# ESTIMATING 3D FOREST STRUCTURE USING LIDAR DATA FOR RISK ASSESSMENT OF SLOPE COLLAPSE CONSIDERING ROOT SYSTEM DEVELOPMENT

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**KEY WORDS:** LiDAR data, forest structure, slope failure, root system development, weathered layer thickness, tree density

**ABSTRACT:**

In order to predict slope failure, it is useful to be able to grasp the state of root system development of trees by remote sensing techniques. Since there is a positive correlation between tree diameter and root system development, a field survey to verify how predictable the number of trees and breast height diameter can be from LiDAR data was conducted in the Abukuma Mountains Granite Area and the Yamizo Mountains Jurassic Sedimentary Rock Area. It was carried out for the logging site. As a result, it was found that the relative tree density can be determined and that the laser transmittance and the sum of cross-sectional areas of the trees are inversely correlated.

## 1. INTRODUCTION

Various studies have been conducted on the topography and geological predisposition of slope collapse, but few studies focusing on developments of tree root systems have not been conducted. Since the extension depth of the root system of trees is generally about 1 to 3 m, it is considered that the soil and weathered layers that make up the surface layer of the slope and the root system have a great influence on the surface collapse. However, there are few data on root system development because it is necessary to dig up the roots of trees. According to Okatani et al. (2013), it suggested that LiDAR data may be used to determine tree height, number of trees and diameter at breast height. Therefore, in order to use LiDAR data to enhance the risk assessment of slope failure in forests, the authors conducted two research studies in felled areas where the developmental state of the root system is easy to observe. One is to investigate the relationship between stump diameter, weathered layer thickness and root system development. The other is a study of the possibility of obtaining forest structures such as the number of trees and diameter from LiDAR data.

## 2. SURVEY AREA

The study areas are the set for logging areas in North-Eastern Japan. The target areas are roughly divided into two areas according to the geology. One is the Abukuma granite area in Fukushima prefecture, and the other is the Jurassic accretionary prism area in the Yamizo Mountains in Tochigi prefecture.
There are five surveyed logging areas in the Abukuma granite area. Abukuma granite has a large area where granite is distributed and an area where granodiorite is distributed. In the area where granite is distributed, there are three surveyed logging areas, Onigajo, Yadaijin, and Saiso, and in the area where granodiorite is distributed, there are two surveyed logging areas, Ojiroi and Kawauchi. In the Jurassic sedimentary rock area of the Yamizo Mountains, there is one logging area located in Nakagawa Town, Tochigi Prefecture. Figure 1 shows the approximate locations of a total of six logging areas.

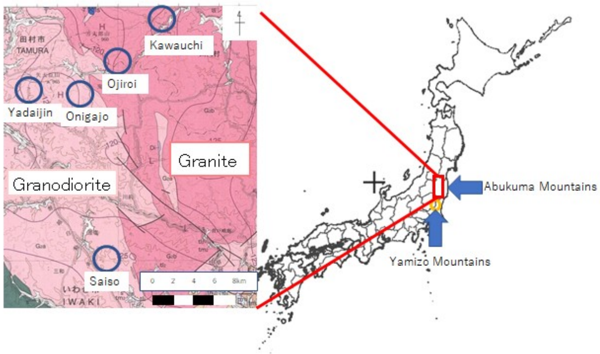


**Figure 1**. Index map of studied areas

## 3. RESAERCH METHOD

Field surveys can be divided into two types. One is a survey to investigate the relationship between tree root system development and weathering, topography, and geology. The other is a survey of all trees to compare LiDAR data with local conditions.
As a root system development survey, we conducted a survey along the work roads that allows observation of the root system condition, and measured the diameter of the stump, the width of the root, and the depth of the root. In addition, the thickness of the weathered layer was measured and classified into four layers: soil layer, strong weathered layer, medium weathered layer, and weakly weathered layer.

