The Effect of Different Forest Types on Hydrological Characteristics in Central Japan

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(中部日本における異なる森林タイプが水文特性に与える影響)

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SUMMARY

Water is essential to life, the environment, and human development. Flora and fauna depend on water for growth, development, and survival, and water sustains human societies. However, drought and flood are the two remarkable disasters related with water, which are still major challenges for human well-being. Increasing water demands for agriculture, industry, urban and rural population have led to accelerate the water scarcity in many parts of the world. On the other hand, intensity of rainfall caused by extreme weather conditions in the areas with low infiltration capacity induces flash of water, which increases the frequency of severe floods. The issue of water scarcity or flood has consequently received much attention from researchers in different disciplines. FAO (2007), reported that around 1.2 billion people live in areas of physical water scarcity, 0.5 billion were approaching this situation, and 1.6 billion faced economic water shortage where countries lack the necessary infrastructure to take water from rivers and aquifers. The factor influences the rising the frequency of drought and flood is failure in environmental management. One strategies to facing this problem is improving in forest watershed management to control the water resource.

Water and forests are two of the most important resources on Earth. They both provide food, energy, habitat, and many other biological, chemical, physical, and socioeconomic functions and services to living things and the environment. The forest can be used for recreation, prevention of soil erosion and flooding, sink of carbon dioxide, and one most important is a preservation of water resource. With forest, the occurrence, distribution, and circulation of water are modified, the quality of water is enhanced, and the timing of flow is altered.

After World War II, many natural or secondary forests in Japan were changed to coniferous plantation forests for the purpose of timber production. The plantations were dominantly formed by converting broadleaf forests to coniferous forests. Changing the vegetation type has a significant impact on the hydrological cycle in the watershed scale. Moreover, most of the mountainous regions located upstream of agricultural and urban areas are covered by forests in Japan. From the viewpoint of water resource management, the forested areas are considered to be water sources and are closely linked to downstream ecosystems. Thus, when establishing policies for water resource management, how the conversion of broadleaf forests to coniferous forests influences the hydrological conditions should be considered.

Canopy coverage combined with floor vegetation strongly influences its hydrological responses. Since every tree species have different type of leave, twig, and branch structures in the space, different species induce different hydrological responses through canopy interception, evapotranspiration and percolation. Therefore, the effects of land cover and vegetation management on the hydrological processes have been observed in various ways such as changing interception losses, evapotranspiration, soil moisture, peak discharge, discharge flow and total runoff. Thus, the information on the effect of land cover or vegetation management changes on water quantity and quality is valuable in developing catchment management policies. From the above descriptions, a series of field experiments has been conducted in Kuraiyama experimental site, Gero City, Gifu Prefecture, Japan. Our objective was to investigate the influences of forest types on hydrological characteristics in forest watershed scale.

The study site is the Kuraiyama experimental forest at Gifu University (137°11′-137°14′E and 35°58′-36°01′N), which is located in Gero City, Gifu Prefecture, Japan.

Elevation lies in the range of 820-1,451 m a.s.l. The management office is located at an elevation of 750 m. The yearly minimum, maximum and average air temperatures observed at the office are -10°C, 30°C and 10°C, respectively. The annual precipitation is about 2,400 mm. While the main observations were carried out at the paired catchments of the C1 and D1 basins, supplemental observations were also carried out at the C2 and D2 basins for use as reference data.

The C1 basin is mainly covered by an evergreen coniferous forest, whose dominant tree species is Japanese cypress (*Chamaecyparis obtusa*). The basin is located southeast of the experimental forest station. Its elevation lies in the range of 926-1,278 m and its area is 0.6 km^2. The 40- to 50-year-old artificial coniferous forest cover 74% of the basin area, 18% is covered by a broadleaf forest, and 8% is covered by a natural coniferous forest. The D1 basin is mainly covered by a deciduous broadleaf forest, whose dominant species is *Quercus spp*. The basin is located to the south of the C1 basin. The elevation lies in the range of 909-1,278 m and its area is 0.73 km^2. A deciduous broadleaf forest cover 77% of a basin area, 14% is covered by a 50- to 70-year-old artificial coniferous forest, and 9% is covered by a natural coniferous forest. The forest floor is also covered with a high density of bush, Sasa bamboo grass and a litter layer.

The C2 basin is covered by an evergreen coniferous forest located at an elevation from 1,088-1,312 m and its area is 0.21 km^2. The D2 basin is a deciduous broadleaf forest, which is located near the C2 basin. The elevation lies in the range of 1,037-1,228 m and its area is 0.09 km^2. The D2 basin area was covered by broadleaf forest around 73%.

In this research we investigate some variable relate to water and the soil characteristics in the Kuraiyama experimental forest. The variable relates to the water are discharge, precipitation, and snow depth, while related to soil characteristics are soil

texture, soil organic matter, soil particle density, soil permeability, and soil pH.

The results show that the annual discharge from the deciduous forest was higher than that from the coniferous forest. However, the peak discharge, the direct runoff during rainfall events and the runoff coefficient were higher in the coniferous forest than in the deciduous forest. In addition, the snow depth in the deciduous forest was higher than that in the evergreen coniferous forest due to the difference in canopy interception between the two forests. The forest canopy and the floor vegetation might two of factors in determining all of these hydrological characteristics. This research confirms that deciduous broadleaf forests are better able to foster water resources and to control flooding than evergreen coniferous forests.

概要

水は生命，環境と人類の発展に非常に重要である。すべての動植物の成長は水に大きく依存している他、水は人間社会を支えている．しかし、干ばつと洪水は水と関連する2つの顕著な災害であり、現在でも人類の生活にとって大きな課題となっている．農業、工業や生活による水需要は増加しつつある中、水資源不足は世界中の多くの地域で課題となっている．その一方、浸透能の低い地域における異常気象条件に起因する高強度の雨量は、出水を誘発し深刻な洪水の頻度が増加している．FAO（2007）によると、約12億人が渇水地域に住み、約5億人がこの状況に近づき、河川や帯水層から取水する技術が不足しているために直面している経済的な水不足が約16億人であると報告されている．このような旱魃と洪水の頻度が増加している要因の一つとして不適切な環境管理が考えられる．これらの問題を解決するための戦略として、森林管理を改善することによる水資源の制御が挙げられる．

第二次世界大戦後、木材生産の目的で日本の多くの天然林または二次林が針葉樹林に変更された．植林は主に広葉樹林を針葉樹林に変換することによって行われた．このように植生を変化させることは、流域規模の水循環に大きな影響を与える．また、日本では農村・都市部の上流に位置する山岳地帯の多くは森林に覆われている．水資源管理

の観点からみると森林地帯は水源と考えられ、下流域の生態系と厳密に関連している。したがって、水資源管理の施策を確立する際には、広葉樹林から針葉樹林への変換が水文学的条件にどのように影響するかを考慮する必要がある。このようなことから、土地被覆と植生管理の変化が流出水の水量や水質に及ぼす影響に関する情報は、流域管理施策の策定や改善において重要である．以上の背景により、岐阜県下呂市の位山演習林で 10 年間にわたる一連のフィルード実験を行った．その目的は、森林流域における森林植生の相違が水文特性に及ぼす影響を検討することである.

本研究は岐阜県下呂市に位置する岐阜大学の位山演習林で行った。年間最低、最高、および平均気温は演習林事務所で観測され、それぞれ-10℃、30℃と 10℃であった. また、年間降水量は約 2,400mm であった．主要観測は一対の流域として C1 流域および D1 流域で実施し、参考データとして C2 流域および D2 流域でも補足観測を行った．C１流域は主に常緑針葉樹林であり、樹種はヒノキ(*Chamaecyparis obtusa*)である．D1 流域は主に落葉広葉樹林でおり、その樹種はナラ(*Quercus spp*). であった。D1 流域はＣ1 流域の南方に隣接し、ほぼ同程度の流域面積を有する．C2 流域は常緑の針葉樹林で覆われている．D2 流域は落葉広葉樹林で、C2 流域に近接しほぼ同程度の流域面積を有している．土壌有機物、土粒子密度、土壌の透水性、土壌 pH、流出量、降水量、積雪深な

どを測定した.

10 年間の観測結果から、落葉広葉樹林流域（D1, D2）の年間流出量は針葉樹林流域（C1, C2）の流出量より大きくなった. しかし、ピーク流量、降雨時の直接流出量、および流出率は、針葉樹林流域が落葉樹林流域より大きくなった.　また、5 年間の測定結果から落葉広葉樹林内の積雪深は、常緑針葉樹林内よりも大きくなる傾向が見られた. この要因としては、2 つの森林流域の樹種が異なることによる樹冠による降雪遮断の相違であると思われる. 森林の樹冠と下床植生は森林流域の水文学的特徴を決定する最も重要な要因であることを確認した。この研究は、落葉広葉樹林が常緑針葉樹林より水資源を涵養し、洪水を抑制できることを示唆するものである.

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I INTRODUCTION

1.1 Background

Water is essential to life, the environment, and human development. Flora and fauna depend on water for growth, development, and survival, and water sustains human societies. However, drought and flood are the two remarkable disasters related with water, which are still major challenges for human well-being. Increasing water demands for agriculture, industry, urban and rural population have led to accelerate the water scarcity in many parts of the world (Hoekstra et al., 2012). FAO (2007), reported that around 1.2 billion people live in areas of physical water scarcity, 0.5 billion were approaching this situation, and 1.6 billion faced economic water shortage where countries lack the necessary infrastructure to take water from rivers and aquifers. On the other hand, intensity of rainfall caused by extreme weather conditions in the areas with low infiltration capacity induces flash of water, which increases the frequency of severe floods. Moreover, according to the population growth, natural forest areas have been largely converted to developed areas (Suryatmojo, 2015) or to plantation forests to fulfil industrial demands (Fuchigami et al., 2016).

One strategies to facing this problem is improving in forest watershed management to control the water resource. The combination of forest management and water resource are important to provide habitat, food, and energy for all living things in the earth. The existence of forest can modify the occurrence, circulation, distribution of water, enhance the water quality, and alter the timing of flow (Chang, 2013).

After World War II, many natural or secondary forests in Japan were changed to coniferous plantation forests for the purpose of timber production. The plantations were dominantly formed by converting broadleaf forests to coniferous forests (Fuchigami et al., 2016). Changing the vegetation type has a significant impact on the hydrological cycle in the watershed scale (Rahmat et al., 2018). Moreover, most of the mountainous regions located upstream of agricultural and urban areas are covered by forests in Japan. From the viewpoint of water resource management, the forested areas are considered to be water sources (Sawano et al., 2005; Kumagai et al., 2014) and are closely linked to downstream ecosystems (Gomi et al., 2002). Thus, when establishing policies for water resource management, how the conversion of broadleaf forests to coniferous forests influences the hydrological conditions should be considered.

Land use changes have a big impact on hydrologic cycle at the watershed scale (Chen et al., 2009). Soil, topography, and land cover are three primary watershed characteristics that govern rainfall-runoff-erosion response in watersheds. Therefore, the response of watershed hydrology will be varied over time depending on a change in the distribution and types of land cover (Miller et al., 2002). The change of land cover may influence evapotranspiration, canopy interception, percolation and eventually promote flood or drought disaster (Chang, 2007, Chen et al., 2009, Lin et al., 2015). The hydrological cycle inside of forest was strongly influenced by floor vegetation under the canopy coverage (Swank and Douglass, 1974; Bosch and Hewlett, 1982). Every species of tree have different structures of leaves, twigs, and branch not uniformly in the space. The different species of forest vegetation will have different response on hydrological character depending on forest types (Yavitt et al., 1995; Asner et al., 2004, Hisada et al., 2011, Wu et al., 2015). That means, the change of forest types will influence hydrological character, because the raindrop water must through the canopy at first, prior to reaching the forest floor. Because of the canopy's complexity, the path of the raindrop water was not well understood (Zinke, 1967).

In previous studies, the annual runoff of two types of forests at the same basin was measured by a long-term observation while the forest was being converted from a deciduous broadleaf type to an evergreen coniferous type (Komatsu et al., 2008, Swank and Dauglass, 1974). It was concluded that the annual runoff (long-term runoff) in broadleaf deciduous forests is higher than that in coniferous evergreen forests in regions with high winter precipitation. However, these studies could not compare the hydrological characteristics of the two forest types directly due to the fact that the weather conditions were not the same. By comparing the runoff characteristics of two types of forests in the plot scale and analyzing only the final data (Hirano et al., 2009, Sakai et al., 2009), other studies have shown that short-term runoff characteristics, such as surface runoff and peak discharge, were higher from coniferous evergreen forests than from broadleaf deciduous forests. However, the studies could not explain the annual characteristics in the basin scale.

1.2 Research Objectives

From the above descriptions, a series of field experiments has been conducted in the Kuraiyama experimental forest at Gifu University, which is located in Gero City, Gifu Prefecture, Japan, with the following objectives is to investigate and to reveal the difference in hydrological characteristics between deciduous broadleaf and evergreen coniferous forests, through a 10-year hydrological observation.

II LITERATURE REVIEW

2.1 Effect of afforestation on the hydrological response

Afforestation is the conversion of croplands, grasslands or the other land uses into forests. Before the conversion, the land should not be forested by human planting for at least 50 years (Bredemeier and Dohrenbusch, 2008). Afforestation is considered as one of effective strategies for global warming, because forests have a potential to absorb CO_2 from the atmosphere (Lal, 2003; Pan et al., 2011). Furthermore, the Kyoto Protocol adopted in 1997 encourages each country to increase the rates of carbon uptake and storage in forest biomass by afforestation program. Since then, many countries adopted afforestation programs, whose typical examples are China (Feng et al., 2012), New Zealand (Fahey and Payne, 2017), and Portugal (Hawtree et al., 2015).

Forests generally have a higher leaf area index (LAI), surface roughness, and a deeper and more developed root systems than other land cover types such as shrub lands or grasslands, resulting in a higher transpiration rate. In other words, the hydrologic response of forests is characterized by two primary causes, i.e., the greater capacity of interception associated with high LAI of the higher structured vegetation (Calder, 1986) and increase of transpiration through accessing to deep water or drawing stored soil water (Calder et al., 1993; Zhang et al., 2001). Thus, it can be expected that runoff from a watershed will decrease after afforestation due to the increase of evapotranspiration.

By compiling and modelling the catchment data mainly obtained from the northern hemisphere, Farley et al. (2005) concluded that when grasslands and shrub lands were afforested by many species, annual runoff reduction rate compared with the runoff before the afforestation, was 44 (±3) % for grasslands and 31 (±2) % for shrub lands. The reason for higher reductions of runoff in afforested grasslands compared with shrub lands may be inherently the lower transpiration with herbaceous cover. Calder (1986) reported that in India, transpiration losses from shrub vegetation tended to be relatively high because that type vegetation absorbed soil water twice than annual crops. And case study in China by Wang et al. (2012), evapotranspiration of grassland reach 6 mm 7-day^{-1}, while 7.2 mm 7-day^{-1} in shrub lands. The shrub vegetation has greater similarity to trees in terms of maximum root depth and total root biomass compared to grasses vegetation (Jackson et al., 1996). Moreover, shrubs vegetation type can be characterized by a longer active transpiration period than seasonally dormant grasses, which contributes to the total annual transpiration. The total annual transpiration of shrubs also may be higher than grasses, and more similar to the trees. As the consequence, runoff reductions may be more severe when grasslands are afforested compared to shrub lands. The different results of runoff reduction between grasslands and shrub lands are caused by differences among the ratios of evapotranspiration.

Farley et al. (2005) also reported that eucalyptus had a larger impact in afforested grasslands and reduced more runoff by 75% (±10%), compared to the average decrease by 40% (±3%) with pines, and that shrub lands afforested by eucalyptus reduced runoff by 38% (±5%), compared to pine only 30% (±2%). Because eucalyptus is a fast-growing tree, in the same age eucalyptus has greater sap flux and total water use than pine (Maier et al., 2017).

Buytaert et al. (2007) studied the impact of afforestation with Pinus species on runoff in the Paute river basin in South Ecuador. The results indicated that afforestation with *Pinus patula* reduced the amount of runoff by an average of 242 mm year^{-1} or about 50% compared to natural grassland vegetation with annual rainfall 939 mm year^{-1}. Moreover, afforestation in this site drastically reduced peak flow and base flow. The lowest flow rate approached zero (0.016 mm day^{-1}), which was clearly reflected by the higher water consumption of *Pinus patula*.

