survey was carried out.

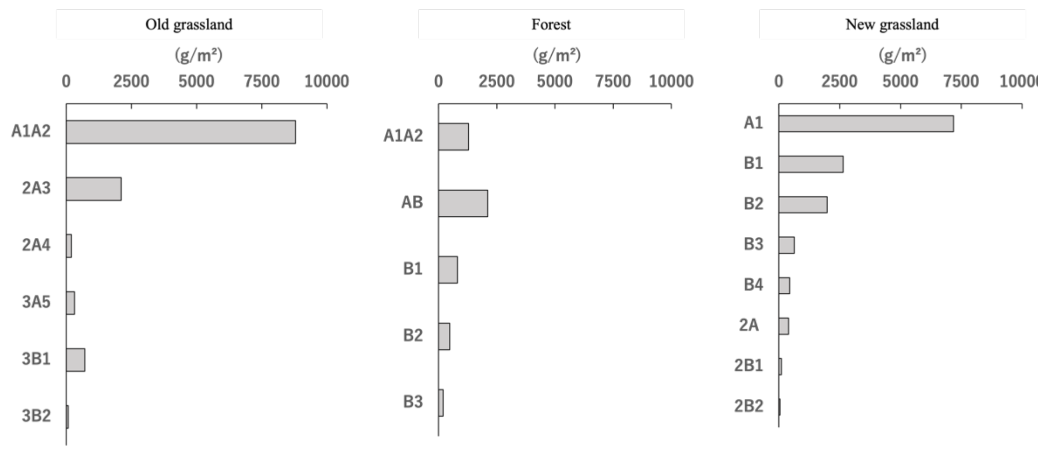


Fig. 12 Total layer root mass (g/m²) determined using the root mass value of the surface layer of 1000㎤ core sampling

Discussion.

1. soil carbon stocks considering roots

A comparison of soil carbon stocks with roots and soil carbon stocks alone showed a slight difference in the upper layer, but not in the lower layer (Fig. 13). The reason for this was thought to be that the root mass was upper layer > lower layer. The reason why the magnitude of soil carbon accumulation in both sites was grassland > forest at the two sites was considered to be because the root mass was grassland > forest, as indicated in 3-5.

Comparison of the conventional method using 100 cm^3 metal cores and the new method with cross-sections taken out to 10 x 10 x 10 cm^3 showed no difference between the methods in the old grassland, except at the surface, but in the forest there was a large difference in the upper layers and a slight difference overall in the new grassland (Fig. 14). The large difference in soil carbon stocks between the two methods in the upper layers of the forest was thought to be due to the difference in carbon stocks in the soil only and in the metal cores. The fact that there was little difference at depths greater than 60 cm at all sites suggests that the conventional method is sufficient in the lower layers, considering the labour required for the new method. The differences were large in the forest area, so it was considered necessary to conduct another survey to verify whether a similar trend could be observed. 2.

2. the effect of different soil cross-sectional survey sampling and core sampling on the assessment of soil carbon stocks to depths of 30 cm and 50 cm

Tukey's one-way ANOVA between soil cross-sectional survey sampling and core sampling survey methods showed no significant differences ($p \leq 0.05$) at either 30 cm or 50 cm depth (Fig. 15). Therefore, there was no effect of soil sample collection method on the assessment of root mass by depth, suggesting that simplification and efficiency of the soil cross-sectional survey is possible. As sample collection was not successful in this study and comparisons could only be made up to 50 cm, it was considered necessary to make comparisons of root volume assessments up to a maximum depth of 80 cm in the future. It was also considered necessary to perform other assessments commonly performed in soil cross-sectional surveys and to consider them again.

Conclusion.

In recent years, large-scale landslides have become more frequent and cause significant damage every year. It has generally been thought that forests are better able to control landslides than grasslands, as trees have vertical roots of 1 m - 1.5 m and can anchor a large amount of soil. However, both collapse depth and sediment production have been reported to be greater in forests compared to grasslands due to greater root depth (Koyanagi et al., 2018), suggesting that root depth and root mass are related to the magnitude of landslides. In this study, root mass and soil carbon were determined at different depths, and a new evaluation method for soil carbon stocks that takes into account root mass between forest and grassland in the inter-stratum and the efficiency of soil cross-sectional surveys using core sampling methods were investigated.