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Soil: A dark layer with no minerals other than quartz.
Strong weathered layer: A little mineral is seen, but it is almost close to the soil, and it is a brown layer.
Medium weathered layer: A layer that is easily broken by hands or a sickle, although mineral particles remain.
Weakly weathered layer: A layer that has strong bonds between minerals and is difficult to scrape even with a sickle.
The local topographical conditions were divided into ridge type and valley type, steep slope and gentle slope. The analysis focused on the relationship between stump diameter and root system development, and the relationship between root system development and topography / weathering. Figure 2 shows the state of root system development.

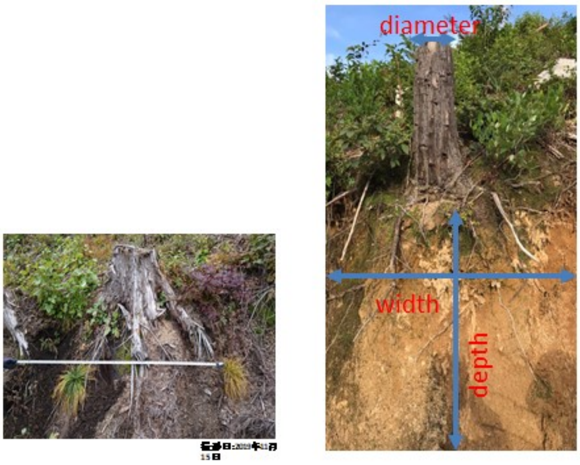


**Figure 2**. Survey of root system development

For the survey of all trees, a square sections with a size of 20m to 10m based on a 5m square were set up, the positions of the four corners of the square section are measured by GNSS, and the positions in and near the square section are measured. The position and diameter of the stump were measured.
For the analysis of LiDAR data, the authors focused on tree height, number of trees, and diameter at breast height. Regarding the tree height, the difference between DSM and DEM was judged the height of the tree, and compared it with the result of measuring the tree height using the laser tree height measuring instrument Vertex in the place where logging was not done.
For the number of trees, two methods were done. One is to extract trees using the point cloud data processing software ENVI LiDAR, and the other is to create DCHM (Digital Canopy Height Model) using ArcGIS to extract trees. Then, it was compared with the position and number of trees grasped in each tree survey.
For the diameter at breast height, the ratio of the total cross-sectional area of the tree to the area of the square section was calculated, and the relationship with the laser transmittance was analysed.

## 4. RESULTS AND DISCUSSION

### 4.1 Relationship between root system development and weathered layer thickness

The following information was obtained from observations of root system development in logging areas. No correlation was found between diameter and root depth, but a very weak positive correlation was found between diameter and root width. Regarding the relationship between the thickness of the weathered layer and the depth of the roots, it was confirmed that the depth of the roots was included up to the middle weathered layer.
To see the effect of geological differences in the granite area on root system development, the relationship between stump diameter and root depth was researched. Figure 3 shows the relationship between stump diameter and root depth in granodiorite area. Figure 4 shows the relationship between stump diameter and root depth in granite area. Granodiorite is more prone to weathering because it contains more colored minerals than granite. Granodiorite tends to have deeper roots, but it is not so remarkable. Figure 5 shows the thickness of the weathered layer due to the difference in geology, and the soil layer is thicker in granodiorite.