Pair-catchments Glendhu experiment was carried out in New Zealand by Rowe (2003), of which one catchment was planted with *P. radiate* in 1982 and the other one was still tussock grassland (natural/control). About 7 years after planted *P. radiate*, the annual runoff yields began to show a definite decline compared with grassland catchment. The average reduction of runoff amount was 330 mm year^{-1} or about 40% compared with the natural tussock grassland during the period of 7-20 year after planting with average precipitation of 1300 mm year^{-1}. Afforestation of the tussock grassland has resulted in decreased annual flood peaks compared to control catchment. And based on 7-day low flows after 6 year of planting, low flows in afforested site was lower than control site.

It was reported from the experiment carried out in the South African Cathedral Peak, that an average runoff amount was reduced by 257 mm years^{-1} or about 40% with mean annual precipitation 1300 mm years^{-1} after replacing the original vegetation (Themeda grassland) by *P. patula*, and maximum reduction was 440 mm year^{-1} occurring in 22 years after afforestation (Bosch and Hewlett, 1982).

Afforestation activities dominantly convert natural grasslands to pine or eucalyptus forests. Based on the above research, it is summarized that the afforestation on grasslands reduces the amount of runoff between 40-50% in average for pine tree and especially eucalyptus forest reduces the runoff amount up to 75%. Based on these conclusions, the watershed manager must apply afforestation under consideration about climatological conditions in the surrounding area and what is the main problem to solve related to forest watershed. Afforestation is not recommended to apply in countries with a little amount of precipitation, because mature forests can reduce a lot of runoff. However, afforestation can be adopted in many countries with much precipitation to decrease the risk of flood in the downstream area and to produce raw materials for industry.

2.2 Effect of forest thinning on the hydrological response

Forest thinning is activities to remove a portion of the trees on a site to reduce forest stand density, which has been commonly adopted to enhance the growth of remained trees in silviculture (Smith et al., 1997). This technique can improve the quality of trees and produce saleable products (Kerr and Haufe, 2011). Thinning technique was applied by forest management operation in plantation forest (Lopez-Vicente et al., 2017). Furthermore, it can also be used to diversify structure and composition of a forest. For example, heavy thinning can increase the growth of the shrub layer with potential as wildlife food (Bowyer et al., 2009).

The hydrological response of thinning is highly influenced by the reduction of vegetation cover via forest thinning. Bosch and Hewlett (1982) reviewed 94 catchments and analyzed the runoff increase compared to vegetation cover reduction; coniferous and eucalypt forest caused 40 mm increase of the annual runoff corresponding to 10% decrease in land cover, while deciduous hardwoods and bushes showed 25 and 10 mm year^{-1} increase of the annual runoff per 10% decrease in land cover. Furthermore, Sahin and Hall (1996), based on fuzzy linear regression analysis to 145 experiments data, showed the result that 10% reduction of canopy cover in eucalyptus type forest could increase water yield by 6 mm, while water yield was increased by 20-25 mm for conifer type forest.

Forest thinning treatment generally results in an initial increase in runoff and then the runoff will return to pre-treatment levels. The uniform and intensive thinning treatment which reduced 80% of crown cover of eucalyptus tree in the Hansen catchment in Australia resulted in a maximum increase of 260 mm year^{-1} runoff (19% of annual rainfall) at the 4th year. Five years after the treatment, there were systematic declines in the runoff. Annual runoff was approximately 90 mm year^{-1} higher at 10 years after thinning than the pre-treatment runoff (54 mm year^{-1}). This declining trend in runoff is attributable to the forest regrowth following treatment (Bari and Ruprecht, 2003).

At the Higgens catchment in Australia, the forest cover of eucalyptus was reduced by 60%, which promoted to increase the runoff up to 12% of rainfall or 156 mm year^{-1} at 4th years after treatment. In the post-treatment period, runoff was considerably higher than the pre-treatment (39 mm year^{-1}). After the runoff reached the maximum at the 4th year, it declined and returned to pre-treatment level after 10 years (Bari and Ruprecht, 2003).

At the Jones catchment in Australia, where 40% of forest cover of eucalyptus was thinned, the runoff increased up to the maximum (103 mm year^{-1} or 9% of rainfall) at 4th years after the treatment and returned to pre-treatment level (around 12 mm year^{-1}) after 10 years (Robinson et al., 1997).

In a paired catchment experiment in the southwest Western Australia, where the average annual precipitation was about 1,200 mm per year, Ruprecht et al. (1991) reported the effect of thinning in a small forest catchment dominated by Jarrah tree (*Eucalyptus marginata*) and marri tree (*Eucalyptus calophylla*) where trees were thinned from 700 to 110 trees per hectare (84%). The groundwater levels in the thinned catchment began to rise within the first year after thinning. The groundwater attained to a new equilibrium after 2 years, rising approximately by 2 m and 5 m in the lower and higher stations of the slope, respectively. The peak flow increased by 50% compared to control. The amount of runoff increased from approximately 6% of annual rainfall before thinning to about 20% after thinning 3 years after the treatment.

Stoneman (1993) reported the results of reducing one-third of canopy by thinning small catchment covered with Jarrah (*Eucalyptus marginata*) as a dominant tree. The rainfall condition during the pre and post treatment periods was 21% and 10%, respectively below the long-term average of rainfall (1120 mm year^{-1}). The results showed that after 8 years of thinning, the groundwater level at valley and mid-slope was increased by 4 m and 8 m respectively. After 9 years of thinning, the amount of runoff was increased from 0.5% (4.3 mm year^{-1}) to 7.6% (90 mm year) of the annual rainfall.

Grace et al. (2003) reported that selective thinning of 70% trees (69% canopy coverage) in watershed covered by 15-year-old loblolly pine (*Pinus taeda*) in North Carolina, USA, showed the average annual runoff increase 1.36 times than the control. The peak flow also increased by 40% after thinning compared to control. Moreover, total phosphorous, total nitrogen and total suspended solid increased following thinning treatment.

On the other hands, Rahman et al. (2005) showed that there was no significant change of direct flow and peak flow by thinning 6.35% of canopy in small mountainous watershed in Kochi Prefecture, Japan, whose vegetation was Japanese cedar (*Cryptomeria japonica*), Japanese cypress (*Chamaecyparis obtusa*), red pine (*Pinus densiflora*), and oak (*Quercus* spp).

The effect of thinning the forest cover on soil erosion and water pollution must be cautiously considered. Erdogan et al. (2018) reported based on experiment in Belgard Forest in Istanbul, Turkey whose dominant vegetation cover was mainly composed of *Quercus* sp, that 18% forest thinning caused to increase 7.3 μScm^{-1} of electric conductivity, 2.8 NTU in turbidity, 15.1 mgL^{-1} in suspended sediment concentration compared with the control.

The main purpose of thinning is to improve the quality of trees and produce saleable products with a reduction of the tree density. The consequence of thinning treatment is decreasing the evapotranspiration and increasing the net precipitation reaching to the forest floor and the total amount of runoff. It is concluded based on linear regression from Hansen, Jones and Higgens watershed data (Bari and Ruprecht, 2003) that the annual runoff can be increased by 40mm of rainfall per thinning 10% of eucalyptus canopy cover. However, the decline time of runoff is still varied depending on location and watershed conditions.

Applying thinning treatment is useful to increase the quality of tree and also to increase the total amount of runoff. However, the percentage of the canopy reduction must be decided under considering how much runoff increases and environment deteriorates such as soil erosion and water pollution.

2.3 Effect of clear-cutting on the hydrological response

Clear-cutting (sometimes called clear-cut logging) is a logging practice in which all the trees are uniformly cut. The objective of clear-cutting is to create a specific type of forest or to grow new tree species uniformly (Bowyer et al., 2009). It is different from the deforestation, where the trees naturally or artificially regenerate soon after the clear-cutting treatment. It is also different from forest thinning, where all trees are cut in the specific area in clear-cutting while trees are partly cut in the forest thinning, the difference can be seen in **Fig.1.**

The amounts of runoff from forest catchments typically increase in the short term after forest clear-cutting (Bosch and Hewlett, 1982; Harr, 1983; Stednick, 1996). Such increases in runoff can cause higher turbidity and nutrient loads, resulting in degradation of water quality and eutrophication in the downstream rivers and waters (Ahtiainen 1992, Rosén et al., 1996, Carpenter et al., 1998, Ahtiainen and Huttunen, 1999, Nisbet, 2001, Gomi et al., 2005, Laurén et al., 2009, Webb et al., 2012).

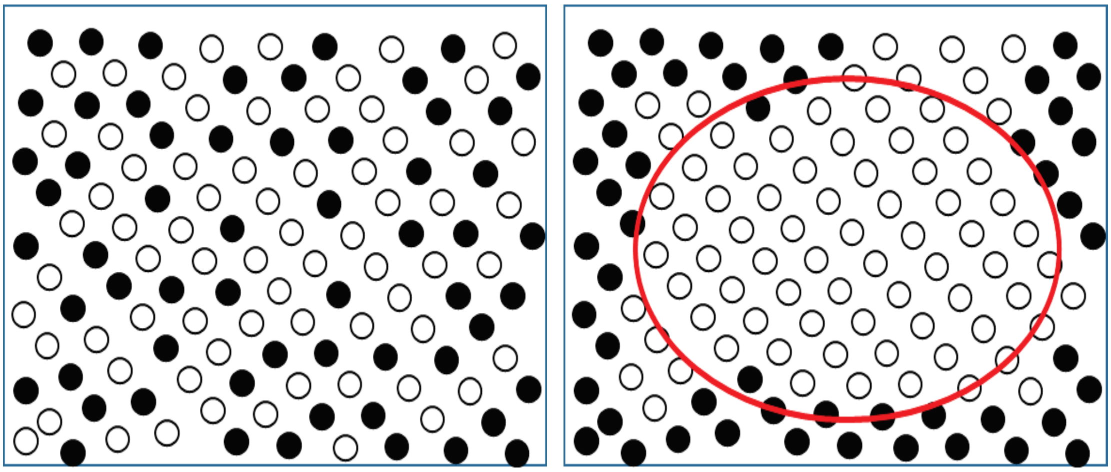


Fig.1 Forest thinning (left) and forest clear cutting (right) (white circle: tree was cut, black circle: stand tree)

Ahtiainen (1992) reported the change of water quality after 1-year of clear cutting in Kivipuro watershed in eastern Finland, that the annual of N-tot, NO_3, NH_4, P-tot, PO_4, Fe and COD was increased by 75 kg km^{-2} year^{-1} (1.47-fold), 0.8 kg km^{-2} year^{-1} (1.61-fold), 6.6 kg km^{-2} year^{-1} (3.4-fold), 3.2 kg km^{-2} year^{-1} (1.46-fold), 0.6 kg km^{-2} year^{-1} (1.37-fold), 63 kg km^{-2} year^{-1} (1.24-fold), and 3 kg km^{-2} year^{-1} (1.22-fold) respectively. The most noticeable effect is to increase the suspended solids up to the 3-year mean being 83 ton km^{-2} year^{-1}, over 200 times of that during the pre-treatment period (0.4 ton km^{-2} year^{-1}). Degradation of water quality may have high impact to deterioration of river ecosystem also organism living surrounding the river.

In central Sweden, trees of three areas were clear-cut by 0% (as for control), 50% and 95% respectively. During 8 years after clear-cutting, compared with the control (276 mm

$year^{-1}$), the average runoff increased up to 478 mm $year^{-1}$ and 528 mm $year^{-1}$, respectively. Moreover, Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{-2}, Cl^{-}, K^{+}, NH_4^{+}, NO_3^{-}, N-org, and N-tot was increased following clear-cutting treatment. After 8 years' observation period, the runoff and water quality return to pre-treatment period (Rosén et al., 1996).

Borg et al. (1988) reported that four small catchments (Crowea, Poole, Iffley and Mooralup) were observed during 1975-1985 to study the effect of clear-cutting to the regeneration of runoff and groundwater level. Groundwater levels rose for two-four years after logging and then started to fall again. Because of clear cutting, the amount of runoff increased for two years and then gradually declined again as the vegetation regenerated. Runoff also returned to pre-treatment within fifteen years after the beginning of regeneration. Hornbeck et al. (1993) and Andréassian (2004) noted, after several years, clear-cutting can lead to reductions in the amount of runoff due to increase in transpiration by regenerating young-growth tree stands.

Jones and Post (2004) reported that daily runoff increased by up to several hundred percent in the late summer and early autumn during the years immediately after clear-cutting in the coniferous and deciduous forest catchments in the northwest and eastern of the United States. Schelker et al. (2013) conducted a paired-catchment study in the northern Sweden and specified that clear-cutting of a boreal coniferous forest altered snow accumulation, runoff responses to spring snowmelt and the amount of snowmelt runoff.

Ide et al. (2013) examined the effects of clear-cutting on annual and seasonal runoff from a boreal forest headwater catchment in Finland with Norway spruce and Scots pine as a plant over a period of 18 years. As found in the other catchment studies, the annual runoff in the study catchment largely increased soon after the clear-cutting and subsequently tended to return to the pre-treatment level. The effect of clear-cutting was the highest in the 1st year after the clear-cutting and tended to decrease with time, gradually diminishing after 8 years from the treatment. The changes in the seasonal runoff, i.e. the spring and summer runoff, more clearly represented the persistence of the clear-cutting effects than in the annual runoff and continued for at least 18 years in the study catchment. In boreal forest catchments, the greater snow accumulation and the subsequent increase of runoff in spring are important mechanisms, as well as the decrease in summer runoff caused by the increased evapotranspiration associated with regenerating young-growth coniferous stands. The results suggested that investigating seasonal runoff was needed for better understanding of the mechanisms behind changes in an annual runoff after forestry operations.

Clear cutting in general has a positive impact to increase the amount of runoff. The absence of forest canopy can increase the net precipitation reaching the forest floor and consequently increase the total runoff. As reported by Rosen et al. (1996), clear cutting can increase annual runoff until 90% than control. However, at the same time, the quality of water and environment surrounding area became worse. Therefore, the watershed manager must consider the magnitude of negative impact caused by clear cutting treatment. Clear cutting treatment can be replaced by heavy thinning treatment and the remained trees in this treatment can work as a filter and decrease the nutrient loss or erosion, so that the risk of degradation of the environment and water quality can be suppressed.

2.4 Hydrological response under broadleaf deciduous and coniferous evergreen

Swank and Douglass (1974) compared the annual runoff from two forest types at the same location (Coweeta catchment in USA) in different periods. Where the original broadleaf deciduous forest was converted to a coniferous evergreen forest and they compared the runoff between these two forest types. The result showed that the annual runoff from the coniferous evergreen forest was smaller than that from the broadleaf deciduous forest. Komatsu et al. (2008), Swift et al. (1975), Calder et al. (2003), and Nisbet (2005) obtained the same results as well. In addition, a pair-catchment study reported by Hisada et al. (2011) also indicated that the annual runoff from a broadleaf deciduous forest was higher than a coniferous evergreen forest during the same periods (see **Fig.2**).

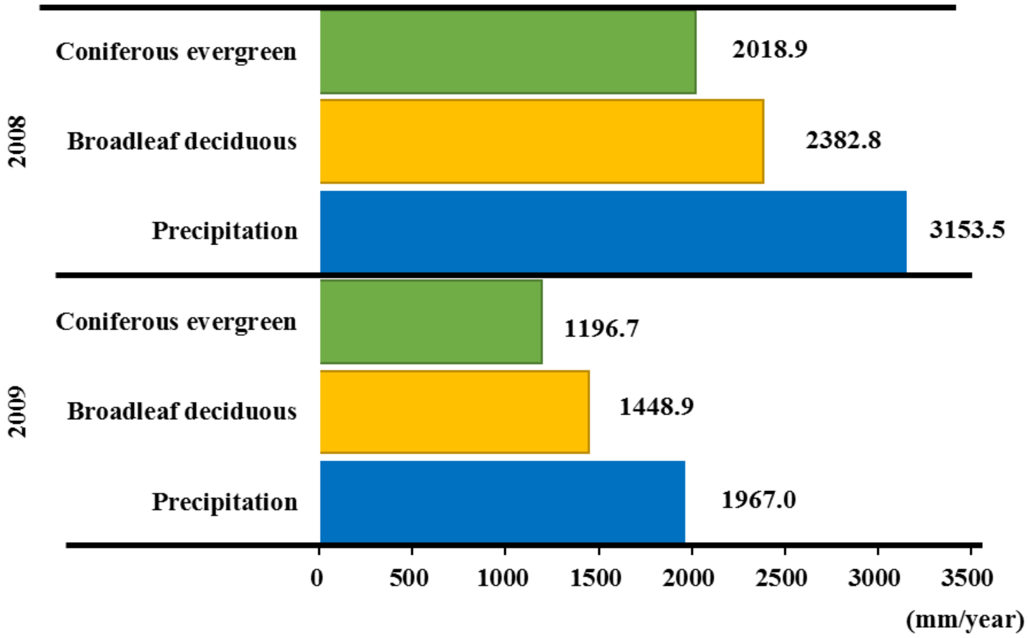


Fig. 2 Annual runoff from the catchments occupied by deciduous broadleaf and evergreen coniferous forest at Kuraiyama experimental site, Gero city, Japan. (long: 137º11′-137º14′ E and lat: 35º58′-36º01′ N) (Hisada et al., 2011)

One of the reasons of this difference in the annual runoff can be the phenological difference between broadleaf deciduous and coniferous evergreen forests. While coniferous evergreen forests always keep leaves, broadleaf deciduous forests lose almost all leaves in autumn. Due to no leaves in broadleaf deciduous forests during winter season, the more snow can reach the ground. In contrast, coniferous evergreen forests intercept a lot of snow by canopy, and thus, the less amount of snow reaches the ground (illustrated in **Fig.3**). Consequently, interception losses in coniferous evergreen forests might be larger than those in broadleaf deciduous forests (Rahmat et al., 2017).