The study was conducted in the Minonohara Kogen Plateau (Suzaka City, Nagano Prefecture, Japan), using 'old grasslands' where grasslands have been maintained for more than 100 years, 'forests' planted after the war and 'new grasslands' where forests were cleared and turned into grasslands less than 100 years ago as the study sites. Soil cross-sectional surveys were conducted at each site and soil and core samples (1000 cm^3 and 100 cm^3) were taken for each stratum; for the 1000 cm^3 core samples, roots were separated and classified as large/medium (≥2 mm), small (0.5 mm≤X<2 mm) and fine (>0.5 mm), and carbon content was measured together with the soil samples using the dry fuel method. The carbon content was measured using the dry fuel method together with soil samples. Borehole surveys were also conducted at forest sites using 30 cm soil sampling tubes to determine the amount of roots contained at different depths up to about 60 cm.

Soil nitrogen concentrations tended to be highest in the upper layers and decreased towards the lower layers at all sites. The concentrations in the upper layers were, in descending order from highest to lowest, old grassland > forest > new grassland, and this order was thought to be due to the nitrogen cycle in the upper layers, which involves nitrogen fixation and nitrification by soil micro-organisms and nitrogen assimilation by plants. Soil carbon concentrations tended to be similar to soil nitrogen concentrations. The upper layer concentrations were, in descending order from highest to lowest, old grassland > forest > new grassland, and the reason for this order was thought to be the mixing of the upper layer soil with the lower layer soil due to surface soil disturbance during forestation and conversion to grassland. Soil carbon stocks were higher in the next surface layer than in the topmost layer in old grasslands and forests, but not in new grasslands. This was considered to be due to the highest carbon concentration in the topmost surface layer but lower specific gravity and higher provisional specific gravity in the lower layers. The reason why the carbon accumulation in the next surface layer was palaeoprairie > forest was considered to be because the transition from prairie to forest affects the carbon accumulation in the next surface layer. Cumulative soil carbon accumulation at soil depth was higher in old grassland compared to forest and new grassland, suggesting that the longer the area was used as grassland, the higher the soil carbon accumulation. A significant ($p \leq 0.01$) trend towards higher surface root mass was observed in old and new grasslands compared to forests, but not in the understorey. These results suggest that the low root mass in the surface layer in forests causes cracks in the surface layer to penetrate deeper through the roots, resulting in greater damage from landslides.

Secondly, the root mass was highest in the surface layer at all sites and highest in the fine layer at all sites. The breakdown from the surface to the second layer was fine > large medium > small in the two grasslands and fine > small > large medium in the forest. Root carbon concentrations were not significantly different ($p \leq 0.05$) at all sites. The soil carbon assessment method that does not take roots into account (hereafter referred to as the conventional method) and the soil carbon assessment method that takes roots into account (hereafter referred to as the novel method) resulted in lower carbon stocks in the understorey in the novel method due to the low root mass in the understorey at all sites. Therefore, the new method was considered to be accurate in assessing carbon stocks in the surface layer, but it was considered necessary to increase the sample collection in the lower layers, where the dry fuel method could not collect sufficient root mass to be analysed.

Finally, no significant differences ($p \leq 0.05$) were found between borehole sampling with a 30 cm soil tube and cross-sectional sampling for root volume to 30 cm and 50 cm depths, suggesting that borehole sampling with a 30 cm soil tube could be used to improve the efficiency of root volume assessment.

These results show no significant differences ($p \leq 0.05$) in soil carbon stocks between grasslands and forests, although,

grasslands had significantly ($p \leq 0.01$) more roots in the surface layer than forests, suggesting that grasslands are more effective in reducing landslides. The new method for soil carbon stocks was considered to be more accurate than the conventional method if a large number of samples could be taken. No significant difference ($p \leq 0.05$) was found between the core sampling method and the cross-sectional survey in terms of root mass, suggesting that efficiency can be improved.

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