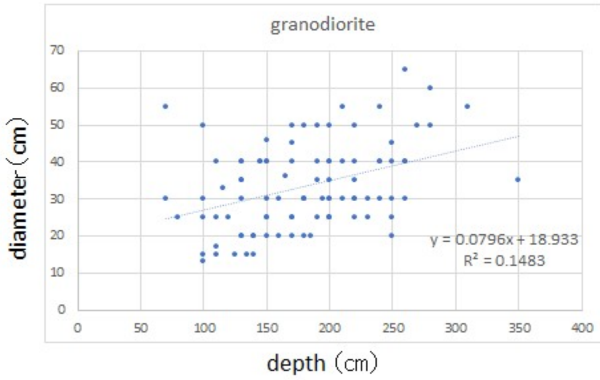


**Figure 3**. Relationship between diameter and depth in granodiorite area

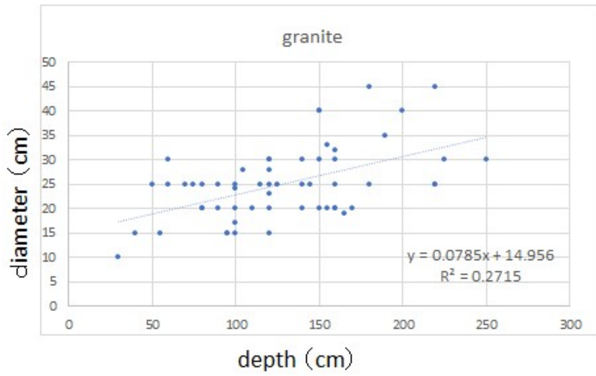


**Figure 4**. Relationship between diameter and depth in granite area

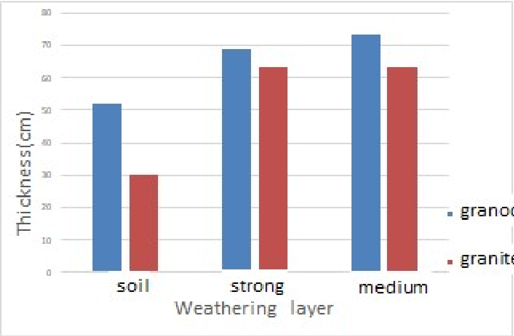


**Figure 5**. Thickness of weathering layer in Abukuma Granite area

Next, the stumps were divided into 99 ridges and 71 valleys, and the relationship between the diameter of the stump, the width of the roots, and the depth of the roots was researched. The results are shown in Figures 6-11. There is a very weak positive correlation, but the ridges are slightly more correlated than the valleys.

It is considered that the root binding effect is related to the root depth and the root width. If the diameter of the tree can be estimated, it can be considered that the binding effect on the width of the root can be taken into consideration. On the other hand, the depth of the roots is affected by the thickness of the weathered layer, and it is generally considered that the roots invade only to the medium weathered layer. As for the granite area, it is estimated that the valley topography is more likely to be weathered, so we would like to consider an evaluation method that takes into account topographical factors in the future.