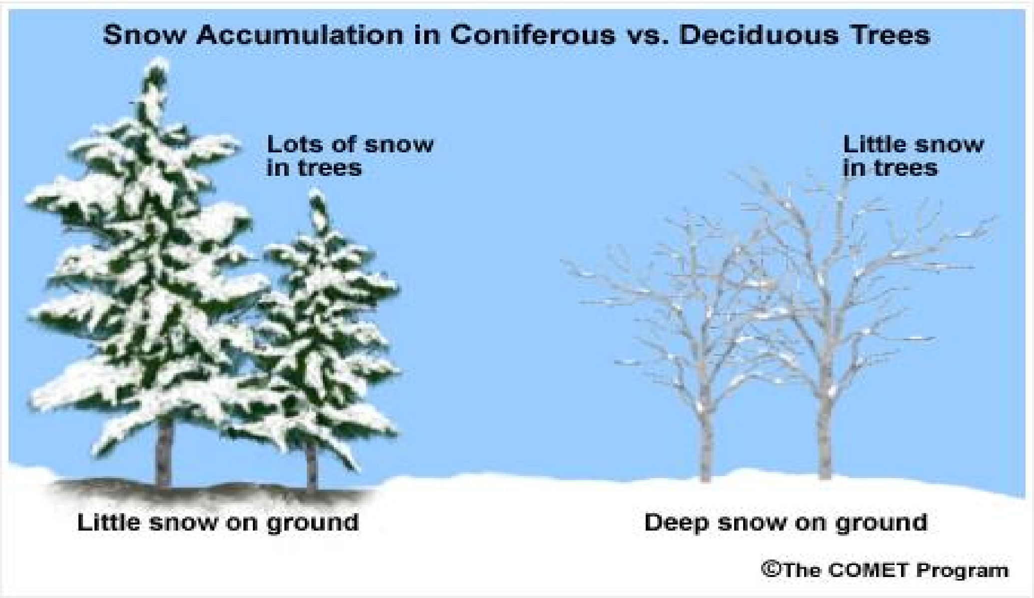


Fig.3 Illustration of snow interception in deciduous broadleaf and evergreen coniferous (COMET, 2018)

The review of interception losses shown in **Table. 1** is supporting the above-mentioned mechanism. The highest interception for the broadleaf deciduous forest was 29% in UK (Herbst et al., 2008), while that for the coniferous evergreen forest was 45% in Sweden (Alavi et al., 2001). Leaf shape and configuration affect LAI and water storage (Jonckheere et al., 2004; Keim et al., 2006). Some leaves only store water as a thin coating whilst others also store in capillary spaces between leaves. For these reasons, flat leaves (deciduous species) store water less than trees with needle leaves type (coniferous species) (Keim et al., 2006). Water storage by mature deciduous with and without leaves is 0.2-2 mm and 0.03-0.8 mm repectively (Leyton et al., 1967), and 0.1-4.3 mm for mature

Table. 1 Reviews of interception loss under broadleaf deciduous forest and coniferous evergreen forest

References	Forest type	Latitude (º)	Longitude (º)	Location	Interception (%)
Broadleaf Deciduous Forest					
Price and Carlyle-moses (2003)	*Quercus ruba* (red oak), *Acer saccharum* (sugar maple), *Fagus grandifolia* (american beech)	43.6	-79.7	Erindale ecological research area, University of Toronto. Mississauga, Ontario, Canada	18.8
Masello et al., (2002)	*Quercus robur* (european oak)	46.0	13.2	Bosco Boscat, Udine, Italy	22.6
Masello et al., (2002)	*Quercus petraea* (sessile oak)	44.7	10.2	Carrega, Carrega Ligure, Alessandria, Italy	7.2
Masello et al., (2002)	*Quercus ilex* (holm oak)	44.3	11.4	Colognole, Livorno, Italy	19.7
Sraj et al., (2008)	*Carpinus orientalis* (hornbeam)	45.4	13.8	The Dragonja watershed, Istrian Peninsula, Slovenia	28.4
Sraj et al., (2008)	*Quercus pubescentis* (pubescent oak)	45.4	13.8	The Dragonja watershed, Istrian Peninsula, Slovenia	25.4
Herbst et al., (2008)	*Quercus robur* (european oak), *Betula pubescens* (downy birch/white birch), *Corylus avellana* (Hazelnut), *Ilex aquifolium* (holly/ common holly) (Leafed period)	51.5	1.3	Grimsbury wood, Newbury, Berkshire, UK	29
Herbst et al., (2008)	*Quercus robur* (european oak), *Betula pubescens* (downy birch/white birch), *Corylus avellana* (hazelnut), *Ilex aquifolium* (holly/ common holly) (Leafless period)	51.5	1.3	Grimsbury wood, Newbury, Berkshire, UK	20
Deguchi et al., (2006)	*Quercus Serrata* (konara), *Clethra barbinervis* (clethra) (growing season)	35.0	137.2	Toyota, Aichi, Japan	17.6
Deguchi et al., (2006)	*Quercus Serrata* (konara), *Clethra barbinervis* (clethra) (dormant season)	35.0	137.2	Toyota, Aichi, Japan	14.3

				Average	20.3
Coniferous Evergreen Forest					
Llorens (1997)	*Pinus sylvestris* (scots pine)	42.2	2.0	Cal parisa research basin, Vallcebre, Eastern Pyrenees, Spain	17.6
Domingo et al., (1994)	*Pinus pinaster* (maritime pine) , *Pinus nigra* (austrian pine/ black pine)	37.2	−2.4	Micaschist nachimiento catchment, Filabres mountains, Almerai, Spain	15.5
Valente et al., (1997)	*Pinus pinaster Ait* (maritime pine).	38.8	−8.9	Pinhal da carrasqueira (Companhia das lezirias), south-east of Lisbon, Central Portugal, Portugal	17.1
Alavi et al., (2001)	*Picea abies* (norway spruce)	56.6	13.0	Skogaby site, Halmstad, South-western of Sweden	45
Moore et al., (2008)	*Pinus contorta* (lodgepole pine), *Picea,glauca x engelmanni* (hybrid spruce), *Abies lasiocarpa* (subalpine fir)	49.7	-119.4	Mayson lake, Thompson plateau, Northwest of Kamloops, British Columbia	31.1
Murakami (2007)	Young planted *Chamaecyparis obtuse* (Japanese cypress) (annual: year 1)	36.6	140.6	Hitachi ohta experimental watershed, Eastern Japan	18.9
Murakami (2007)	Young planted *Chamaecyparis obtuse* (Japanese cypress) (annual: year 2)	36.6	140.6	Hitachi ohta experimental watershed, Eastern Japan	19.1
Price et al., (1997)	*Picea mariana* (black spruce)	55.5	−98.2	BOREAS experimental, Thompson, Northern Manitoba, Canada	23.3
Link et al., (2004)	*Pseudotsuga menzesii* (douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar) in 1999	45.8	−122.0	Munger research natural area, Gifford Pinchot national forest, southwestern Washington, U.S.A.	22.8
Link et al., (2004)	*Pseudotsuga menzesii* (douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar) in 2000	45.8	−122.0	Munger research natural area, Gifford Pinchot national forest, southwestern	25

				Washington, U.S.A.	
Pypker et al., (2005)	*Pseudotsuga menziesii* (douglas-fir)	45.8	−122.0	Munger research natural area, Gifford Pinchot national forest, southwestern Washington	21.3
Reid and Lewis (2009)	*Sequoia sempervirens* (california redwoods), *Pseudotsuga menziesii* (douglas-fir)	39.4	-123.7	North fork casper creek watershed, Fort Bragg, California, USA	22.4
Huber and Iroume (2001)	*Pinus radiate* (Monterey pine) in 1997	−37.7	−72.5	Andes, Chile	29.0
Huber and Iroume (2001)	*Pinus radiate* (Monterey pine) in 1998	−39.8	−73.2	Andes, Chile	16.6
Gash et al., (1980)	*Picea sitchensis* (sitka spruce)	52.5	−3.7	Hafren forest, Central Wales, U.K.	26.7
Gash et al., (1980)	*Pinus sylvestris* (scots pine)	57.7	−3.5	Roseisle forest, Northeast Scotland, U.K.	42.4
Gash et al., (1980)	*Picea sitchensis* (sitka spruce)	55.2	−2.4	Kielder forest, Northumberland, U.K.	31.7
Johnson (1990)	*Picea sitchensis* (sitka spruce)	56.5	−4.4	Kirkton Glen, Balquhidder, Highland Scotland, U.K.	28
Teklehaimanot and Jarvis (1991)	*Picea sitchensis* (sitka spruce)	55.7	−3.3	Cloich, South of Edinburgh, U.K.	29
Viville et al., (1993)	*Picea abies* (norway spruce)	48.2	7.2	Strengbach catchment, Aubure, Vosges, France	34.2
Loustau et al., (1992)	*Pinus pinaster* (maritime pine)	44.7	−0.8	The Bray Forest, southwest of Bordeaux, France	17.5
Mosello et al., (2002)	*Picea abies* (norway spruce)	43.4	10.7	Bolzano, Italy	18.8
Lankreijer et al., (1999)	*Picea abies* (norway spruce), *Pinus sylvestris* (scots pine)	60.1	17.5	NOPEX site, North of Uppsala, Sweden	25.8
Tallaksen et al., (1996)	*Picea abies* (norway spruce)	59.9	10.6	Saeternbekken experimental catchment, Norway	27
				Average	25.3

coniferous tree (Link et al., 2004). Thus, if we can assume that annual interception of both forest types is comparable, annual evapotranspiration of coniferous evergreen forest is larger than that of broadleaf deciduous forest. Then, under the same climatic conditions, we can conclude that annual runoff from coniferous evergreen forests is smaller than that of broadleaf deciduous forests.

For short-term runoff (based on rainfall event) characteristics between different forest types, few researches have been conducted. Hirano et al. (2009) found that the surface runoff in a coniferous evergreen forest was always higher than that in a broadleaf deciduous forest regardless of the magnitudes of storm events: a small autumn rainfall, a middle typhoon storm, and a large typhoon storm.

Fig.4 Forest floor condition in (a) coniferous evergreen and (b) broadleaf deciduous forest at Kuraiyama experimental site, Gero city, Japan. (long: 137º11′-137º14′ E and lat: 35º58′-36º01′ N) (Rahmat, 2017).

Cypress plantations usually exhibit overstocked stands having sparse or no understory vegetation cover due to the low light conditions (Onda et al., 2010). The similar phenomenon was observed by Rahmat et al. (2017) about little or no understory vegetation cover in coniferous forest (**Fig.4(a)**). On the other hands, **Fig.4(b)** shows a high dense understory vegetation cover in a broadleaf deciduous forest. Consequently, poor litter layers or no understory vegetation which were strongly affected by coniferous evergreen forest induced high peak discharge and high surface runoff compared with the broadleaf deciduous site (**Fig.5**). Sakai et al. (2009) also indicated that a litter layer had become very sparse and soil surface was exposed at both cypress and cedar plots, while the deciduous plot was covered by a thick litter layer and understory vegetation. The existence of the understory vegetation cover can delay the speed of surface runoff and reduce peak discharge in broadleaf deciduous forests. Sakai et al. (2009) and Hirano et al. (2009) suggested that surface runoff at the cypress and the cedar plot was a root flow (shallow flow through the root layer because of no litter layer) and that the surface runoff at the broadleaf deciduous plot was a litter flow due to its thick litter layer. Infiltration rates supported this theory of different surface runoff mechanisms; the highest final infiltration rate was found in the deciduous plot with 321 mm/h, while, cypress and cedar plot had lower infiltration of 76.4 mm/h and 173 mm/h, respectively.

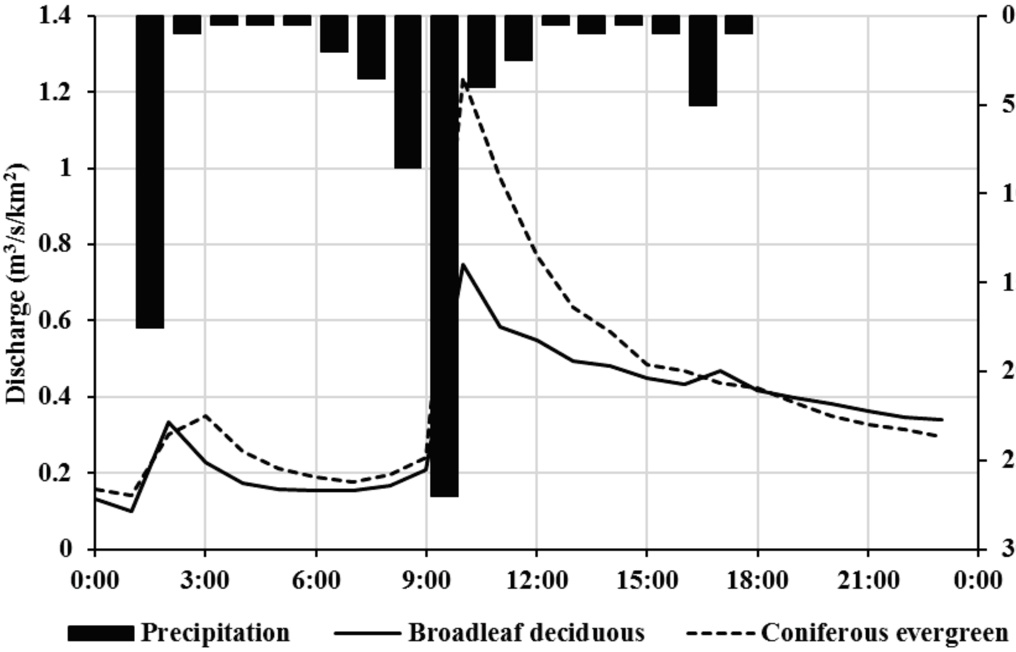


Fig.5 Hyeto-hydrograph between broadleaf deciduous and coniferous evergreen forest on 23 July 2015 at Kuraiyama experimental site, Gero city, Japan. (long: 137º11′-137º14′ E and lat: 35º58′-36º01′ N) (Rahmat, 2015).

According to Swank and Douglass (1974), Swift et al. (1975), Calder et al. (2003), Nisbet (2005), Komatsu et al. (2008), Komatsu et al. (2011) and Hisada et al. (2011), it can be concluded that the annual runoff (long-term runoff) in broadleaf deciduous is higher than coniferous evergreen in the region with high winter precipitation. Futhermore, Sakai et al. (2009), Hirano et al. (2009), and Rahmat (2015) showed that the short term runoff (based on each rainfall event) characteristics such as surface runoff and peak discharge from coniferous evergreen forest were higher than broadleaf deciduous forest.

2.5 Hydrological response under pine forest and eucalyptus forest

Pine and eucalyptus forests are the important resources for timber production in many regions. Since eucalyptus has high productivity (>35 $m^3ha^{-1}year^{-1}$) compared to pine (25-27 $m^3ha^{-1}year^{-1}$) (Albaugh et al., 2013; Fox et al., 2007), and short rotation length of 6-8 years is enough for eucalyptus while pine needs more than 10 years (Dougherty and Wright, 2012), the plantation of eucalyptus is widely progressed compared to pine. However, for sustainability of plantation, the effect of eucalyptus and pine trees related to water resource required to be evaluated.

Catchment experiments showed that eucalyptus caused a faster reduction in streamflow compared to pines (Scott and Lesch, 1997). Furthermore, effect of eucalyptus plantation is to reduce around 90-100% of streamflow in the first eight years after planting, while pine planting decreased only 40-60% of streamflow compared with that before planting. The streamflow reduction was significant from the third year after planting eucalypt in both the wet and dry seasons, and the stream was dried up completely in the ninth year after planting (Scott and Lesch, 1997). Their analysis showed the maximum reductions of streamflow were 235 mm $year^{-1}$ by eucalypts plantation at the seventh, and

198 mm year^{-1} by pine at the ninth year are shown in **Fig.6**.

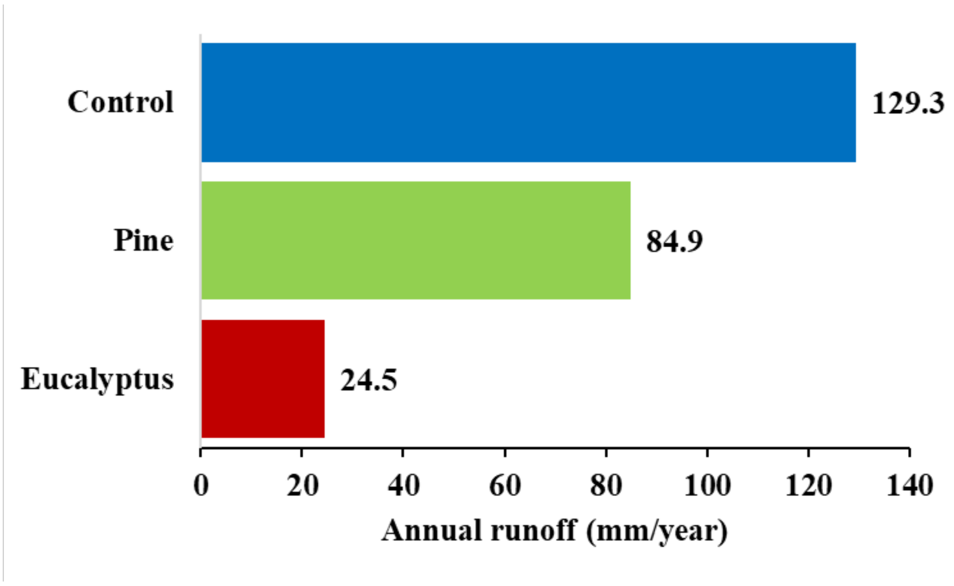


Fig.6 The mean annual runoff between Eucalyptus (*Eucalyptus grandis*) and Pine (*Pinus patula*) during 20 years after planting at Mokobulaan experimental site, South Africa, (25°17′S 30°34′E) (Scott and Lesch, 1997)

Farley et al. (2005) showed that afforestation by converting grasslands to eucalyptus plantation reduced runoff by 25% more than converting to pine, which was driven from a higher rate of water consumption by eucalyptus. Eucalyptus plantations have some of the highest evapotranspiration rates of tree species (Dye, 2013; Farley et al., 2005; Hubbard et al., 2013).

Moreover, the differences in the proportions of interception loss and transpiration to water consumption between eucalyptus and conifers might be important too. Interception is often higher in conifers than in eucalyptus as shown by Calder (1986), Pook et al., (1991) and Valente et al., (1997). After reviewing the studies about interception of various vegetation types, Zhang et al. (1999) concluded that pine forests intercepted 28% of rainfall on average while 14% for eucalyptus forests. One inference from this is that catchments forested with conifer yield less water than those forested with eucalypt (Pook et al., 1991). Average interception is 19 (±4.9) % of annual rainfall in *Eucalyptus globulus*, which is smaller than 31 (±11.1) % in *Pinus radiata*. However, higher annual interception in *Pinus radiata* did not result in higher total evapotransporation, because annual evaporation from the forest floor averaged 29 (±4.9) % of rainfall in *Eucalyptus globulus*, but only 15 (±3.5) % in *Pinus radiata*. Hence, the relative contribution of annual interception plus forest floor evaporation to evapotranspiration did not differ significantly between the two species, averaging 48 (±7.3) % of annual rainfall in *Eucalyptus globulus* compared with 46 (±11.8) % in *Pinus radiata* (Benyon and Doody, 2015). Conversely, in some regions, as expressed by Shiva et al. (1982) and Shiva and Bandyopadhy (1983, 1985), eucalypts are voracious consumers of water that refer to high water use (WU) or water use efficiency (WUE) and are likely to deplete water resources (Calder, 1986). Here, WUE is defined as biomass growth per unit water transpired.

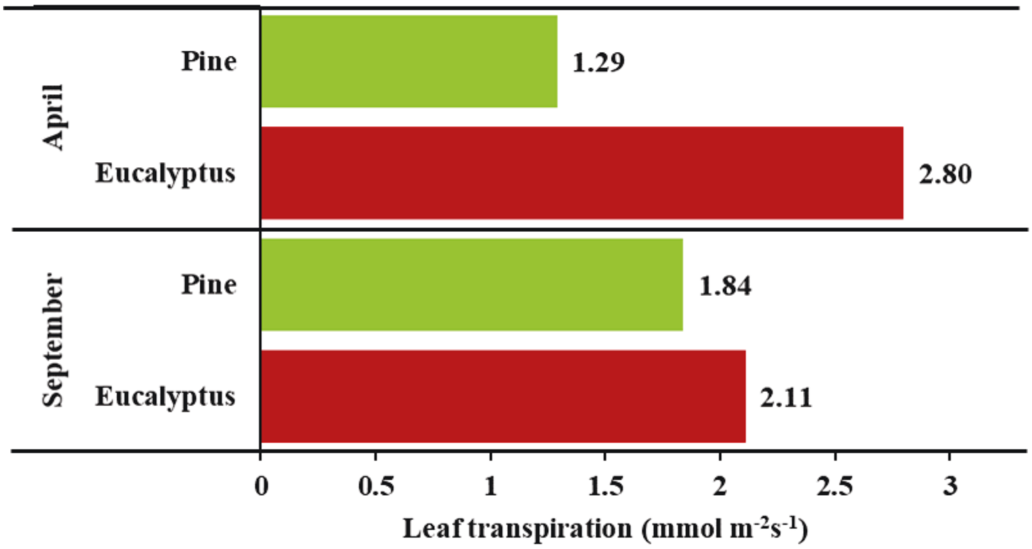


Fig.7 The mean mid-day leaf transpiration between Pine (*Pinus taeda*) and Eucalyptus (*Eucalyptus benthamii*) at Ravenel, South Carolina, United States, (32º45′N 80º14′W) (Maier et al., 2017)

Eucalyptus plantations generally have high WUE (Stape et al., 2004), and fast growing of eucalyptus trees are thought to use water more efficiently than slower growing trees (Otto et al., 2014). Myers et al. (1996) found after several years of irrigation, that 3-year-old *Eucalyptus grandis* plantations had 42% greater standing volume and use 22% more water than *Pinus radiata*. Similarly, in France, Moreaux et al. (2012) found that hybrid eucalyptus (*Eucalyptus gunni* x *Eucalyptus dalrympleana*) plantations had 25% higher ET compared to the native maritime pine (*Pinus pinaster*), but eucalyptus had 1.6 times of WUE.

Table. 2 Water use between Pine (*Pinus taeda*) and Eucalyptus (*Eucalyptus benthamii*) at Ravenel, South Carolina, United States (32º45′N 80º14′W) (Maier et al., 2017)

Parameters	Unit	Eucalyptus	Pine
Higher Sap flux	g $cm^{-2}day^{-1}$	196.6	105.8
Mean daily tree water use	L day^{-1}	24.6	15.2
Annual tree water use	$m^3H_2Oyear^{-1}$	9.13	5.79
Annual steam biomass increment	kg $tree^{-1}year^{-1}$	22.9	11.8
Water use efficiency	kg biomass m^{-3} H_2O $year^{-1}$	2.86	1.72

From **Fig. 7** and **Table 2**, Maier et al. (2017) clearly described the leaf transpiration from eucalyptus tree was higher than pine tree. The leaf transpiration of eucalyptus was 2.17 times in April and 1.14 times in September than that of pines. Furthermore, the annual WUE of eucalyptus trees was 1.66 times higher than that of pine trees. In here we can conclude that eucalyptus forest can decrease annual runoff larger than pine forest due to high water consumption (water use).

III MATERIALS AND METHODS

3.1 Study area and sites

The study site is the Kuraiyama experimental forest at Gifu University (137°11′-137°14′E and 35°58′-36°01′N), which is located in Gero City, Gifu Prefecture, Japan (**Fig.8**) and the aero photograph can be seen in **Fig.9**. Elevation lies in the range of 820-1,451 m a.s.l. The management office is located at an elevation of 750 m. The yearly minimum, maximum and average air temperatures observed at the office are -10°C, 30°C and 10°C, respectively. The annual precipitation is about 2,400 mm. According to the Köppen climate classification system, the climate at the study site is classified as Cfa type. A rainy season from late June to mid-July and a typhoon season from August to October are the typical characteristics of a Cfa climate zone. In particular, typhoons can produce high rainfall and sometimes cause disastrous landslides and/or debris flows in the region. The bedrock is Nohi rhyolite, shallowly covered by brown forest soil. While the main observations were carried out at the paired catchments of the C1 and D1 basins, supplemental observations were also carried out at the C2 and D2 basins for use as reference data.

The basic characteristics of the four basins are summarized in **Table. 3.** The C1 basin is mainly covered by an evergreen coniferous forest, whose dominant tree species is Japanese cypress (*Chamaecyparis obtusa*). The basin is located southeast of the experimental forest station. Its elevation lies in the range of 926-1,278 m, and its area is 0.6 km^2. The 40- to a 50-year-old artificial coniferous forest was cover 74% of the basin area, with a broadleaf forest covers 18% of basin area, and a natural coniferous forest covers 8% of basin area, Forest floor and canopy of C1 was shows in **Fig.10** and **Fig.11**. The D1 basin is mainly covered by deciduous broadleaf forest, whose dominant species is *Quercus* spp (**Fig.12, Fig.13**). The basin is located to the south of the C1 basin. The elevation lies in the range of 909-1,278 m, and its area is 0.73 km^2. The deciduous broadleaf forest cover 77% of this basin area, 14% is covered by a 50- to a 70-year-old artificial coniferous forest, and a natural coniferous forest covers 9% of basin area. The forest floor is also covered with a high density of bush, Sasa bamboo grass, and a litter layer. The C2 basin is covered by an evergreen coniferous forest located at an elevation from 1,088-1,312 m and its area is 0.21 km^2 (**Fig.14**). The D2 basin is a deciduous broadleaf forest, which is located near the C2 basin. The elevation lies in the range of 1,037-1,228 m and its area is 0.09 km^2. A broadleaf forest cover 73% of the basin area (**Fig.15**).

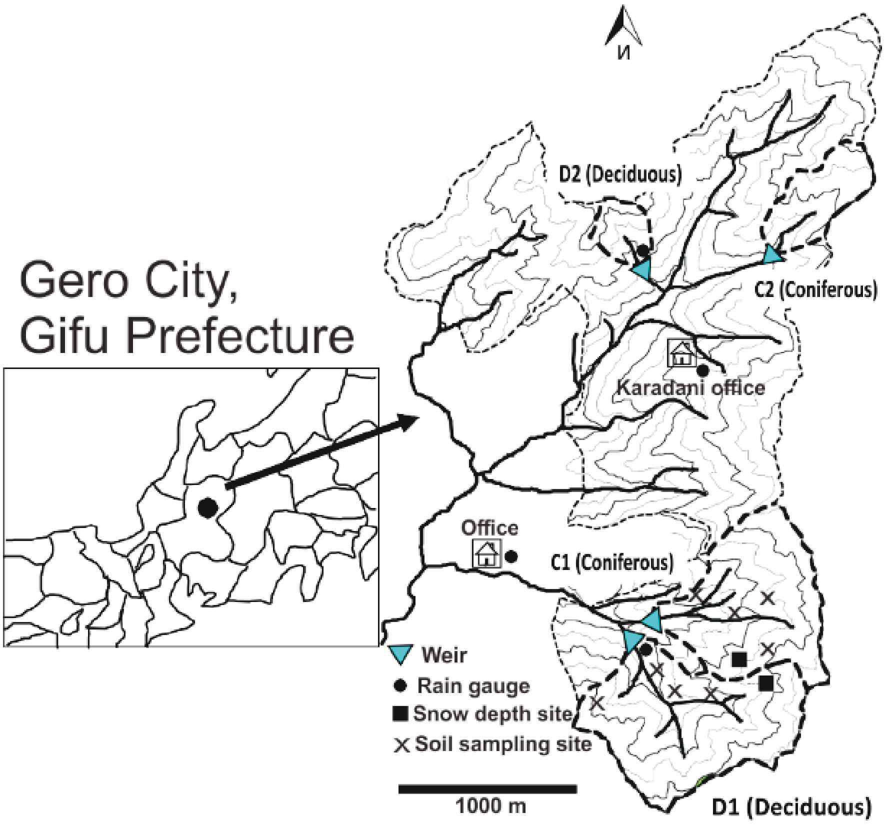


Fig.8 Location of basins in Kuraiyama experimental forest, Gero city, Japan

Table. 3 Characteristics of four study basins in Kuraiyama

Parameters	**Unit**	**C1**	**D1**	**C2**	**D2**
Basin area	km^2	0.61	0.73	0.21	0.09
Main stream length	km	1.01	1.21	0.71	0.37
Total stream length	km	3.75	3.63	1.2	0.37
Main stream slope		0.346	0.305	0.315	0.467
Average basin slope	(^{o})	21.1	21.1	23.2	26.32
Coefficient of basin shape		0.6	0.49	0.41	0.69
River channel density	km^{-1}	6.29	4.98	5.85	4.09
Maximum altitude	m	1278	1278	1312	1228
Minimum altitude	m	926	909	1088	1037
Altitude difference	m	352	369	224	191
Vegetation type (upper: area (km^2) (lower: rate of coverage (%))	Broadleaf deciduous	0.11	0.56	-	0.07
		18	76	-	73
	Plantation coniferous	0.45	0.1	-	0.02
		75	14	-	27
	Natural coniferous	0.04	0.07	0.21	-
		7	10	100	-