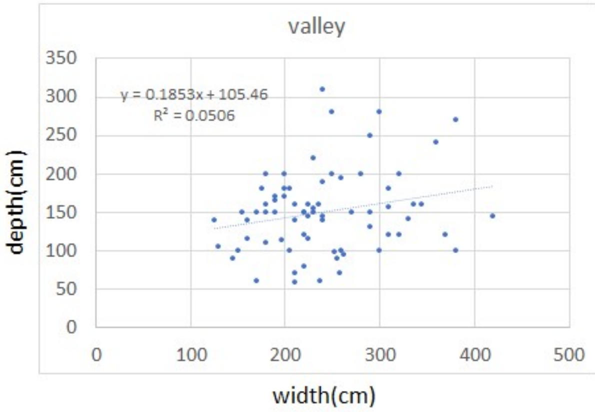


**Figure 6**. Relationship between depth of roots and width of roots in valley

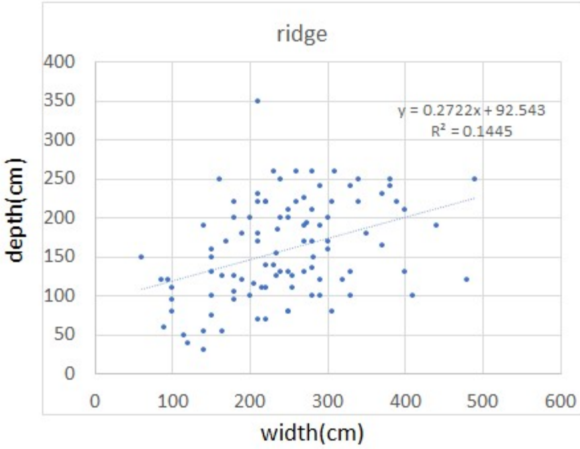


**Figure 7**. Relationship between depth of roots and width of roots in ridge

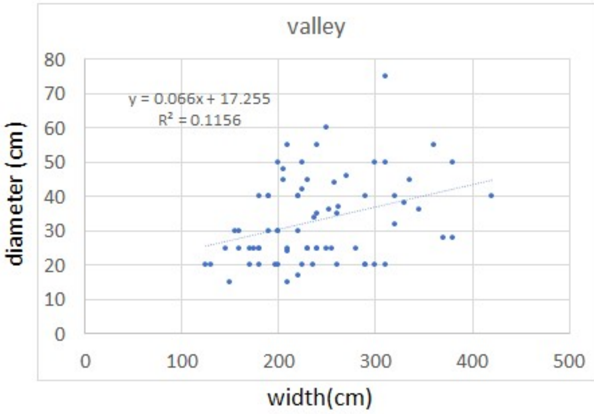


**Figure 8**. Relationship between diameter and width of roots in valley

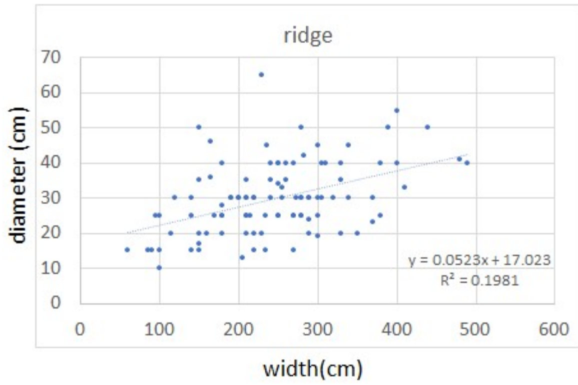


**Figure 9**. Relationship between diameter and width of roots in ridge

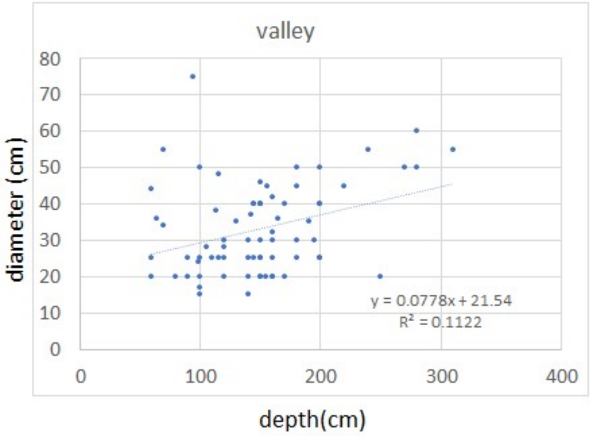


**Figure 10**. Relationship between diameter and depth of roots in valley

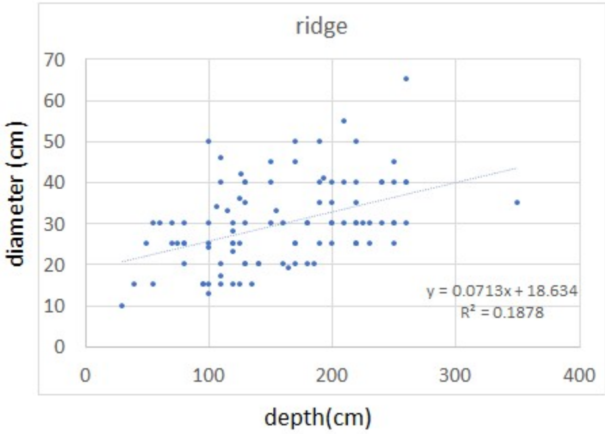


**Figure 11**. Relationship between diameter and depth of roots in ridge

### 4.2 Estimating tree height

When the tree height obtained by the difference between DSM and DEM was compared with the tree height measured using Vertex, the maximum error was 2 m, but most of them were within 1 m. The tree height can be calculated accurately with DSM-DEM. Since the diameter at breast height was measured at the same location, the relationship with tree height is shown in Figure 12. It is in a proportional relationship and has a strong positive correlation. If the tree height can be accurately obtained by LiDAR data, it is possible to estimate the diameter of the tree from it.