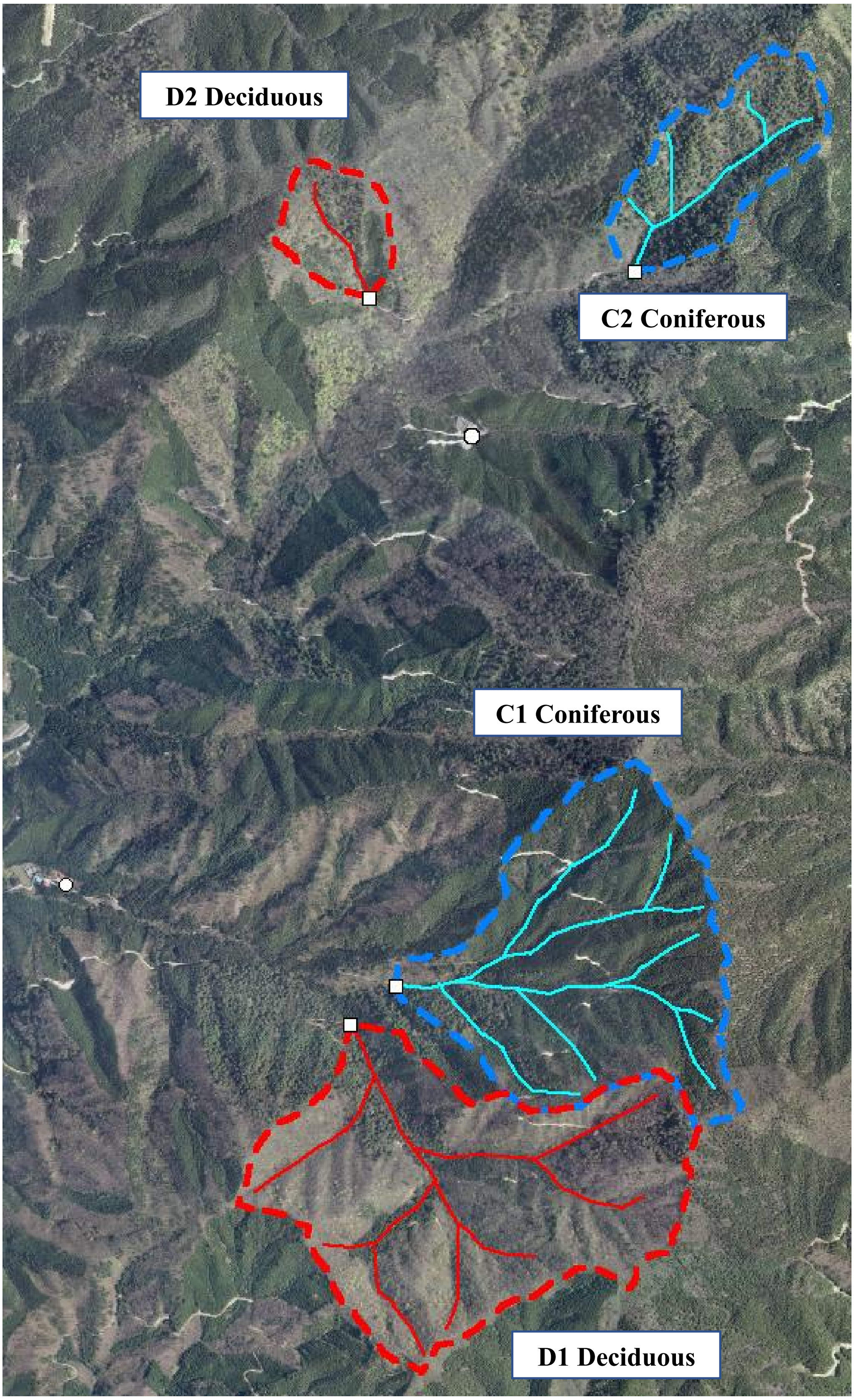


Fig.9 Aero photograph of observation basins

Fig.10 Forest floor in C1 coniferous basin

Fig.11 Canopy in C1 coniferous basin

Fig.12 Forest floor in D1 Deciduous basin

Fig.13 Canopy D1 deciduous basin

Fig.14 Photos of C2 coniferous basin

Fig.15 Photos of D2 deciduous basin

3.2 Field Methods

3.2.1 Discharge

In order to measure the discharge from each basin, a right-angle triangular weir was built and a water level logger (HOBO-U20, Onset Computer Corporation (**Fig.20**)) was installed at the downstream end of each basin. The data utilized for our analysis were taken from 1st November 2007 to 15th April 2018 (total of 3819 days). The recording intervals were 10 minutes from November to May (winter season) and 3 minutes from May to November (other than the winter season). The discharge can be calculated from the water level using the following formula (Hisada et al., 2010):

$$Q = KH^{\frac{5}{2}}$$

$$K = 1.354 + \frac{0.004}{H} + \left(0.14 + \frac{0.2}{\sqrt{W}}\right)\left(\frac{H}{B} - 0.09\right)^2$$

$$\begin{cases} \mathrm{H}_3 = \mathrm{h}_3 - 0.045 \\ \mathrm{H}_6 = \mathrm{h}_6 - 0.058 \\ \mathrm{H}_{10} = \mathrm{h}_{10} - 0.145 \\ \mathrm{H}_{12} = \mathrm{h}_{12} - 0.076 \end{cases}$$

where, Q: discharge (m^3/s), K: discharge coefficient (-), H: overflow depth (m), W: weir height (m), and B: weir width (m).

The streamflow from a rainfall event is generally composed of two components, direct runoff and base flow. Thus, the two components were separated by a straight line between the rising point just after the rainfall had started and the gradient changing point between the reduction coefficients of 0.024 h^{-1} and 0.011h^{-1} on the hydrograph after the rainfall had ended (Blume et al., 2007; Hisada et al., 2011). In this research, direct runoff is defined as the total discharge above the straight line drawn by the above-mentioned method. **Fig 16-19** is scheme (upper) and actual (lower) of right-angle triangular weir in each basin.

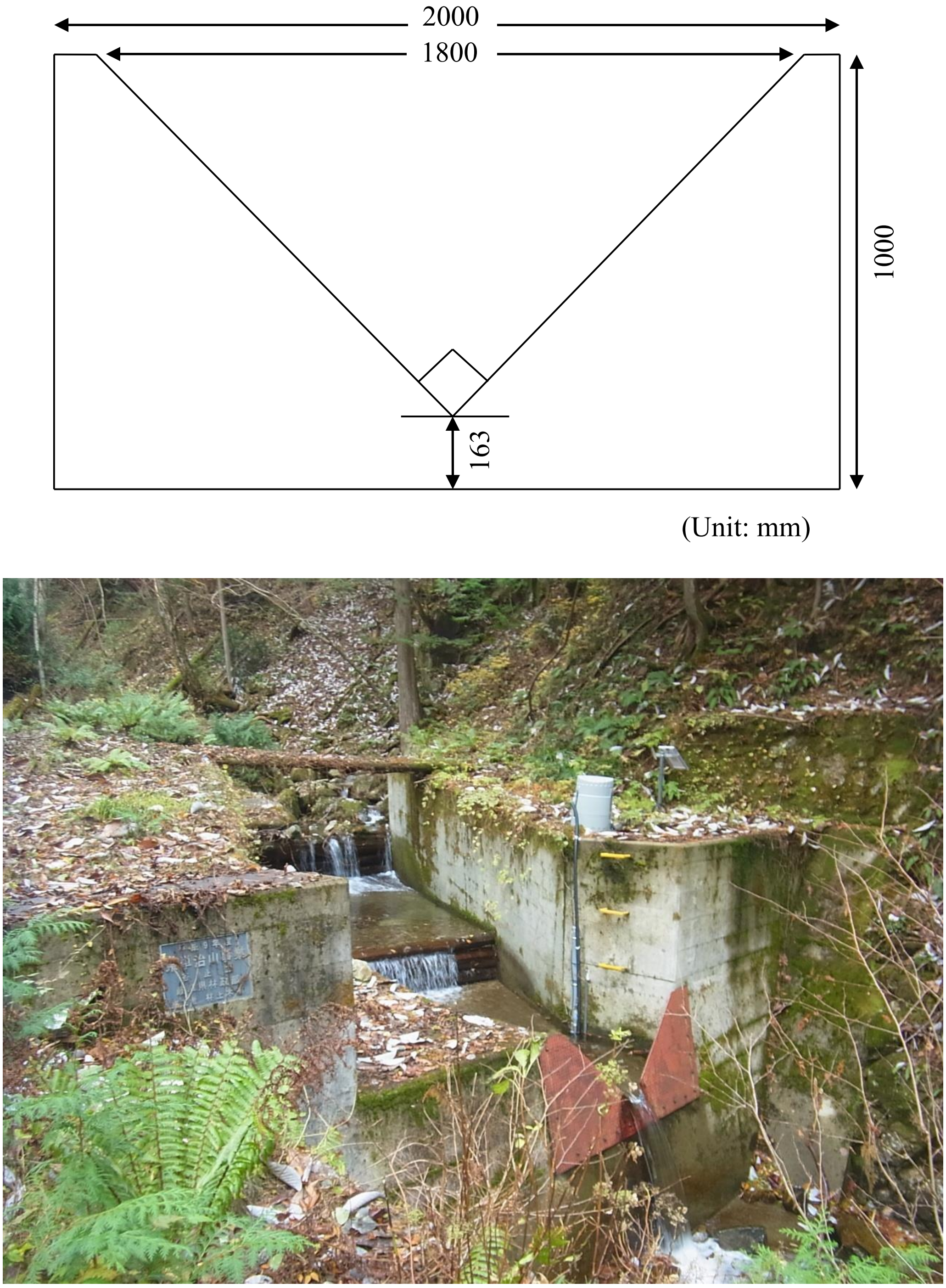


Fig.16 Schema of weir and actual photo of C1 coniferous basin

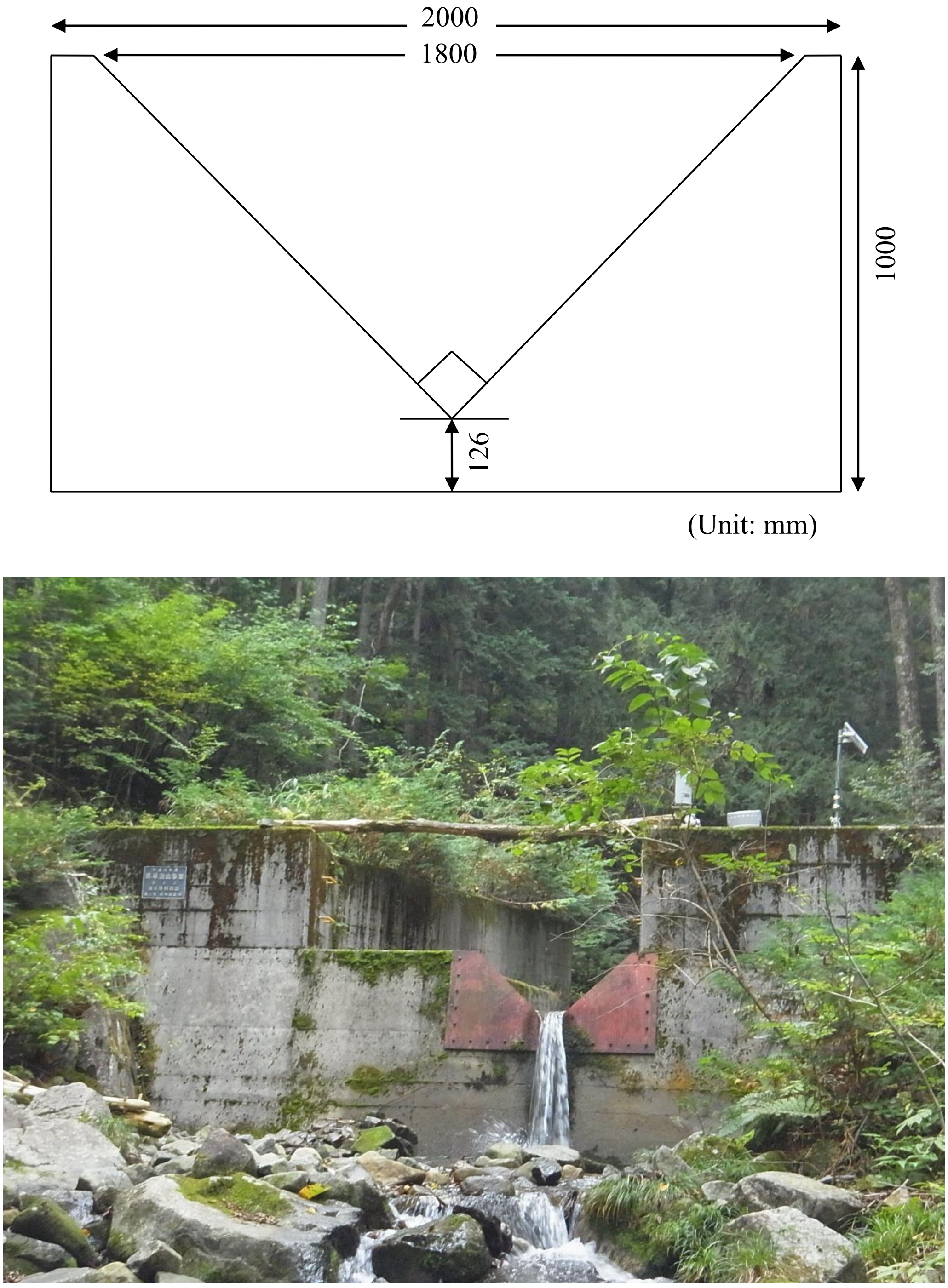


Fig.17 Schema of weir and actual photo of D1 deciduous basin

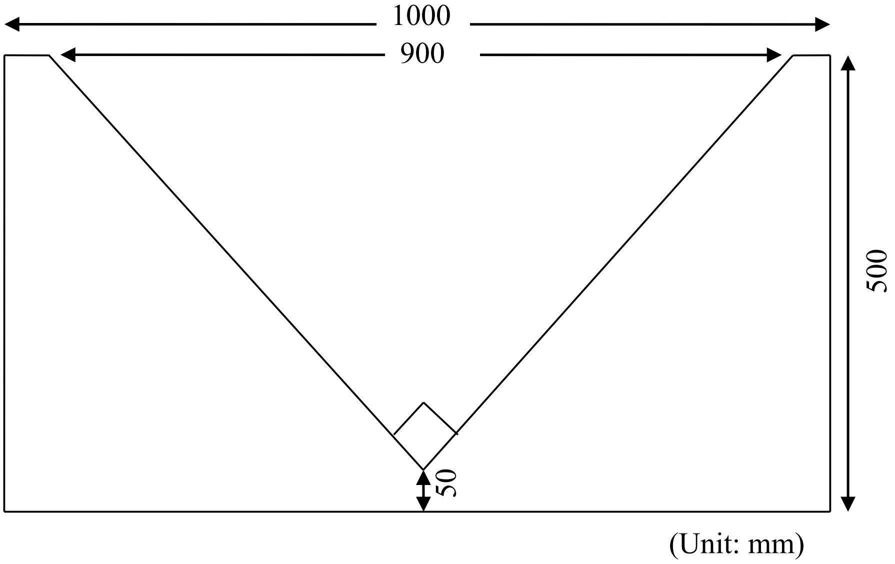


Fig.18 Schema of weir and actual photo of C2 coniferous basin

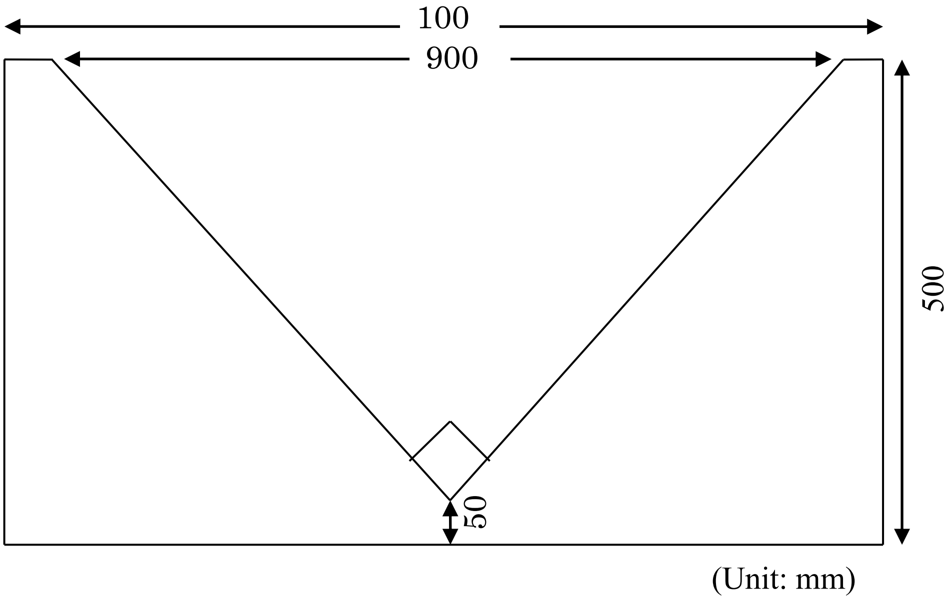


Fig.19 Schema of weir and actual photo of D2 deciduous basin

Fig.20 Air and water pressure data logger HOBO-U20

3.2.2 Precipitation

Two rain gauges (**Fig. 21**) were set up inside the experimental forest stations. One gauge was set up at the downstream end of the D1 basin for analysis of the C1 and D1 basins. The other gauge was set up at the downstream end of the D2 basin for the analysis of the C2 and D2 basins. However, these two rain gauges could not observe snowfall. Therefore, the precipitation during the winter period was obtained by a heater rain gauge which was set up at the management office. All these rain gauges were of the tipping bucket type with a minimum observed value of 0.5 mm.

Fig.21 Tipping bucket rain gauge

3.2.3 Soil analysis

Soil samples were collected inside the C1 and D1 basins. There were four sample sites inside each basin (**Fig.8**). The soil samples were collected from three different depths, 0-10 cm, 10-30 cm and 30-60 cm, with three replications for analyzing the following parameters: (a) soil texture (determined with the hydrometer method based on Stoke's law), (b) soil organic carbon (measured by the Walkey and Black Method (Baker, 1936)), (c) particle density (measured by the pycnometer gravimetric method), (d) permeability (using a 100-cc core sampler and the falling head method based on Darcy's law) and (e) soil pH (1:5) (measured by a pH meter: D71-s, Horiba Corporation).

3.2.4 Snow depth observation

Changes in the snow depth during winter were estimated by handmade instruments composed of an aluminum pole, 2 m in length, with 16 temperature sensors (HOBO pendant logger: UA-002-64, Onset Computer Corporation) at 10-cm intervals from 0 cm to 150 cm in height (**Fig.22**). Changes in the snow depth could be estimated by the changes in temperature measured by each sensor installed at different heights above the ground surface. The principle of the measurement method was the same as that of the equipment proposed by Fujihara et al., (2015).

One aluminum pole was set up inside each of the C1 and D1 basins, respectively, and the air temperature at each height above the ground surface was measured at one-hour intervals only during the winter season from 2013 to 2018.

Fig.22 Snow temperature pole

3.2.5 Observation of coverage understory vegetation

The sasa bamboo grass (*Sasa senanensis*) is dominant understory vegetation in Kuraiyama experimental forest of Gifu University. The distribution or coverage of Sasa bamboo grass was reported by Ashihara (2012). Ashihara (2012) analyzed the coverage by direct visual observation in the whole of Kuraiyama experimental forest and satellite observation. The duration of the survey is April –November 2011. Ashihara (2012) classified the coverage of Sasa grass in 4 class. There are 0-10%, 10-50%, 50-90% and 90-100%. The detail information of classification of coverage can be seen in **Fig. 23**.

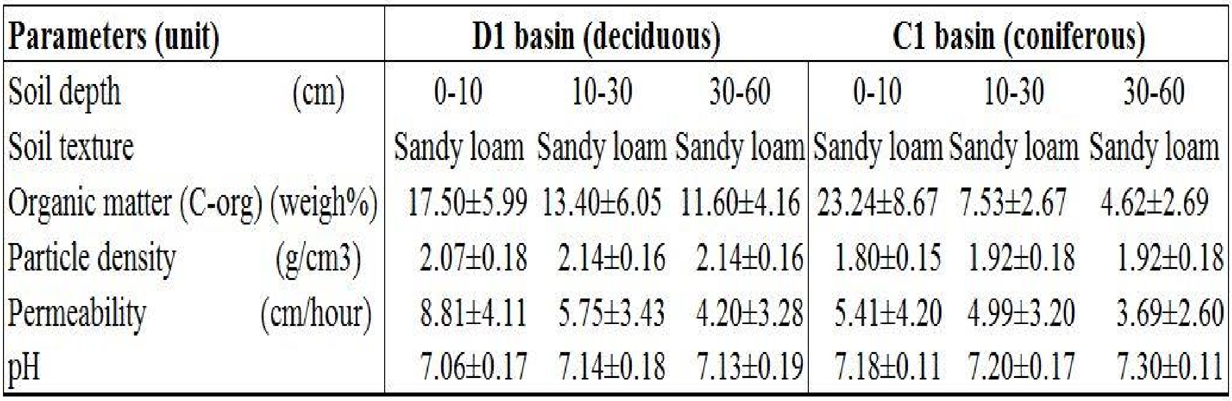
Fig.23 Photos of the coverage classification degree of sasa bamboo grass (a: 0-10%, b: 10-50%, c: 50-90%, d:90-100%) Ashihara (2012).

IV RESULTS

4.1 The effect of forests type on soil properties

The soil texture of all the layers of both basins was classified as sandy loam (**Table. 4**), suggesting that the parent materials were almost the same. The soil particle densities in the two basins were low (around 2 g/cm^3) compared to mineral soil, which means that the soil contained much organic matter. The organic matter at a depth of 0-10 cm in the C1 basin (23.4%) was higher than that in the D1 basin (17.5%), while the organic matter at a depth of 10-60 cm in the D1 basin (13.4-11.6%) was higher than that in the C1 basin (7.5-4.6%). This indicates that the organic matter in the C1 basin was concentrated only in the surface soil due to the accumulation of hardly decomposable fallen leaves. In the D1 basin, however, the organic matter was distributed to the deep soil layer because the understory was dead and decomposed. It supplied a great deal of organic matter throughout the whole soil profile. The soil permeability in the D1 basin was higher than that in the C1 basin and decreased with depth. The soil pH in both basins was almost the same and close to the neutral value (pH 7.0).

Table. 4 Soil properties of D1 (deciduous) and C1 (coniferous) basins



Parameters (unit)	D1 basin (deciduous)			C1 basin (coniferous)		
Soil depth (cm)	0-10	10-30	30-60	0-10	10-30	30-60
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Organic matter (C-org) (weigh%)	17.50±5.99	13.40±6.05	11.60±4.16	23.24±8.67	7.53±2.67	4.62±2.69
Particle density (g/cm3)	2.07±0.18	2.14±0.16	2.14±0.16	1.80±0.15	1.92±0.18	1.92±0.18
Permeability (cm/hour)	8.81±4.11	5.75±3.43	4.20±3.28	5.41±4.20	4.99±3.20	3.69±2.60
pH	7.06±0.17	7.14±0.18	7.13±0.19	7.18±0.11	7.20±0.17	7.30±0.11

4.2 The effect of forests type on flow duration curve

The flow duration curve (FDC) represents the relationship between the magnitude and the frequency of the daily streamflow for a particular river basin, providing an estimate of the percentage of time a given streamflow was equal to or exceeded a historical period (Richard et al., 1994).

Fig. 24 shows FDCs for the D1 and C1 basins, based on the daily specific discharge over 3,455 days from November 2007 to December 2017. Some data (259 days) are missing due to a sensor error. The three-month discharge, D_{25} (probability of exceedance: 25%), the six-month discharge, D_{50} (50%), the nine-month discharge, D_{75} (75%), and the droughty discharge, 355-day discharge, $D_{drought}$ (97%), are important for water resource management (Nakane et al., 1983). Each discharge, D_{25}, D_{50}, D_{75} and $D_{drought}$ of the D1 basin was 5.57, 2.85, 1.63 and 0.73 mm/day, respectively, which was higher than that of the C1 basin (4.53, 2.05, 1.07 and 0.44 mm/day). The average daily discharge estimated from the FDC was 5.39 mm/day in the D1 basin, which was also higher than the C1 basin (4.76 mm/day). However, all the daily discharge values with frequency less than 4.86% in the C1 basin were higher than those in the D1 basin.

Fig. 25 also shows FDCs of the pair catchments, the D2 and C2 basins, based on the daily specific discharge over 1,462 days for the same duration. However, many data (2,252 days) are missing in the C2 and D2 basins due to a sensor error or frequently occurring mudslides. Therefore, all the results obtained from the FDCs of the C2 and D2 basins could not be directly compared with the results obtained from the curves of the C1 and D1 basins. The discharge values for D_{25}, D_{50}, D_{75} and $D_{drought}$ of the D2 basin were 10.20, 6.19, 4.39 and 2.55 mm/day, respectively, which were higher than those of the C2 basin (9.85, 5.49, 3.29 and 1.44 mm/day). The average daily discharge estimated from the FDC was 10.08 mm/day for the D2 basin, which was larger than for the C2 basin (9.59 mm/day). Almost all the daily discharge values with frequency less than 14.6% in the C2 basin were higher than those in the D2 basin.

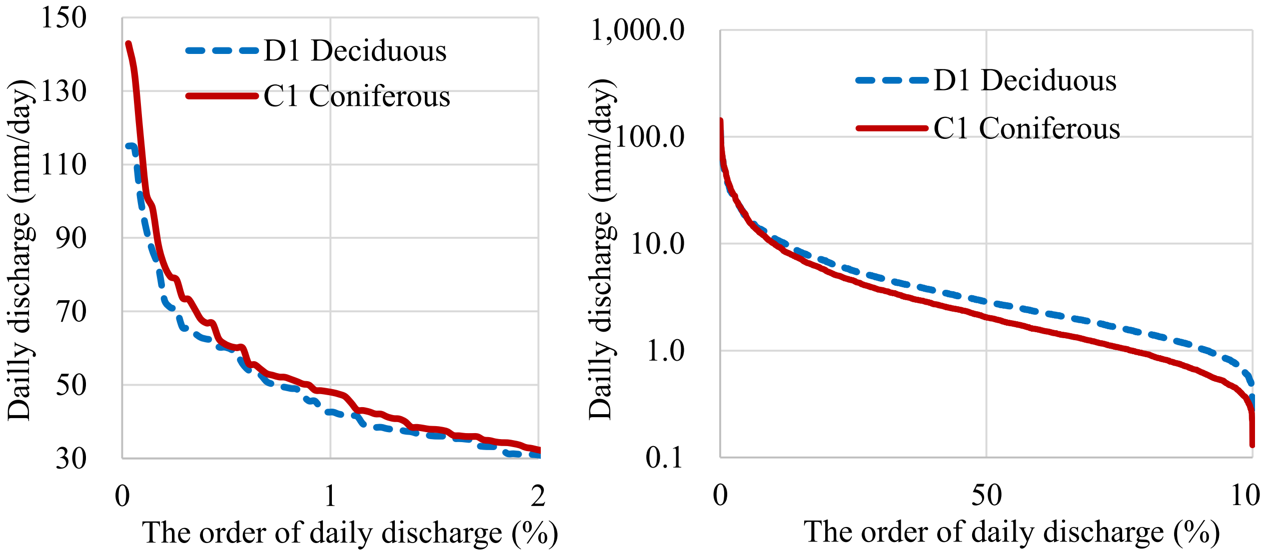


Fig.24 Flow duration curves of D1 and C1 basins

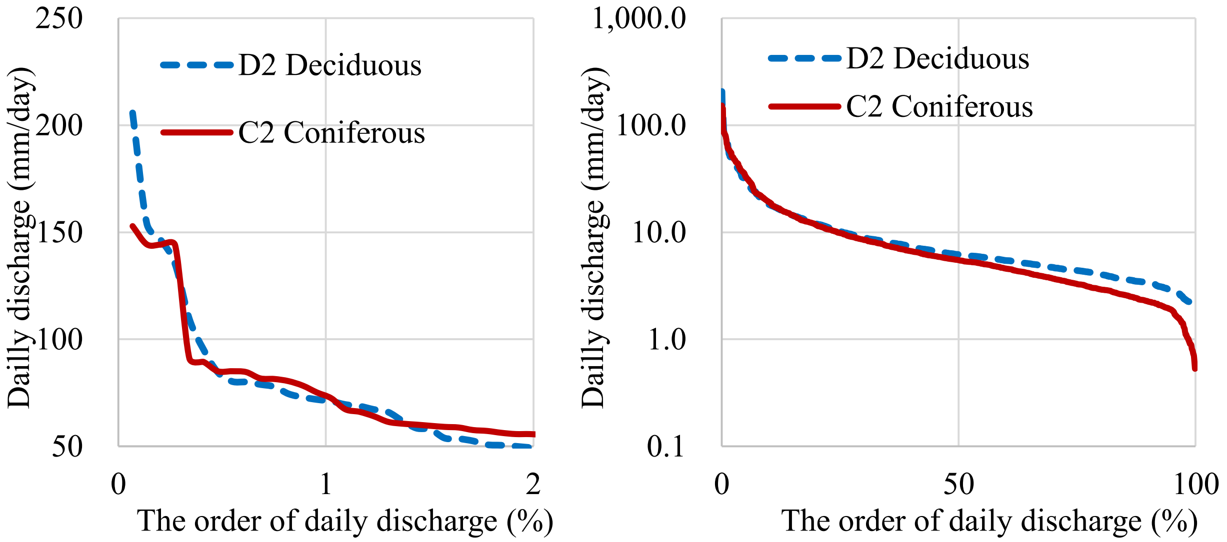


Fig.25 Flow duration curves of D2 and C2 basins

4.3 The effect of forests type on hydrograph

Figs. 26-28 shows of the representative hydrographs for each of the four test basins observed, which has peak of discharge by a rainfall event of 35 mm, 100 mm and 200 mm, respectively.

The peak discharge in the C1 basin (coniferous) was higher than that in the D1 basin (deciduous). However, after the rainfall event ended, the runoff discharge decreased more rapidly in the C1 basin than in the D1 basin, which showed that the gradient of the recession curve was higher in the C1 basin than in the D1 basin. The relation between the runoff discharge of the C1 basin and that of the D1 basin was reversed around six hours after the peak discharge, when the discharge of the D1 basin was higher than that of the C1 basin.

Furthermore, almost all the hydrographs under the various amounts of rainfall showed the same pattern. This suggests that deciduous forests can mitigate floods better than coniferous forests.

4.4 The effect of forests type on peak discharge

Fig. 29 shows a comparison between the peak discharge of the deciduous basin and that of the coniferous basin during the rainfall events. Based on this figure, the peak discharge from the coniferous basin was higher than that from the deciduous basin. In comparing the C1 and D1 basins, the peak discharge from the C1 basin is 1.49 times higher than that from the D1 basin based on a linear regression with R^2 of 0.96. Moreover, a comparison between the C2 and D2 basins shows that the peak discharge from the C2 basin is 1.16 times higher than that from the D2 basin based on linear regression with R^2 of 0.92.