### 4.3 Estimating tree density

In all the squares of the logging area in the granite area and the sedimentary rock area, the extraction rate was about twice as good as the method of extracting trees by obtaining DCHM than the method of extracting trees using ENVI LiDAR. Even in areas where the point cloud density of LiDAR was small, it was difficult to extract trees with ENVI LiDAR, but it was possible to extract trees by the method of obtaining DCHM.

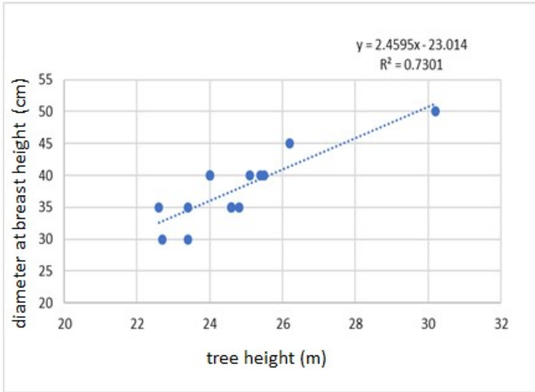


**Figure 12**. Relationship between tree height and diameter

Figure 13 is a diagram comparing the number of trees with a diameter of 20 cm over by each tree survey and the number of trees extracted by LiDAR analysis in all the square areas. The number of trees does not match, but the tendency of the number of trees to be large or small is captured.
Figure 14 shows the result of predicting that the extraction rate of trees is poor in steeply sloping areas and multiplying the number of trees surveyed by the cosine of the slope. Although the effect of the correction is recognized to some extent, it has not reached a significant improvement. However, it is quite possible to think of the density of trees as high or low.
Figure 15 shows a tree density distribution map created in a part of the Yadaijin site of the Abukuma Granite area. Using tree density distribution map, it is possible to create a collapse risk map for each mesh that adds a collapse suppression effect of root system development.