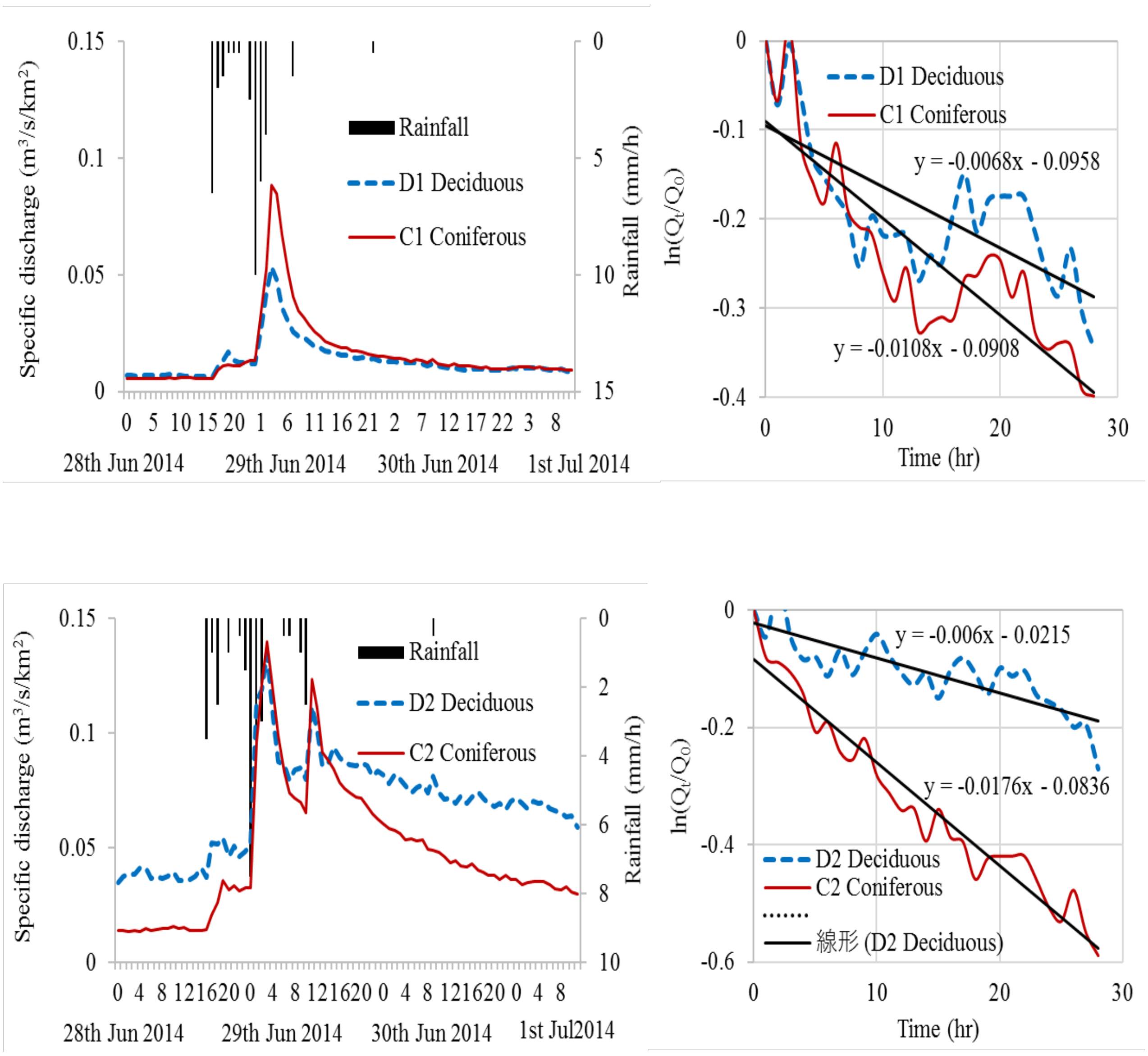


Fig.26 Hydrographs of four test basins at 35 mm rainfall

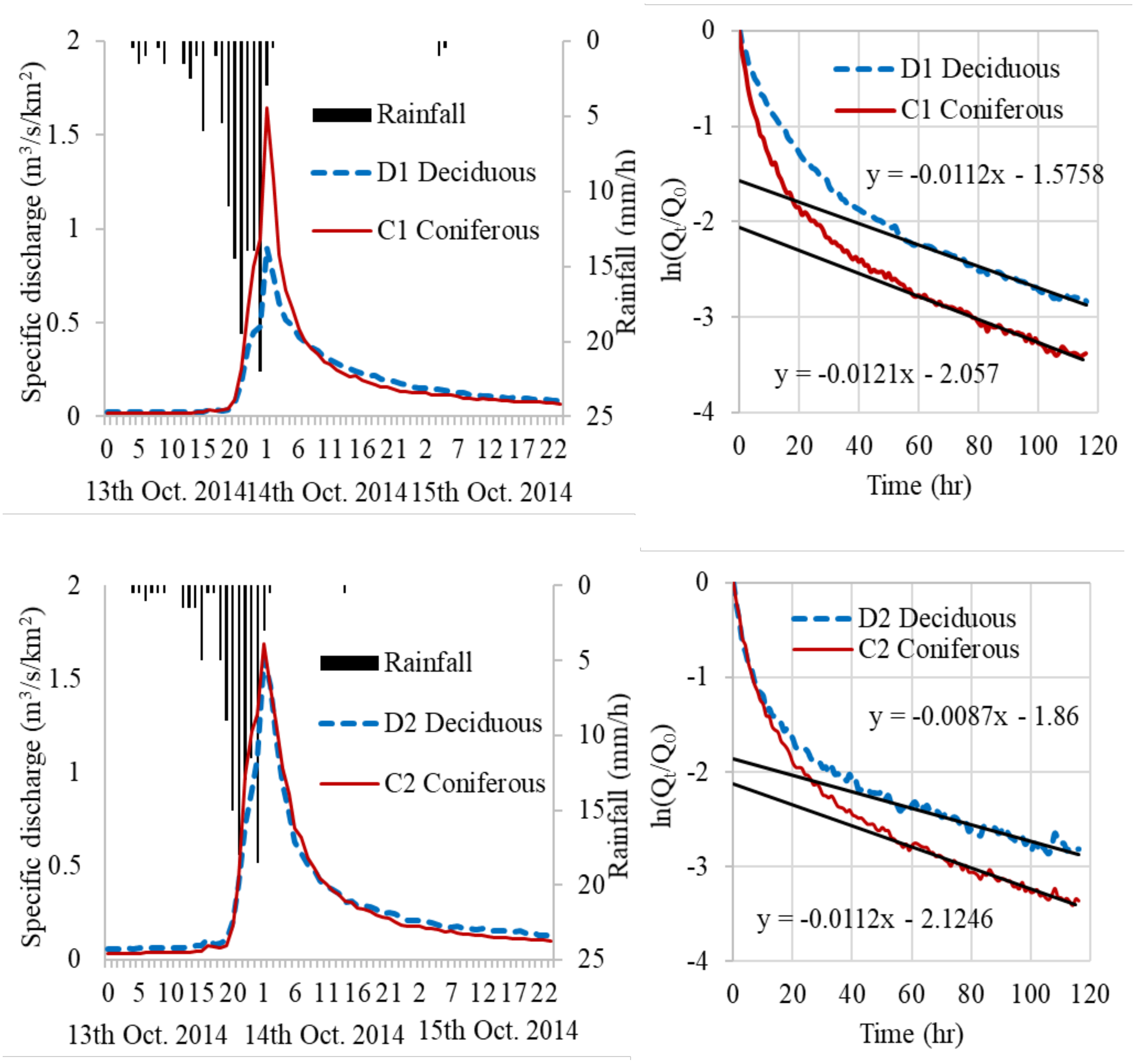


Fig.27 Hydrographs of four test basins at 100 mm rainfall event

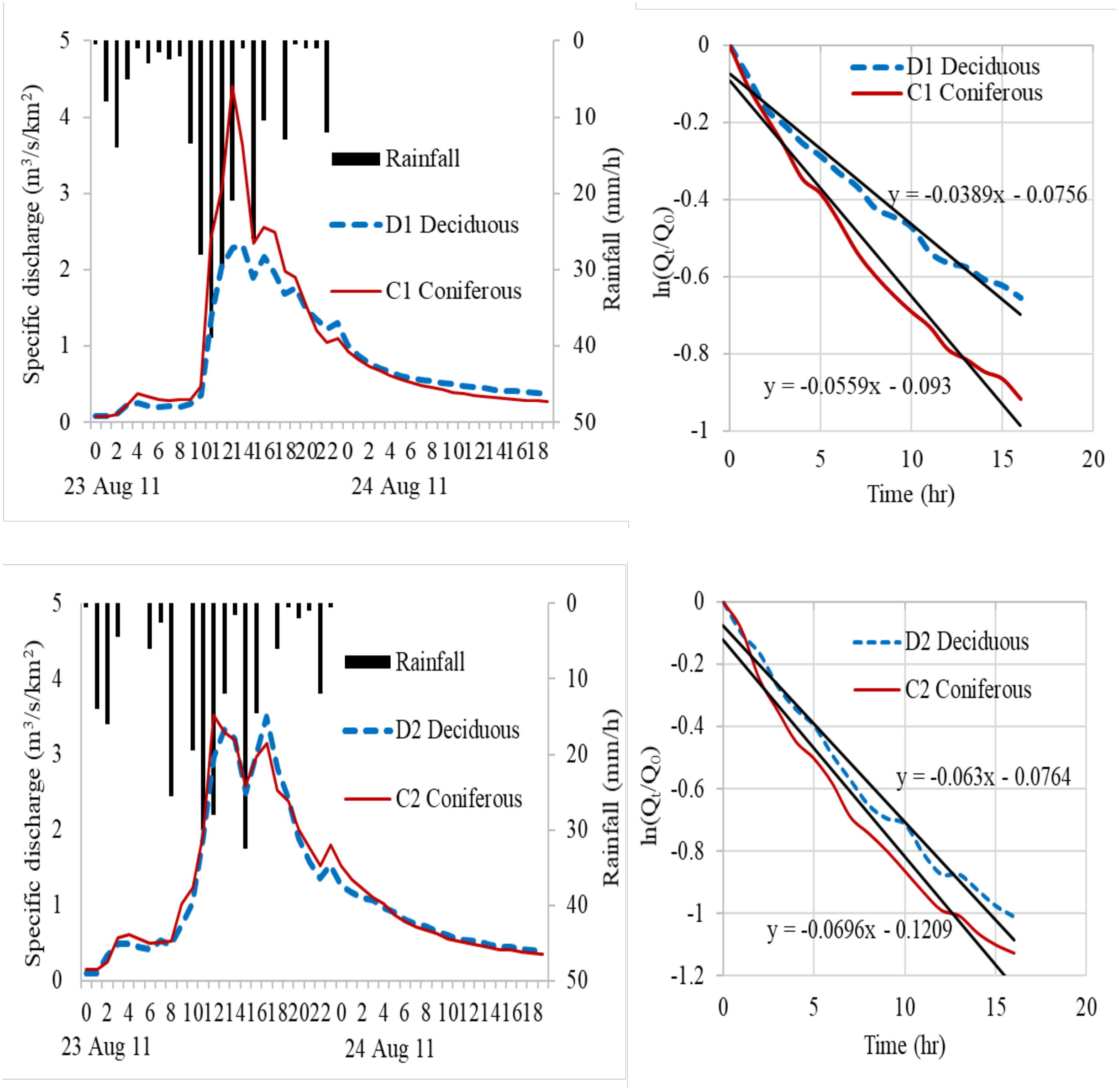
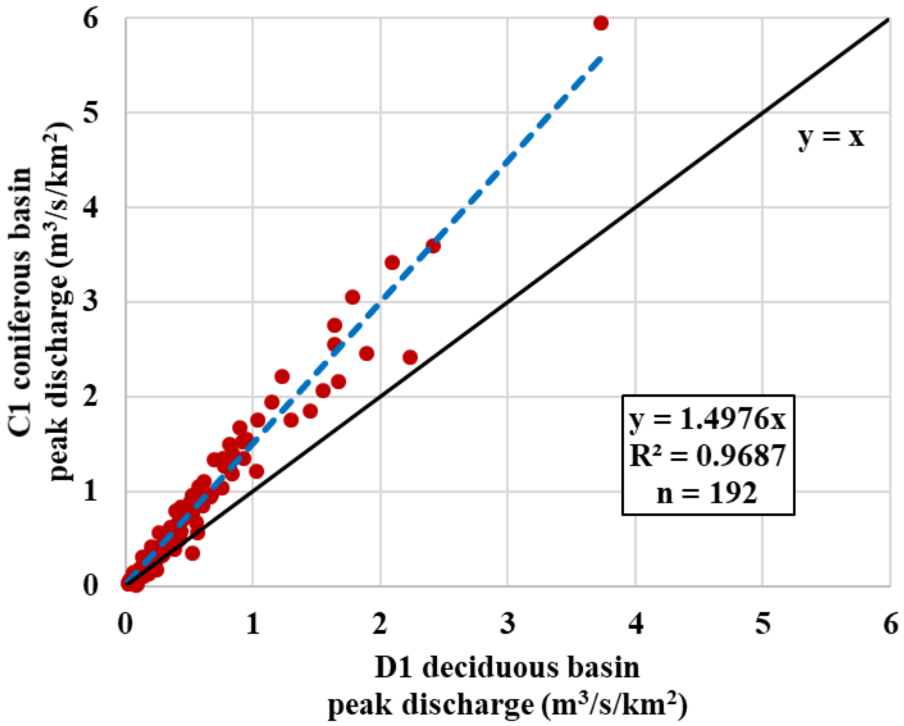


Fig.28 Hydrographs of four test basins at 200 mm rainfall event



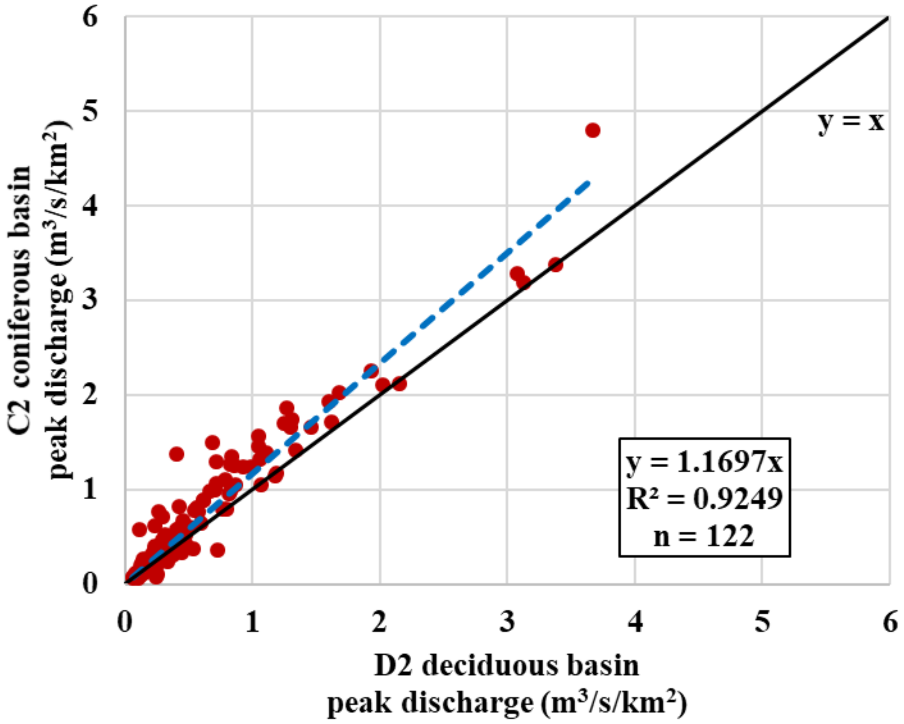


Fig. 29 Comparison of peak discharge between coniferous and deciduous basins

4.5 The effect of forests type on direct runoff and runoff coefficient

The streamflow from a rainfall event is generally composed of two components, direct runoff and base flow. Direct runoff is defined as the runoff caused directly by a rainfall or snowmelt event; it usually forms the major part of the flood hydrograph. Base flow is defined as the part of the streamflow that is not attributable to direct runoff from precipitation or melting snow; it is usually sustained by groundwater. Amount of rainfall event is the total of rainfall in one rainfall event.

Fig. 30 shows the relation between the rainfall and the direct runoff of each basin with the same rainfall events. Based on the linear regression equation, the initial loss (the amount of rainfall before the direct runoff occurs) is estimated by taking the x value when the linear regression equation intercepts the x-axis. The initial loss from the C1 basin is 32.2 mm (=14.8/0.46), which is almost the same as the value for the D1 basin 34.4 mm (=13.4/0.39). And the initial loss from the C2 basin is 23.7 mm (=15.9/0.67), which is also almost the same as the value for the D2 basin (25.9 mm =15/0.58), but it is lower than the values (32.2 and 34.4 mm) for the C1 and D1 basins. These results suggest that the initial loss is less influenced by the forest type and much more strongly influenced by the basin area. This implies that the larger the area is, the larger the initial loss will be. On the other hand, the gradient parameter of the linear equation for the C1 basin is 0.46, which is larger than the value for the D1 basin (0.39). And the gradient for the C2 basin is 0.67, which is also larger than the value for the D2 basin (0.58). These results suggest that the gradient parameter is larger in the coniferous basin than in the deciduous basin when the basins have the same area.

Fig. 31 shows the relation between the amount of rainfall and the runoff coefficient of the coniferous and deciduous forest basins under the same rainfall event. The runoff coefficient is a dimensionless value relating the amount of direct runoff to the amount of precipitation received. It generally has a larger value for areas with low infiltration and high runoff (pavements and steep gradients), and a smaller value for permeable, well-vegetated areas (forests and flat lands). The runoff coefficient tends to increase as the amount of rainfall increases in all basins. The average runoff coefficient for more than 150 mm of rainfall is 38.6 and 58.6% for the C1 and C2 basins, respectively. These values are higher than D1 (33.3%) and D2 (51.7%) basins in the deciduous forest. Furthermore, these values are also strongly influenced by the basin area, which implies that the smaller the area is, the larger these values will be.

4.6 The effect of forests type on snow depth

Fig. 32 shows the changes in snow depth during the winter seasons from 2014 to 2018. The bold black line represents the average snow depth over five years. The snow depth fluctuated a lot every year. The highest snow depths were found in 2015 and 2018, but the snow started to melt faster in 2018 than in 2015. And the lowest snow depth was recorded in 2016. However, it is clear that the snow depth in the D1 basin was higher than that in the C1 basin.

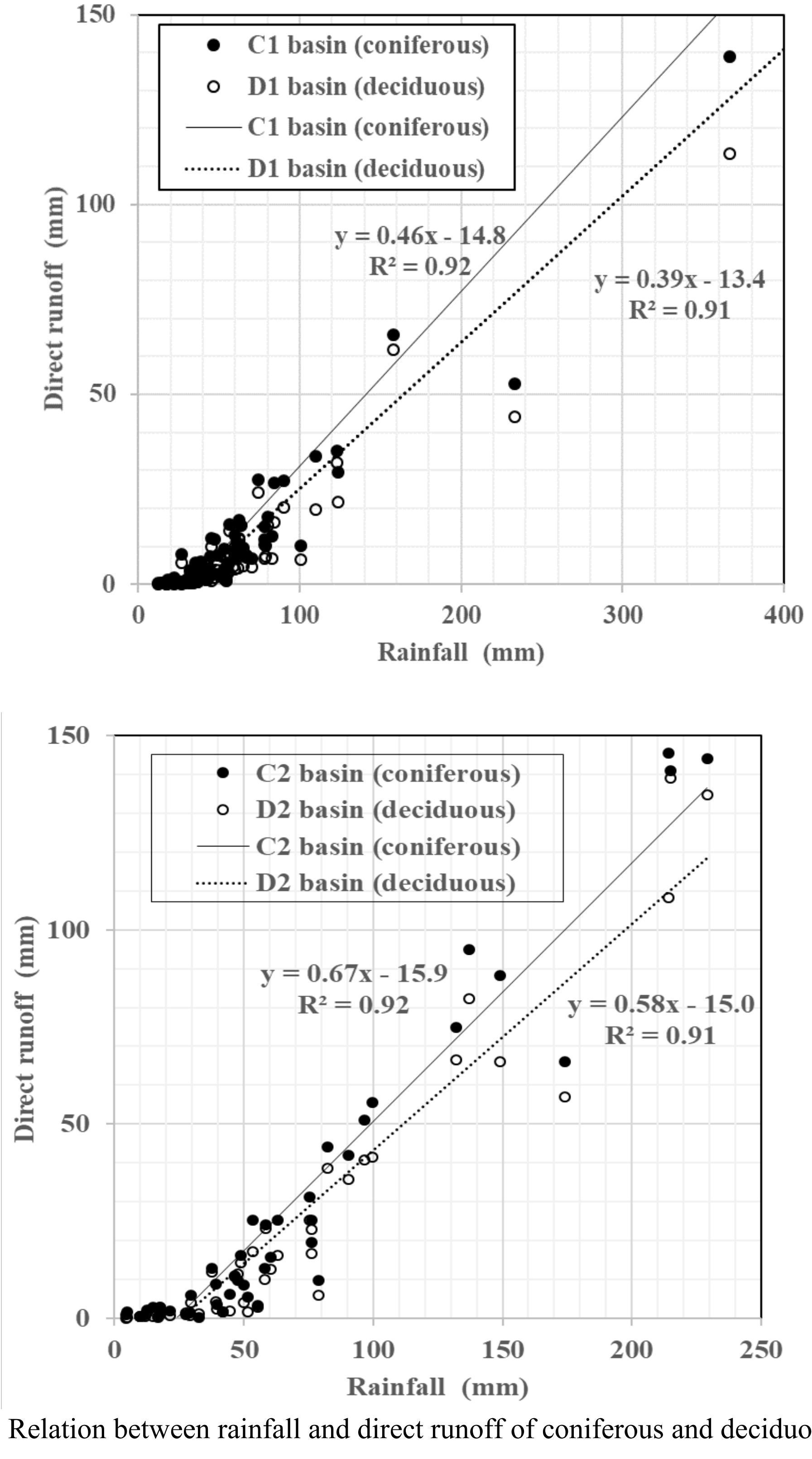


Fig. 30 Relation between rainfall and direct runoff of coniferous and deciduous basins

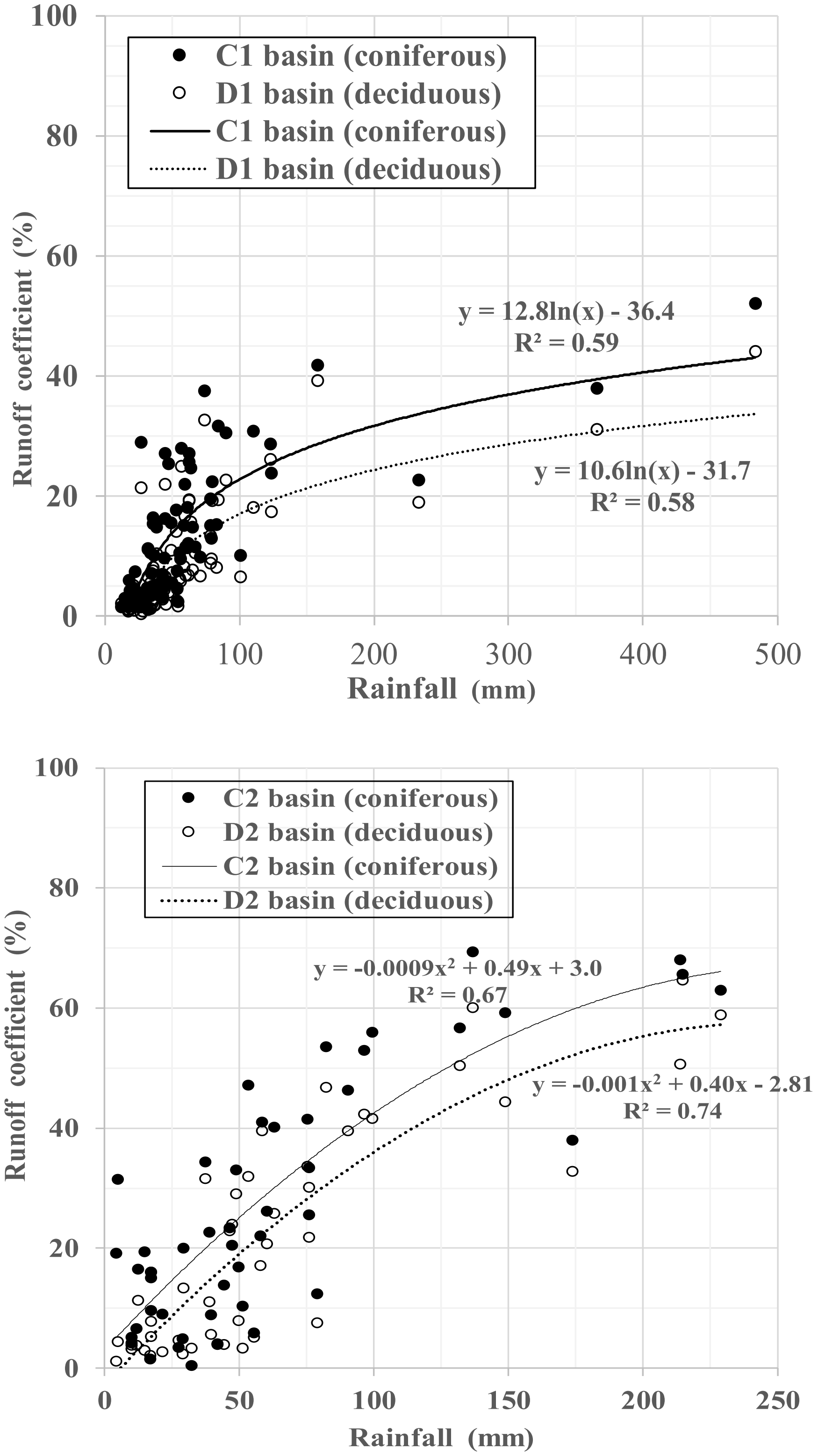
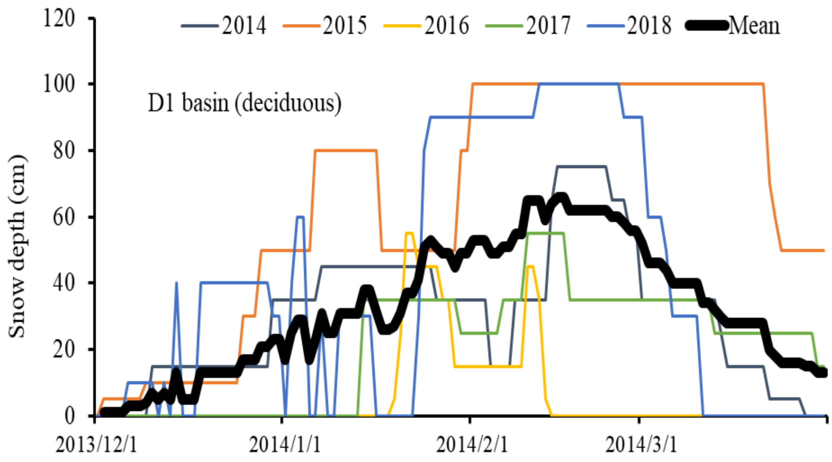


Fig.31 Relation between rainfall and runoff coefficient



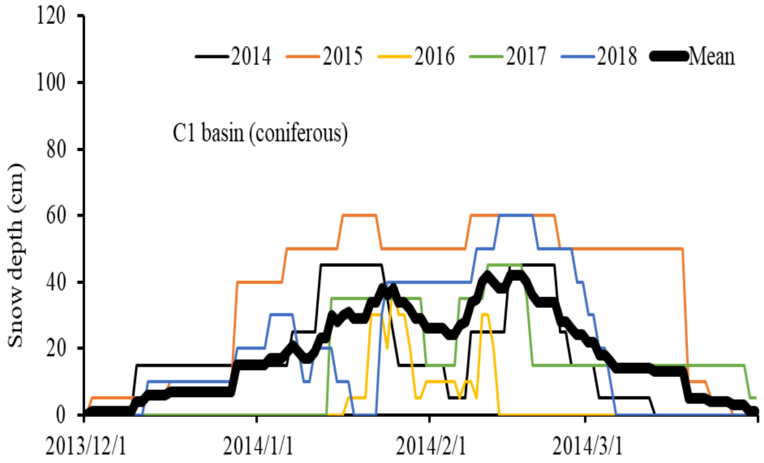


Fig. 32 Snow depth in D1 (deciduous) and C1 (coniferous) basins

V DISCUSSIONS

Our results showed that the annual discharge in the deciduous forest was higher than that in the coniferous forest during the observation period. The phenology difference between deciduous broadleaf and evergreen coniferous forests might contribute to this difference. While the trees in evergreen coniferous forests always keep their leaves, those in deciduous broadleaf forests lose almost all of their leaves in autumn, as shown in **Fig. 33b)** and **d)**. Due to the absence of leaves in deciduous broadleaf forests during the winter season, more snow can reach the ground. In contrast, the canopy in evergreen coniferous forests intercepts much of the snow; and thus, less snow reaches the ground.

On the other hand, in the non-winter periods, the shape and configuration of the leaves affect the LAI (leaf area index) and the water storage (Jonckhere et al., 2004, Keim et al., 2006). It is well known that flat leaves (deciduous species) store water as a thin coating, while needle-type leaves (coniferous species) store water in the capillary spaces between the leaves (Keim et al., 2006). The water stored by mature deciduous trees with and without leaves measures 0.2-2 mm and 0.03-0.8 mm, respectively (Leyton et al., 1967), and 0.1-4.3 mm for the mature coniferous trees (Link et al., 2004). In addition, previous observations have revealed that the annual evapotranspiration in coniferous forests is higher than that in deciduous forests (Komatsu et al., 2008, Swank and Douglass et al., 1974, Hisada et al., 2011).

These facts are consistent with our results, namely, that the annual discharge in deciduous forests is higher than that in coniferous forests. Moreover, this difference might be due to the difference in canopy characteristics, resulting in the difference in evapotranspiration.

The differences in direct runoff and peak discharge during rainfall events result from not only the leaf characteristics, but also the structure of the branches. Coniferous trees have multilayers of branches, which make the canopy look crowded, and narrow hard leaves called scales or needles which are almost evergreen. The multilayers of the branches and the evergreen leaves of coniferous trees block solar radiation from reaching the soil surface. This, in turn, inhibits the growth of the understory on the forest floor due to the low light intensity. Deciduous trees, on the other hand, shed their leaves each autumn and the branches are broadly distributed in the air (not in multilayers). This charters a great deal of solar radiation to the forest floor and promotes the growth of grass and/or shrubs.

It can be seen in **Fig. 33 (c)** and **Fig. 34** that the dominant vegetation of the understory cover in the D1 basin is Sasa bamboo grass where the root systems are well-developed (Kawai et al., 2008). This kind of condition helps to enhance the preferential flow in the soil (Johnson et al., 2006). The forest floor in the C1 basin, on the other hand, has a lower density understory vegetation cover (**Fig. 33(a)**) and lower organic matter and soil permeability compared to the D1 basin (**Table 4**). It was previously mentioned that the root systems, organic matter and litter floor increased the infiltration rate (Chang, 2013), which decreased the proportion of direct runoff to total rainfall. In addition, it was reported that the highest final infiltration rate was found in the deciduous plot with 321 mm/h, while the cypress and cedar plots had lower infiltration rates of 76.4 mm/h and 173 mm/h, respectively (Sakai et al., 2009). Furthermore, the existence of understory vegetation could decrease and delay the speed of the surface runoff, which would reduce the peak discharge in the deciduous basin to a greater degree than in the coniferous basin.

Fig.33 Forest condition in C1 (evergreen coniferous) (top) and D1 (deciduous broadleaf) (bottom) (left: forest floor, right forest canopy in autumn)

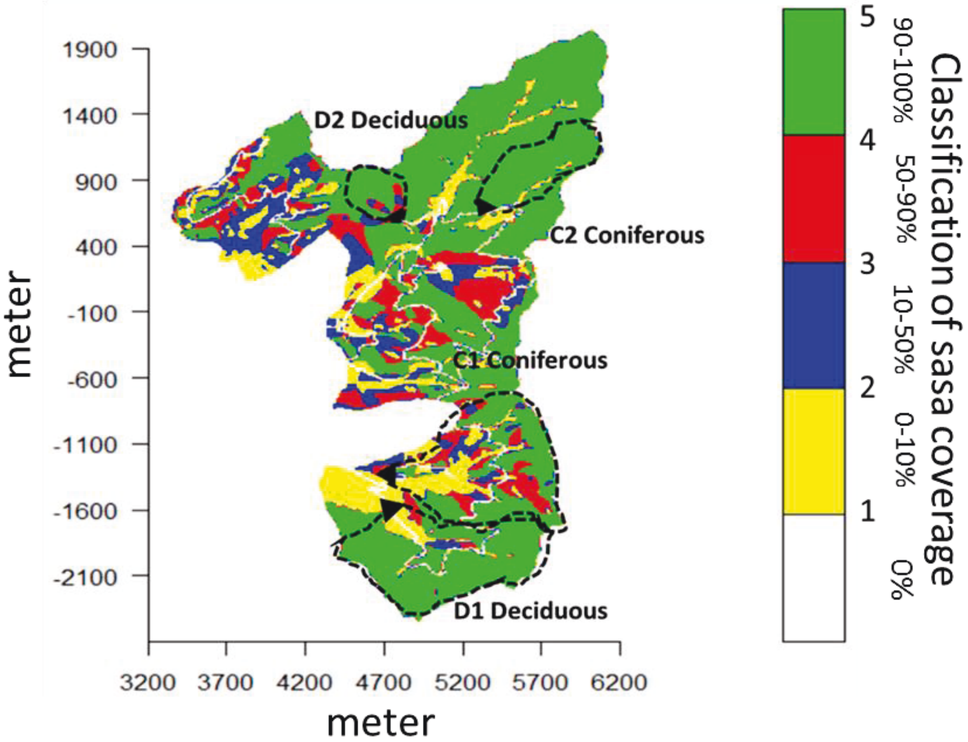


Fig.34 Sasa coverage of forest floor (Ashihara, 2012)

The above explanations are about comparing C1 and D1 or C2 and D2, the condition will change if we compare D1 and C2, the results are opposite with comparison C1 and D1. The reason the results is opposite is in the different of basin area (basin size). The size of C2 (0.21km^2) is smaller than in the D1 (0.73km^2), where, basin area will influence the lag time. In a large drainage basin water takes a long time to travel through tributaries or the ground to reach the channel. Conversely, in a small drainage basin, the water has a shorter distance to travel and will result in a shorter lag time. So that, peak discharge, runoff coefficient, decrease with increasing basin area. C2 have smaller basin compared with D1 basin, so that the runoff coefficient, direct runoff will higher than in D1 basin, because the water has shorter lag time to travel through tributaries and because have short travel time only little water can infiltrate to the soil this condition will promote the high runoff coefficient, direct runoff and peak discharge.

VI CONCLUSIONS

Based on literature review, afforestation is not suitable to be adopted for countries with lack of precipitation because droughts are a major risk, and mature forests can reduce lot of runoff. Moreover, for the flood case, planting trees in the upland part of the catchment to reduce the flooding risk downstream and implement afforestation is recommended. Thinning can be adopted to increase runoff but the percent of cover that will be cut must be considered not to significantly disturb the environment in surrounding area and finally decrease the water quality. Clear cutting can increase the runoff significantly but in same time sharply decrease the water quality. Converting natural/secondary forests to plantation forest strongly decrease total runoff. The broadleaf deciduous could produce high annual runoff and had better runoff characters than evergreen coniferous forest. To replace pine with eucalyptus tree for forest plantation has a positive impact in total amount of material that can be harvested but has a huge impact in decreasing water resource, because of high water use efficiency of eucalyptus due to fast growing characters.

Based on the findings of this study, it was seen that the runoff in the deciduous broadleaf forest was higher than that in the evergreen coniferous forest. The peak discharge, direct runoff and runoff coefficient in the deciduous broadleaf forest were lower than those in the evergreen coniferous forest. The snow depth in the deciduous broadleaf forest was thicker than that in the evergreen coniferous forest. All those hydrological characteristics were influenced by the conditions of the canopy and the forest floor. It was confirmed in this research that deciduous broadleaf forests are better able to foster water resources and to control flooding than evergreen coniferous forests.

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