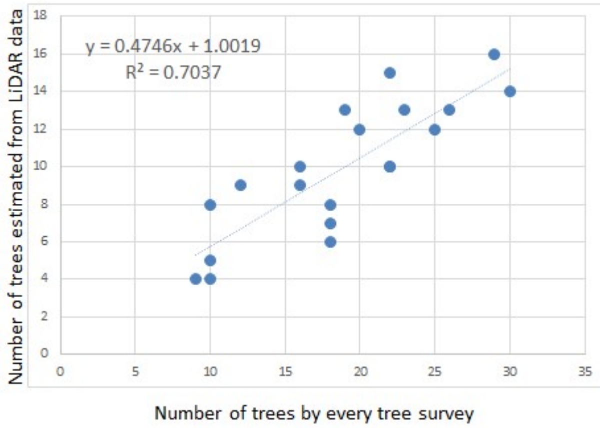


**Figure 13**. Relationship between LiDAR data and every tree survey.

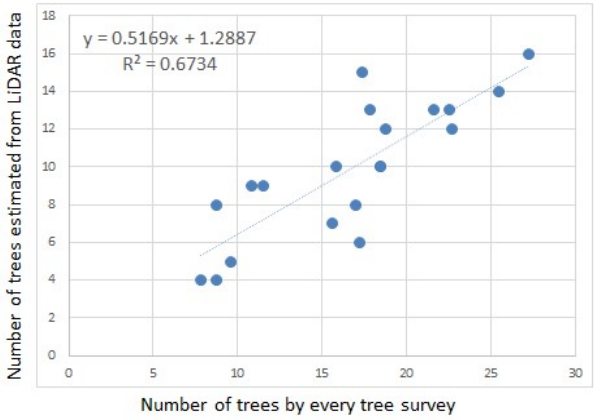


**Figure 14**. Relationship between LiDAR data and every tree survey with inclination correction.

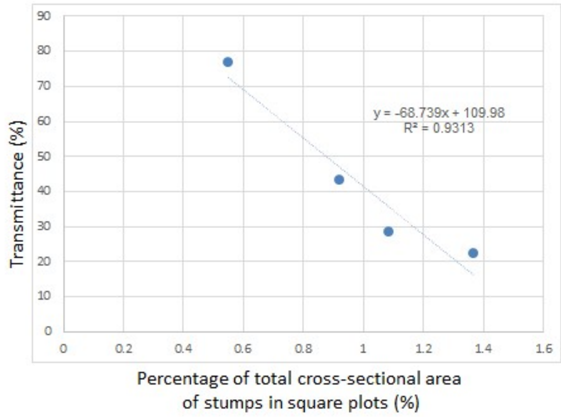


**Figure 16**. Relationship between LiDAR transmittance and total cross-sectional area in Onigajo site.

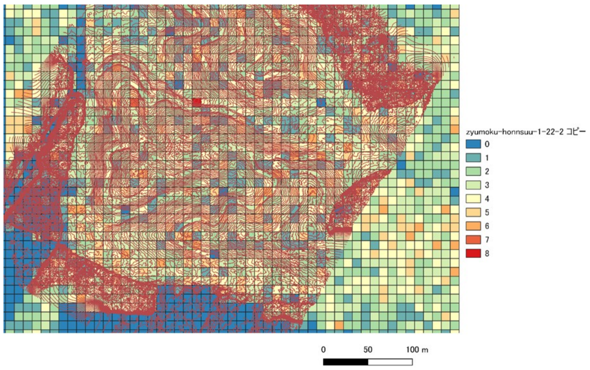

**Figure 15**. Tree density distribution map in the part of the Yadaijin site of the Abukuma Granite area.

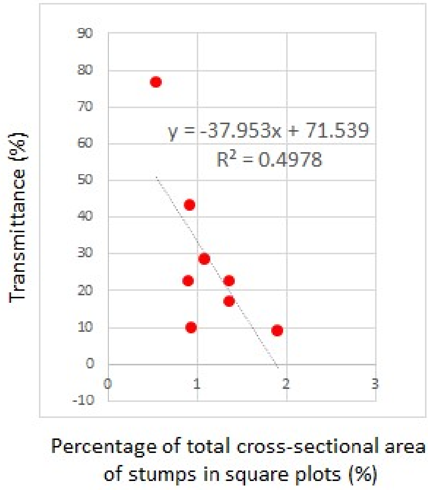


**Figure 17**. Relationship between LiDAR transmittance and total cross-sectional area in granite site (Onigajo and Ojiroi).

### 4.4 Relationship between transmittance and tree diameter

Looking at the relationship between the laser transmittance and the sum of cross-sectional areas of the stump in each square section, the negative correlation shown by Okatani et al. (2013) was found. Figure 16 shows the results of one site (Onigajo) in a granite area, where a strong negative correlation with a correlation coefficient exceeding 0.9 is observed.

Figure 17 shows the combined results of Onigajo and Ojiroi, but the correlation coefficient has dropped to 0.5 or less. The values were significantly different in the two-square section. Excluding these two sites will improve the correlation coefficient to over 0.6 (Figure 18). The reason why the two squares show outliers is that the point cloud density of the original data may be too high due to the overlapping area of the measurement course, and some correction method may be required.

Figure 19 shows a plot of all logging areas that were surveyed every tree in the Abukuma Mountains (Yadaijin, Ojiroi, Onigajo). The results are almost uncorrelated.

Figure 20 shows the results in logging of sedimentary rocks area in Nakagawa Town. Excluding the two outliers of the nine squares, the correlation coefficient is 0.4. The outlier squares are squares with steep slopes of nearly 40 degrees, or squares where artificially modified land such as work roads, which may have an effect. In the future, we would like to consider some kind of correction method.

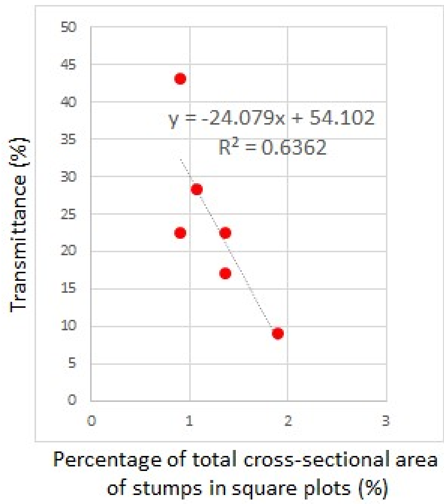


**Figure 18**. Relationship between LiDAR transmittance and total cross-sectional area in granite site (Onigajo and Ojiroi) without two outlier squares.

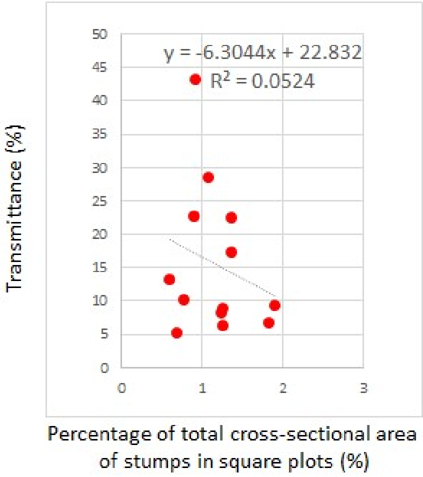


**Figure 19**. Relationship between LiDAR transmittance and total cross-sectional area in granite site (Onigajo, Ojiroi and Yadaijin).

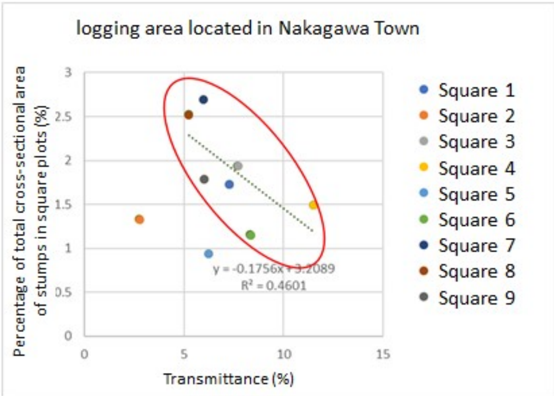


**Figure 20**. Relationship between LiDAR transmittance and total cross-sectional area in Yamizo sedimentary rock area.

## 5. CONCLUSION

There was a weak correlation between stump diameter and width of roots. No correlation was found between the diameter of the stump and the depth of the roots. Since the root depth changes according to the degree of weathering, it is necessary to estimate the degree of weathering from the topography and correct it.
The tree height can be estimated from the difference between DSM and DEM obtained from LiDAR data, and there is a strong positive correlation between the tree height and the diameter at breast height.
Although it is difficult to accurately determine the number of trees, it is possible to judge the relative magnitude of the tree density in the target area by the method of creating DCHM. It is possible to create a tree density map and apply it to the evaluation of slope failure risk.
A negative correlation is found between the transmittance of the LiDAR and the sum of the cross-sections of the trees, but there are many outliers on some square sections. Possible reasons for this include steep slopes, excessive point cloud density, and the effects of artificial modification. It is necessary to consider some kind of correction to the extent possible.

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## REFERENCES

Okatani T., Otoi K., Nakano T., Koarai M., 2013: Acquisition of 3D structure of forest from LIDAR data at Izumozaki district in Niigata prefecture. *Journal of the Japan society of photogrammetry and remote sensing*, 52-2, 56-68.